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Notas Científicas

Reef Restoration at Laughing Bird Caye National Park, Belize

Restauración del Arrecife en el Parque Nacional Laughing Bird Caye, Belice

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Placencia

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Abstract. Laughing Bird Caye National Park (LBCNP) is one of the seven marine protected areas that make up the Belize Barrier Reef World Heritage Site. It is located approximately 12 miles east of Placencia, in Southern Belize, Central America. LBCNP suffered from two major hurricanes, bleaching and disease events (1998 and 2001), extirpating its Elkhorn coral (*Acropora palmata*) population. LBCNP was re-seeded with 19 *A. palmata* fragments transplanted from reefs in Gladden Spit and the Silk Cayes Marine Reserve (GSSCMR). After 22 months the survival rate is 95%. The maximum growth rate was 10.3 cm/year. This methodology establishes a restoration technique for damaged *A. palmata* reefs in Belize, and can be utilized in response to future hurricane events, ship groundings and/or anchor damage. All of the Caribbean *Acroporid* species were recently listed as "Threatened" under the Endangered Species Act in the US and Mexico. The long-term conservation and economic benefits of successful coral restoration are enormous as both the tourism and fishing industry rely on the health of Belize's reefs.

Key words: reef, restoration, National Park, Belize.

Resumen. El Parque Nacional Laughing Bird Caye (LBCNP) es una de las siete áreas marinas protegidas que conforman el patrimonio de una barrera de coral en Belice. Está situado aproximadamente a 12 millas al este de Placencia, en el sur de Belice, Centroamérica. El Parque Nacional sufrió por dos grandes huracanes, blanqueo y eventos de enfermedad (1998 y 2001), extirpando su población "coral Elkhorn" (*Acropora palmata*). En el Parque se resembraron con 19 fragmentos trasplantados de arrecife de *A. palmata* en Gladden Spit y en la Reserva Marina de Silk Cayes (GSSCMR). Después de 22 meses la tasa de supervivencia fue del 95%. La tasa máxima de crecimiento fue de 10.3 cm/año. Esta metodología establece una técnica de restauración de arrecifes dañados de *A. palmata* en Belice y puede ser utilizada en respuesta a los futuros huracanes, encallamientos y/o daños de anclaje de naves. Todas las especies de acropóridos del Caribe recientemente fueron catalogados como "Amenazadas" bajo la ley de especies en peligro de extinción en los Estados Unidos y México. La conservación a largo plazo y los beneficios económicos de restauración del coral son enormes como el turismo y la industria pesquera los cuales dependen de la salud de los arrecifes de Belice.

Palabras clave: arrecife, restauración, Parque Nacional, Belice.

Introduction

Elkhorn coral, *Acropora palmata*, was previously one of the most dominant coral species in Southern Belize, and throughout the Caribbean. It is one of the faster growing corals (6.9 cm/year) (Lirman, 2000) and prefers clear shallow water where there is maximum wave action. Elkhorn coral is structurally important; it protects fragile cayes and shorelines during storms, allows reef growth to keep pace with rising sea levels and provides essential habitat for over 400 species of fish and invertebrates, including the commercially important spiny lobster, *Panulirus argus*. No other Caribbean reef building coral species is able to provide these essential ecosystem services.

In recent years most of the large *A. palmata* thickets have been decimated throughout Southern Belize and the rest of the Caribbean. The estimated loss of abundance over the entire range during the last three decades is >97% (ABRT, 2005). In 2006 the National Marine Fisheries Service (USA) listed both *A. palmata* and the related *A. cervicornis* as "threatened", under the Endangered Species Act of 1973 (USA). As of 2008, one-third of the more than 700 species of reef building corals are listed as threatened with extinction according to a survey by the Global Marine Species Assessment (IUCN Red List).

The primary culprits in the *Acroporids* demise have been hurricanes, bleaching events and types of white band

disease. Because *A. palmata* grows best in shallow, high-wave action oceans, it is most susceptible to hurricane damage. However, fragmentation is a natural form of asexual reproduction for this fast-growing coral and is assumed by some to be more common than sexual reproduction in this species (Highsmith, 1982; Meester, 1995), and an adaptation to high-energy environments.

Laughing Bird Caye National Park is a unique faro reef system, and was declared a National Park in 1994. This status gives it full protection; over 10,000 marine acres are a No-Take (Conservation) Zone. In 1996, LBCNP was one of the seven sites declared as the Belize Barrier Reef World Heritage Site. It is one of the most heavily visited cayes (9476 paying guests in 2006) because of its close proximity to Placencia, and because it is inside the main barrier reef it still offers some protection for snorkelers/ divers during heavy weather conditions. Until 1997/8, thickets of thriving Elkhorn coral fringed LBCNP. It was extirpated then, with not a single colony recovered. There was no monitoring taking place during those years, so it is unknown if the corals were first killed by disease and then demolished by Hurricane Mitch in October 1998, or if the hurricane alone was cause for their disappearance. Friends of Nature, the NGO responsible for co-managing both LBCNP and nearby GSSCMR, commenced coral monitoring at both locations in 2003. While considerable new growth of *A. palmata* had been documented at GSSCMR none was observed at LBCNP. Both of these areas took a direct hurricane hit in October 2001 (Iris).

