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Development of a coral nursery program for the threatened coral *Acropora cervicornis* in Florida

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Abstract. The staghorn coral, *Acropora cervicornis*, was once a dominant reef-building species throughout the Caribbean region. Due to hurricanes, disease, and other human and natural stressors, its populations have declined dramatically in the last few decades. In an attempt to propagate this species for local restoration efforts, coral gardening was initiated in Florida, USA in 2007. Branches of *A. cervicornis* were clipped from donor adult colonies from Biscayne National Park and cemented onto cinder blocks in an underwater nursery. Eighty-eight fragments were monitored regularly during the first four months after transplantation to evaluate patterns of mortality attributable to the collection and transplant methods and to assess initial patterns of growth. Fragment mortality of 17.3% was documented for the first 8 weeks after transplantation, but decreased to <1% in subsequent monitoring intervals. Although there was no significant difference in growth rates between fragments glued in horizontal and vertical position, larger-sized fragments (> 5 cm) grew significantly faster than small (< 3 cm) and medium (3-5 cm) fragments.

Key words: coral gardening, coral nursery, *Acropora cervicornis*

Introduction

The scleractinian coral *Acropora cervicornis* was once a dominant building species in Caribbean coral reefs during the past 500,000 years (Jackson 1994). This species, however, has experienced drastic population declines (>95%) during the last three decades attributed to multiple factors that include increased sea-surface temperatures and associated bleaching, hurricanes, and white band disease (Bruckner and Hourigan 2002). The recent decline of *A. cervicornis* across its full range has prompted the listing of this species as 'threatened' under the U.S. Endangered Species Act in 2006. Furthermore, this species relies heavily on asexual reproduction via fragmentation and has limited success in sexual recruitment, demographic attributes that slow population recovery beyond local habitats (Bak and Engel 1979; Tunnicliffe 1981; Knowlton et al. 1990; Vargas-Angel et al. 2003). The local conservation of *A. cervicornis* populations as well as the build-up of stocks via active restoration can potentially improve recovery by enhancing rates of sexual recruitment (Vollmer and Palumbi 2007).

In the last decades, "coral gardening" (Rinkevich 1995, 2000, 2005; Bowden-Kerby 2001; Epstein et al. 2001; Shafir et al. 2006) has become an increasingly important tool in reef restoration. Coral gardening consists of growing corals in-situ at a nursery site, and then transplanting these coral fragments back onto natural reef environments once they have grown to an appropriate size (Rinkevich 1995, 2000; Epstein et al. 2001; Shafir et al. 2006). Coral gardening has been undertaken using varied methods of fragment or nubbin attachment such as mid-water wire frames, floating platforms, concrete, and suspended lines (Bowden-Kerby 2001; Shafir et al. 2006).

In this study, we describe the initial stages of a local attempt to enhance staghorn coral populations in Florida, USA. The gardening approach used in this study consisted of collecting fragments of *A. cervicornis* from adult colonies and growing these fragments in a coral nursery established within Biscayne National Park, Florida. Due to the depletion of *A. cervicornis* in Florida, the goal of this project is to collect minimal tissue from adult colonies (thereby limiting further depletion of adult stocks) and establish a methodology to maximize growth and survivorship of fragments to provide an expanding source of coral tissue for future restoration activities.

Here we report initial patterns of fragment survivorship and growth based on initial fragment size and orientation of attachment to transplant platforms. This study concentrates on the time period immediately following collection and transplantation of fragments to document directly the impacts of the collection, transportation, and cementation methods on fragment growth and survivorship. Based on the source of stress to the fragments collected, it was hypothesized that fragment mortality would be high initially but would decline with time as fragments

cemented themselves to the platforms and the regrowth process began. Initial high mortality followed by reduced mortality rates of surviving fragments were documented in other coral transplant experiments (Clark and Edwards 1995; Quinn and Kojis 2006).

Material and Methods

Staghorn coral nurseries in Florida

The nursery described in this study is part of a network of four staghorn nurseries established in the Florida Reef Tract from Broward County to the Middle Florida Keys using uniform methods (Nedimeyer and Johnson, unpublished). After a period of growth (6 mo – 1 yr) at the nurseries, the fragments will be transplanted to different habitats where staghorn corals were once abundant as well as habitats damaged by ship groundings.

Coral fragments

Donor adult *A. cervicornis* colonies were located at 11 different sites within Biscayne National Park. Coral fragments were carefully collected from the donor colonies using pruning scissors (Fig. 1).

The nursery

The nursery is located at 6 m depth in Biscayne National Park, Florida, US (25º 21.753′ N, 80º 9.985′ W). A sand patch adjacent to a reef was used to deploy a matrix of 30 cinder blocks. Each block contained a maximum of 10 vertical cement cylinders with a cement "puck" attached at the top (Fig. 1). The fragments were mounted to the puck using underwater epoxy. Identification codes were marked on the pucks using a stone engraver, black marker, and a coat of fiberglass resin. The cement pucks were designed so that the whole unit can be transplanted back to the various reef habitats after a period of regrowth without the need to handle the colonies. The pucks themselves will be cemented to the reef bottom at the future transplant sites.