Acropora palmata transplant success has been demonstrated in other regional restoration projects: Harold Hudson cemented large *A. palmata* fragments unto artificial substrate in the Western Sambo Reef in Florida, which have survived over two years (2002-2004) and two hurricanes (pers. com, Harold Hudson). Three hundred whole *A. palmata* colonies were transferred 1500 m upstream from their natural occurrence in the Dominican Republic to rescue them from a port development. One year later survival was 95%, all of the colonies had overgrown their wire connectors at a growth rate of 3.5 cm/year, and 95% of the colonies had fused to their substrate. Mexico has also reattached *A. palmata* fragments after two hurricanes (Ivan 2004, and Wilma 2005), using a combination of wire and cement. Dr. Jaime Gonzalez Cano (Director, Comisión Nacional de Áreas Naturales Protegidas, México) provided a video of this work, which was instrumental in gaining support from Protected Areas Managers, tour guides and fishermen for this pilot project in Belize. Based on the previous successes, participants at the 2002 Caribbean *Acropora* Workshop concluded that "Transplantation and propagation of Atlantic *Acropora* spp. is a viable tool to enhance recovery at local (reef-site) scales". The goal of this trial project at Laughing Bird Caye National Park was to map near-by reefs for *A. palmata* abundance and distribution and demonstrate successful transplants, thereby establishing a restoration methodology for Belize, and assure genetic diversity of transplanted fragments through DNA analysis by Baums' laboratory.

Materials and Methods

Mapping

Twenty-seven reefs were surveyed by snorkel or SCUBA (maximum depth ~5 m on fore reef sites) in October and November 2006 for the presence of *A. palmata*. Sites were classified into three categories: long-dead, recovering (single or few colonies), or healthy and large enough (>50 m in any direction) to provide naturally broken fragments for transfer. Surveyed sites were chosen based on anecdotal information from the PI, local fishermen and tour guides. GPS waypoints were marked at all sites using the NAD27 Central Datum and UTM coordinates. The only reefs with large enough *A. palmata* stands to provide naturally broken fragments for transfer were in GSSCMR (fore reef, reef crest and back reef/patch). The two reefs chosen for collection of fragments to transfer were labeled GSTF1 (Gladden Spit transfer, 1 Nov 06) and GSTF12 (Gladden Spit transfer, 12 Nov 06) (Figure 1). The site categories above were color coded: Red = long dead sites, Yellow = single or few recovering colonies, Green = healthy and large sites (>50 m in any direction).

Transport

Fragments were placed on a sea saturated foam (sponge), covered in sea saturated towels and sheets, and continuously doused with seawater during transport (48-51 minutes) by skiff. The two reefs at GSSCMR where the fragments originated were swam at length to locate fragments that were naturally broken free, of an appropriate size (>30 cm), relatively far apart (to ensure different genets) and disease-free. Suitable fragments were selected by the PI and marked with flagging tape. Assistants (local Dive Masters, Biologists and boat captain) were then used to pick up the fragments as quickly as possible. Seven fragments (supporting eight *A. palmata* colonies) were transferred from GSSCMR to LBCNP on the 1st of November 2006. Twelve (12) fragments (supporting 14 *A. palmata*

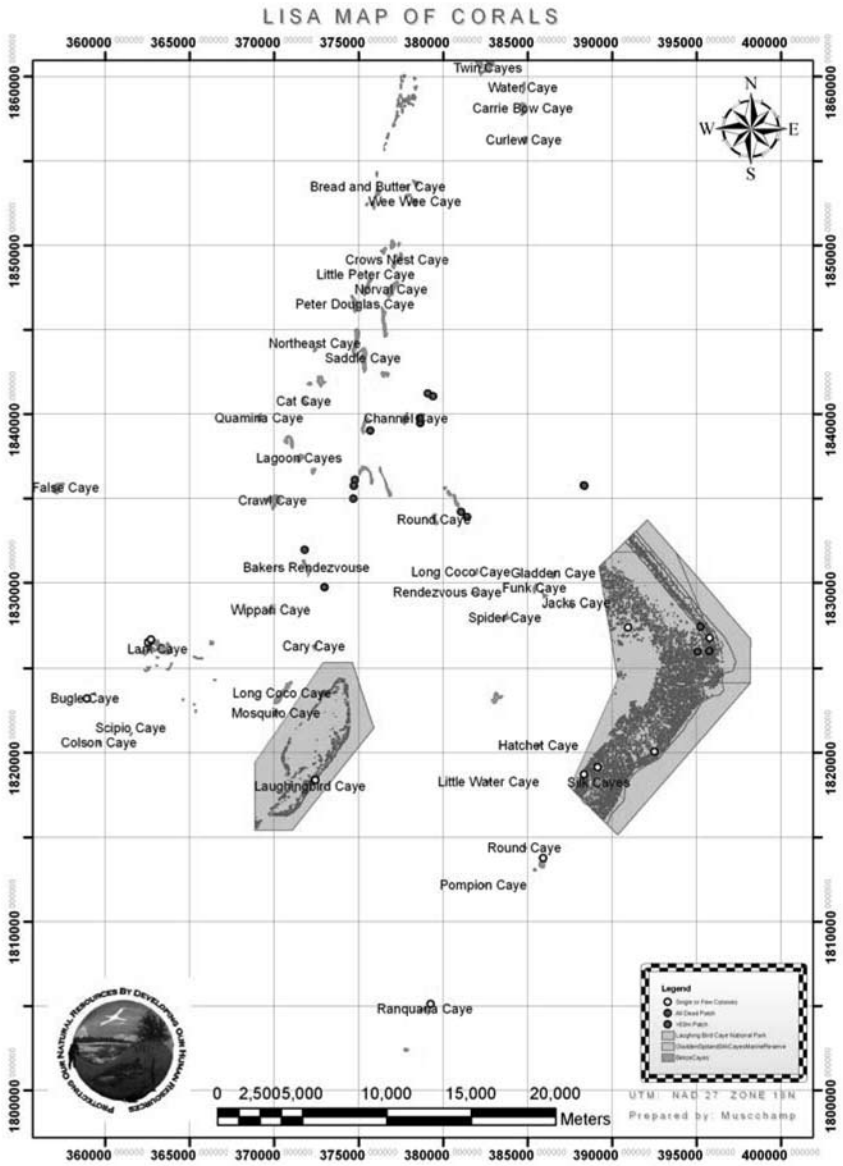

Figure 1. Distribution and abundance of *Acropora palmata* near Placencia. Map produced by William Muschamp at FoN: red = long dead sites, yellow = single or few recovering colonies, green = healthy and large stands (>50 m in any direction).

colonies) were transferred from GSSCMR to LBCNP on 12 November 2006. The number of fragments moved was dictated by availability (of natural, healthy loose fragments) and space on the foam, on the floor of the boat or in the hull, so they would not jostle, bump or touch each other. Five fragments were affixed at GSSCMR on 24 November 2006 as controls; they were out of the water an equal amount of time as the LBCNP transplants. All transfer days were overcast, cool and calm, facilitating the process.

Transplanting the Coral Fragments

Prior to transporting the live fragments from GSSCMR, LBCNP was mapped to find suitable locations for placement of the fragments. The coral stands at LBCNP are mostly old dead *A. palmata* coral heads that are stable, in shallow water (<2 m), large enough to support fragments >30 cm in width/length/diameter, tall enough (height >30 cm) to prevent sedimentation during storms and relatively free of encrusting organisms like sponges (*Cliona* spp.) and zooanthids that might interfere or compete with *A. palmata*

growth. Suitable coral heads were identified and scrubbed with wire brushes ahead of time to remove turf algae in order to facilitate the cement adhesion.

Also prior to transportation of the live coral fragments, a practice transplant session was executed with dead coral fragments at nearby Morris Caye. Previous *A. palmata* transplant projects (Mexico) have used cement alone and/or Monel wire but based on correspondence with Dr. Harold Hudson, a high grade Plaster of Paris (molding material) was mixed with the cement to accelerate the hardening time. The ratios used were approximately 4:1 or 6:1 cement to plaster. Seawater was blended in until a malleable, moldable ball was formed based on the size of the fragment to be affixed. The cement balls were placed in a Ziploc bag and handed to divers in the water where the fragment was then affixed. Plastic cable ties are used to secure the fragment until the cement has sufficiently hardened. In the case of the 24 live fragments transplanted (19 at LBCNP, five at GSSCMR), most of the cable ties were eventually removed, except in the few cases where the coral tissue began to grow over the cable ties. LBCNP transfer fragments were placed in six different locations around LBCNP (Figure 2).

Nineteen *A. palmata* fragments were transplanted to Laughing Bird Caye National Park from two different reefs (GSTF1 and GSTF12) in Gladden Spit & the Silk Cayes Marine Reserve. Transplanted colonies ranged in size from <10 cm to ~55 cm. They were placed in six different locations around LBCNP in depths of 1-2 m and in most cases on remnant (long-dead) *A. palmata* coral heads. Figure 2 illustrates approximate locations on an aerial photograph (GPS coordinates exists for all fragments). Although they were transplanted on two different dates (1 Nov 06 and 12 Nov 06), quantitative (growth rates) and qualitative (observed new growth, tissue health, predation, disease presence/absence) monitoring began for all LBCNP transplants on 29 November 2006. The final qualitative monitoring date was 6 September 2008, so reported survival rates for the LBCNP transplants represent 647 days.

Monitoring, Qualitative and Quantitative

A total of 18 funded monitoring trips were conducted over the course of 13 months (11/2006-12/2007). Subsequent monitoring occurred in February, March, May, June and September 2008 (qualitative only). Frequent monitoring in the beginning of the project was essential to re-affix any dislodged fragments. Later, as the transplants began to grow onto the substrate, monitoring trips became monthly (every 4-6 weeks). Qualitative monitoring of each fragment (including controls) was recorded with photographs and on an underwater slate. New tissue growth (upright, onto the substrate or over the cable ties) was noted, as well as coral

Figure 2. Red X's mark approximate locations of *Acropora palmata* transplants around Laughing Bird Caye National Park (GPS coordinates exists for all transplants).

health: whether or not the polyps were extended, tissue color, and if predation was observed. Also noted were any marine organisms (lobsters, urchins, fish, etc.) utilizing the transplanted fragments for habitat/shelter.

Acropora palmata is a fast growing, branching coral that grows in multiple, 3-dimensions and also encrusts its substrate. A low-tech method was adopted from Mexican Biologist Roberto Ibarra utilizing small plastic cable ties. The ties were affixed to a random branch and the cable tie to tip was measured from Day 0 and throughout the year to obtain growth rates. Sixteen (16) *A. palmata* fragments were measured in this way; 11 LBCNP transplants, 2 LBCNP natural controls and 3 GSSCMR control transplants. Measurements were initially taken with a ruler but later with a caliper for better accuracy.

Results

Survival Rate

Although initially no transplant less than 30 cm was planned to be transferred, two small, healthy, loose fragments were discovered in the mapping process and were moved with the rest. The first small fragment, 1E, was actually a piece of flat dead coral ~20 cm with two small (<10 cm) recruits settled on it. The dead coral substrate made it ideal for transfer (for affixing with cement and plastic cable ties). Fragment 1E was found to be flourishing. The second small (<20 cm) transplant, 12G, was a branched fragment placed in an upright position and the only LBCNP transplant mortality to date. 12G survived 121 days and exhibited 2.3 cm growth (6.9 cm/year see Growth Rate section) but was knocked loose and already dead on the subsequent monitoring trip (Day 165). This span of 44 days was the longest interval between monitoring trips and represents the need for frequent monitoring. Four other fragments were knocked loose (one fragment was knocked loose twice) but were discovered and re-affixed in time to prevent mortality. Fragments were presumably knocked loose by fin kicks.

The survival rate for the LBCNP transplants after 1.7 years (647 days) is 95%. Five *A. palmata* fragments were re-affixed at GSTF12 as control transplants on 24th November 2006. The final monitoring trip for the GSSCMR controls was conducted on 19th November 2007 so the control survival rates reflect 360 days. Four of the five control fragments survived; the single mortality was a small (<10 cm) colony settled on a larger (~20 cm) piece of dead coral (control 5). This fragment was completely missing on the next monitoring trip (21st January 2007). Survival rate for the control fragments after 360 days was 80%. The control site was on the reef crest so much higher wave action takes place there than at LBCNP which was relatively protected (inside the main barrier reef). Tourists do not frequent the control site so it is presumed that storm/wave action knocked this fragment loose. The survival rate for all the transplanted fragments (LBCNP and GSSCMR) combined is 90% (19 of 21 fragments) or, looking at number of colonies, 93% (25 of 27 colonies). Success rate for this project was defined in the original proposal as survival of a minimum of one transplant after one year.

Growth Rate, Quantitative

The maximum growth rate for any fragment was 10.3 cm/year and the minimum was 0.9 cm/year (Figure 3). The growth rates were highly variable so no average was taken; often qualitative monitoring demonstrated better results (i.e. visible growth). These linear calculations do not reflect true overall growth as photographs show growth of corals in dimensions other than the cable tied-tip. There was no real difference in growth rates for the LBCNP natural controls versus the transplanted fragments (in fact the transplants showed higher growth rates with this method) however the GSSCMR controls did seem to exhibit faster growth rates than the LBCNP transplants which could be explained by the higher wave action on the reef crest (preferable conditions for *A. palmata)*. However the sample size is too small to be statistically significant. Three branches broke from three different fragments at or near the placed cable tie, perhaps a result of pinching or weakening the coral at this juncture. This method would not be repeated.

Growth Rate, Qualitative

New growth was observed but not measured on all LBCNP transplants after just two weeks, and throughout the year of monitoring. This growth was recorded with photographs and written down as tissue growth over the plastic ties, growth onto the substrate (encrusting) or new upright growth (nubbins or branches). In the case of fragment 1B, tissue growth was also observed spreading over (inwards) the exposed dead coral fragment. New growth was also observed on the branched tips. While fragment 1B did have a small cable tie affixed to one of its branches for measuring growth, this only yielded a rate of 0.9 cm/year which does not reflect its true overall growth rate. Although Fragments 1G and 12A had no cable tie affixed for quantitative measurements, photographs and

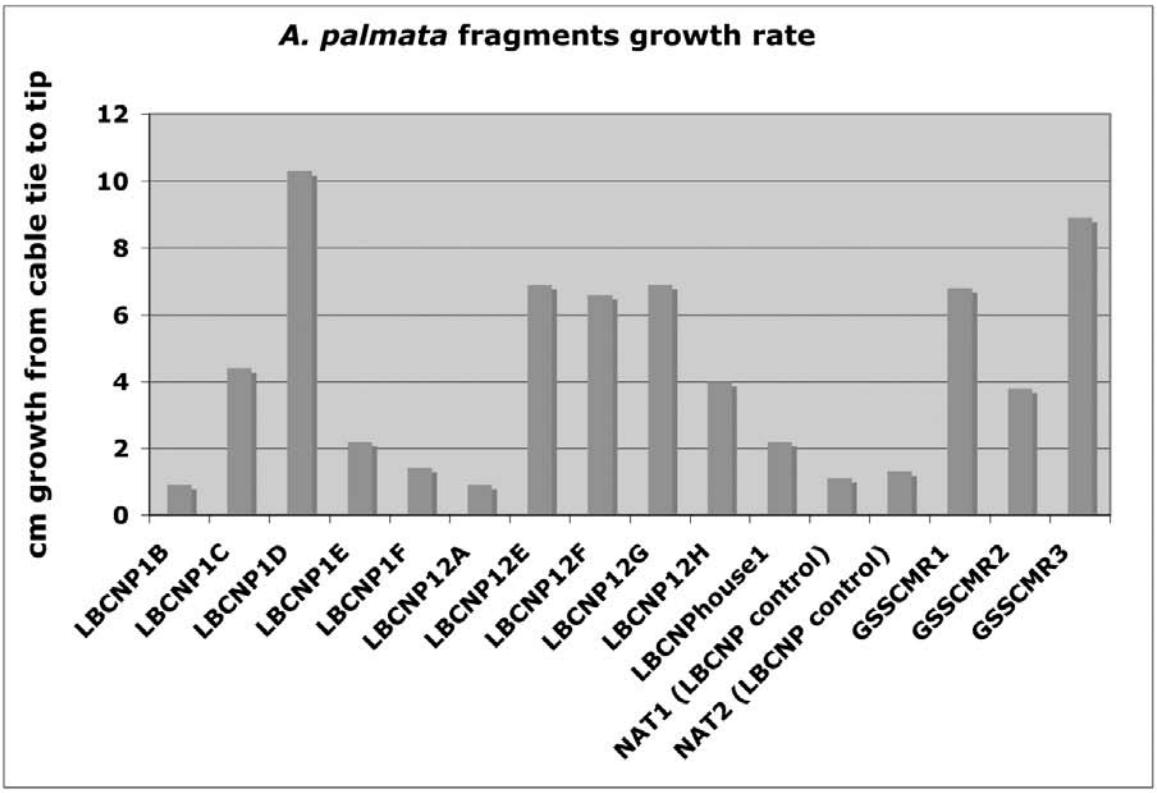

Figure 3. Quantitative growth rates for *Acropora palmata* transplants (and natural controls); linear measurements (cm/yr).

observations indicated massive new upright growths (nubbins) and also self-adhesion (encrusting) onto the substrate. Photo pairs (Day 0 and Day 647) were submitted for these two fragments (Figures 4-7).

Health (Tissue Color, Disease, Predation)

Observations were made on the transplanted corals' health, judged by tissue color, and whether or not the coral polyps were 'out' presumably feeding and therefore thriving (healthy). Several fragments (1C, 12E and 12F) exhibited white spots (pale coloration) that were not diseased and recovery of normal tissue color was made in 1-2 months. Presence of disease was looked for and noted. Disease was observed on all outer reefs mapped and was found on one natural LBCNP recruit (NAT3). This natural colony was assumed to be a sexual recruit because: 1) *A. palmata* was extirpated from LBCNP for many years and there are no 'parent' colonies to form fragments and 2) the location (sea floor), growth pattern (disc-like base) and size suggest a recent larval recruit. While Miller *et al.* (2007) suggest only molecular methods can determine a sexual recruit, LBCNP has sufficient monitoring records to show the complete absence of any *A. palmata* at the park for many years following Hurricane Iris in 2001 (FoN data and personal observations from 2003-2007).

NAT3 was discovered 30 March 2007 and some recent mortality was observed then. Subsequent monitoring revealed increased tissue mortality and based on the pattern of tissue loss, it was determined to be caused by a disease, most likely white band. New growth on the outer branches of NAT3 continued to be observed through December 2007, however by March 2008 the entire colony was dead. The presence of disease on all the mapped thickets and patches combined with this incidence at LBCNP, suggest that disease is and will remain a continued presence and threat for *A. palmata* and may inhibit this coral's long-term recovery.

Predation is a natural threat to *A. palmata* and comes from invertebrates like the Bearded Fireworm, *Hermodice carunculata* and a small snail, *Coralliophila abbreviata,* as well as vertebrates like damselfish and parrotfish. While both invertebrate coralliphores have been observed on *A. palmata* colonies in GSSCMR, it wasn't until June 2008 that a single

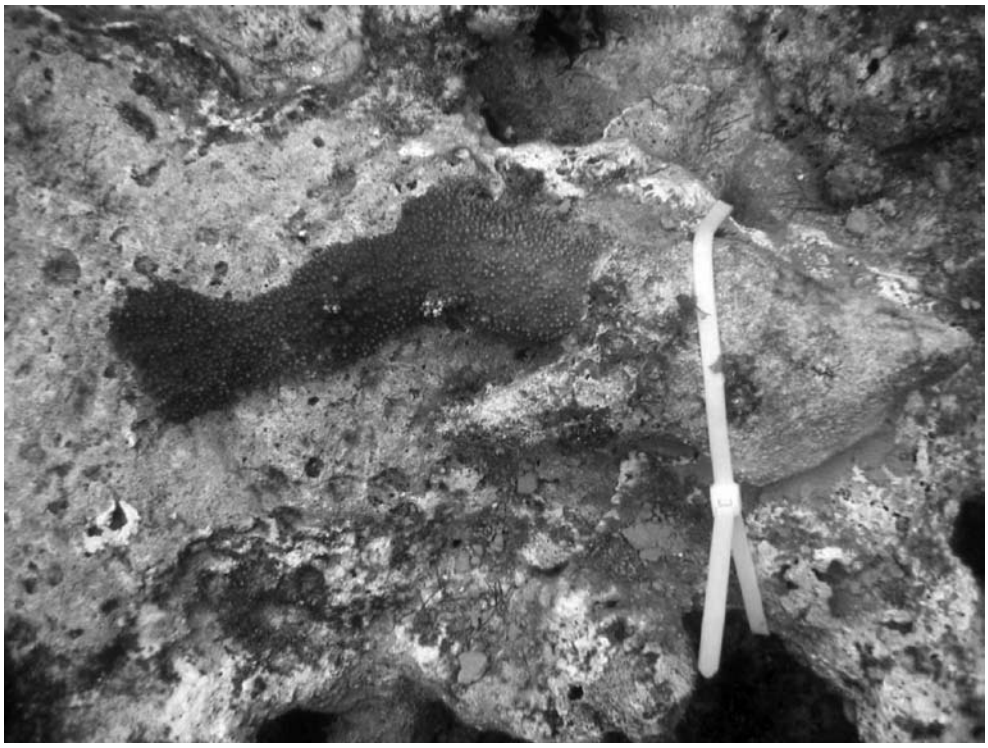

Figure 4. Fragment 1G, Day 0 (note cement and cable tie used on non-live tissue portion of fragment. This cable tie was later removed).

Figure 5. Fragment 1G, Day 647. Note multiple, massive new branches and adhesion onto substrate.

C. abbreviata was found on any transferred fragment (12H). Presumably the low *C. abbreviata* population at LBCNP was because lobsters, their natural predators, are protected in the park and have a significant abundance (3-4 greater inside the park than outside, FoN data collected by PI). This hypothesis warrants further study as it has management implications for the health of existing and recovering *A. palmata* reefs in Belize. The snail was removed and 12H is still alive (Sept. '08). Throughout the monitoring period evidence of fish predation was observed periodically on growing tips but did not affect overall survival rates.

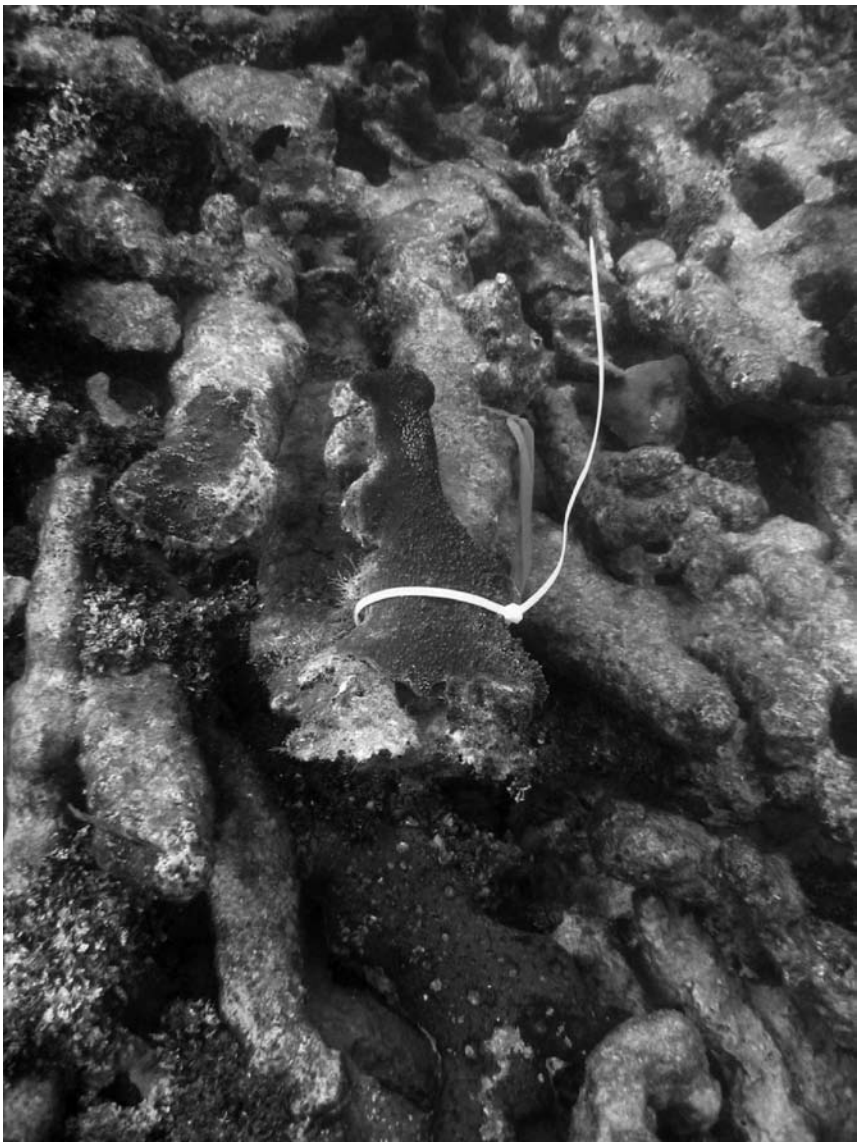

Figure 6. Fragment 12A Day 0 (cable tie and flagging tape later removed).

Habitat for Other Marine Species

Multiple marine species have been observed and recorded utilizing the transplanted *A. palmata* fragments starting from Day 165 (May 13, 2007) and on every subsequent monitoring trip. These species include both the Spiny and Spotted lobster, the Channel and Nimble Spray crab, French and Small Mouth grunts (adults and juveniles), Stoplight Parrot fish and Schoolmaster snappers (adults), Blue head wrasse and Yellowtail damsel fish (juveniles), three species of blennies including the Red-lip blenny, *Diadema* and reef urchins (adults and juveniles), a yellow spotted sting ray and juvenile nurse shark (both under the larger dead coral with the transplant on top). The presence of *Diadema* at LBCNP has facilitated the success of the coral transplants, as algal cover is relatively low at the transfer sites.

Genetics

Thirty *A. palmata* samples were sent to Dr. I. Baums' laboratory at Penn State for genetic analysis. Fifteen samples from both GSSCMR transfer sites (1 and 12) were collected (approximately 1 cm of a growing tip). Genetic analysis was desired for two reasons. The first reason was to make sure multiple genets were transferred to LBCNP. If this restoration project is truly successful, the transplanted fragments will one day grow large enough to spawn and hopefully re-seed LBCNP with new sexual recruits. For

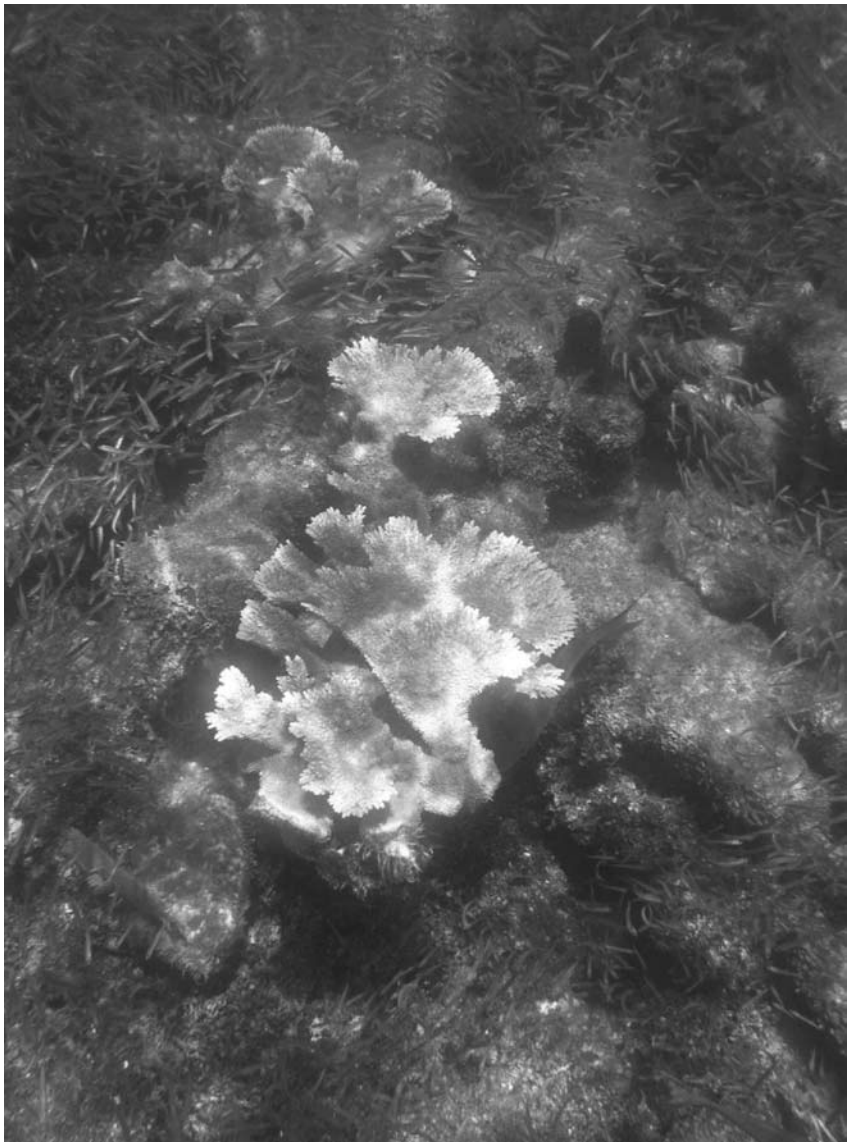

Figure 7. Fragment 12A, Day 647. Note: the fragment in the back was one that was dislodged and reaffixed, which is why it doesn't appear in the Day 0 photograph.

this to occur, multiple genets must be transferred (not multiple fragments of the same colony (ramets)), as that cannot promote sexual reproduction. Twenty-six (26) of the 30 samples have been run for complete genotypes. Of these 26 samples, 17 were different genets.

The second reason for the genetic analysis of GSSCMR's *A. palmata* colonies was to compare their population genetics to the 26 reefs from eight other Tropical-Atlantic regions that Baums has already sampled. This is known as "connectivity"; i.e. to what extent does genetic information get shared/exchanged between reefs/regions through dispersal. These results are still pending as Baums has also recently acquired *A. palmata* samples from Honduras and their genotypes will be compared to Belize's (one site only, two reefs in GSSCMR).

Discussion and Recommendations for Further Study

Ninety-five percent survival rates for the LBCNP transplanted corals after almost two years are extremely encouraging and correlate well with survival rates of other *A. palmata* transplant projects throughout the Caribbean. However the small amount of fragments moved does not begin to replace the original coral cover and was really a

trial experiment. Therefore a true restoration effort will involve moving additional *A. palmata* fragments (50-100) and other coral species. Since nearly twenty (20) different fish and invertebrate species, including the commercially important spiny lobster, were documented utilizing the transplanted fragments, the entire reef ecosystem benefits from increased live coral cover. The following recommendations have been made for future restoration efforts and follow-up.

Continued monitoring of transplanted fragments is necessary for long-term survival and to determine growth rates. Additionally the transplanted fragments at LBCNP should be monitored for evidence of spawning (sexual reproduction), as that would indicate true, long-term success of the restoration project. It is theorized that fragments must attain a certain size (>40 cm) before they spawn, so monitoring should include the *A. palmata* reefs at GSSCMR to determine when the corals spawn there, and the minimum size colony that reproduces sexually.

Ideally all of Belize's reefs should be mapped for spatial distribution and abundance of both *A. palmata* and *A. cervicornis* not only for sources of fragments for future restoration projects, but for the presence of disease, disease-resistant colonies, and further genetics studies.

There should be continued collaboration with Dr. Baums regarding connectivity. As more microsatellite markers are developed for *A. palmata* better information on connectivity within Belize's own reefs can be learned. This information is vital for understanding not only coral larva distribution, but may also be expanded (once it is understood) to other species' larval distribution.

Other corals like *A. cervicornis* (Staghorn), *D. cylindrus* (pillar), *Agaricia tenuifolia* (Thin lettuce leaf) and *Porites porites* (finger) make excellent candidates for restoration/transplant experiments as they all are capable of asexual reproduction through fragmentation, and are fast growing/fast recovering species. A true restoration effort cannot be with a single species as coral reefs have complex interactions between species. There is also precedent for moving even small to medium-sized boulder corals (star, *Montastrea* spp. and brain corals). Trials should be conducted now, so that in the event of future hurricanes/groundings multiple species can be transferred to a restoration site.

Acropora cervicornis is closely related to *A. palmata*; it too reproduces asexually by fragmentation, is fast growing, and has also had its Caribbean-wide distribution and abundance severely reduced in recent years from disease. Natural recovery of this species has been observed more readily than the *A. palmata*, which is why it was not included in this trial restoration project. However, as quickly as *A. cervicornis* grows back, evidence of disease (white band) makes its appearance. Consultation with many reef scientists and managers at the disease workshop at the ITMEMS conference in Cozumel (2006) revealed that culling experiments are a legitimate method for disease reduction of terrestrial organisms but has not been tried with diseased corals. While this experiment in no way addresses the causative agents (pathogens) of disease on *A. cervicornis*, in a protected tourism destination like Laughing Bird Caye National Park it may make the difference in saving the infected colonies there.

Alternatively, (or in conjunction with the above) in situ coral 'farming' of harvested *A. cervicornis* and *A. palmata* fragments should be explored. With climate change a reality and more frequent and intensive hurricanes a surety, and development (dredging and filling) increasing, it makes sense to have a reserve of live corals for future restoration efforts. Southern Belize has many ideal locations for this (many of them in MPAs); protected cayes with relatively healthy ecosystems (presence of *Diadema*, parrotfish and lobster in the case of LBCNP).In the long run, establishing multiple coral 'nurseries' or 'farms' throughout Belize may ensure many threatened coral species' survival.

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