In this study, we report growth data for 88 fragments that were measured regularly during the initial 4 months after transplantation (June to October 2007). Fragments were divided into 3 size classes: small (<3 cm in max length), medium (3-5 cm), and large (>5 cm). Within each size class, fragments were positioned either horizontally or vertically on the pucks (Fig. 2). At each survey, the cinder blocks were scrubbed clean with wire brushes to limit algal overgrowth and sediment accumulation.

Figure 1: Photographs depicting the steps in the coral gardening approach used in this project. 1) Adult *A. cervicornis* colonies. 2) Fragmented colony. 3) Fragment from which smaller sections were cut. 4) Nursery platform with transplanted fragments.

Monitoring and maintenance

Numerous studies have correlated coral growth and survivorship with colony size (e.g., Hughes 1984). For branching corals with complex morphology, it is often impossible to estimate whole-colony size (and growth) in the field and researchers have used the growth of a subset of branches as a proxy of whole-colony growth. In this study, the fragments used had a simple initial morphology (a single cylindrical branch) or simple branching morphology (maximum of 4 branches by the end of the study period). Thus, it was possible to measure and report the initial size and growth of fragments by calculating the sum of all branch lengths. This approach was used successfully to assess growth of *A. cervicornis* fragments and colonies by Bowden-Kerby (2001) and Quinn and Kojis (2006). As colonies grow in complexity, growth patterns will likely need to be assessed by measuring the average linear extension of a subset of marked branches. Patterns of linear growth were compared among fragments with a two-way ANOVA with size and orientation as main factors.

Results

A fragment mortality of 17.3% was documented in the first 8 weeks after transplantation. However, a large portion of this mortality (9.2%) was recorded during the first 3 weeks after transplantation. Mortality decreased to <1% of the remaining fragments during subsequent surveys (Fig. 3). No significant differences in the mean size of the surviving (4.4 cm ± 2.1) and dead fragments (4.1 cm ± 1.3) were observed during the first 8-week period ($p > 0.05$, *t* -test).

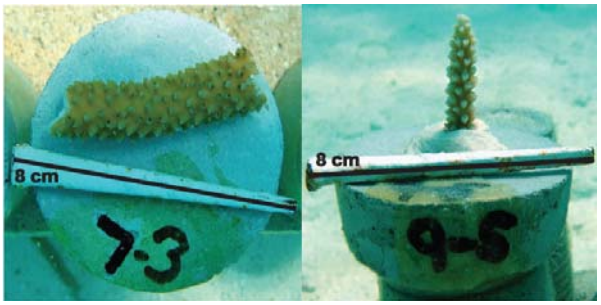

Figure 2: Photographs of staghorn corals cemented in horizontal and vertical growth position.

Fragment growth during the first four months after transplantation was influenced by initial fragment size. There was a significant difference ($p < 0.05$) amongst the linear extension rates of the 3 size classes, with the larger size class growing faster than the smaller ones (Fig. 4). Although fragments placed in horizontal position generally grew faster that those placed in vertical position (except for the smallest fragments), these differences were not significant. Lastly, no significant interaction was found between fragment size and orientation ($p > 0.05$).

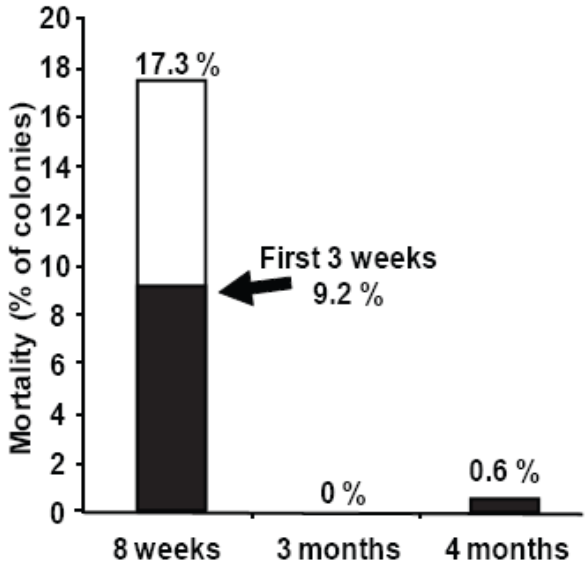

Figure 3: Mortality of fragments transplanted onto the coral nursery.

Discussion

The initial stages of the coral gardening program implemented for *A. cervicornis* in Biscayne National Park have been encouraging and this approach has the potential to become an important tool to provide an expanding stock for future local reef restoration efforts. Moreover, the combination of relatively low initial mortality and fast growth rates of fragments demonstrates that staghorn corals could be appropriate for a coral gardening program in Florida.

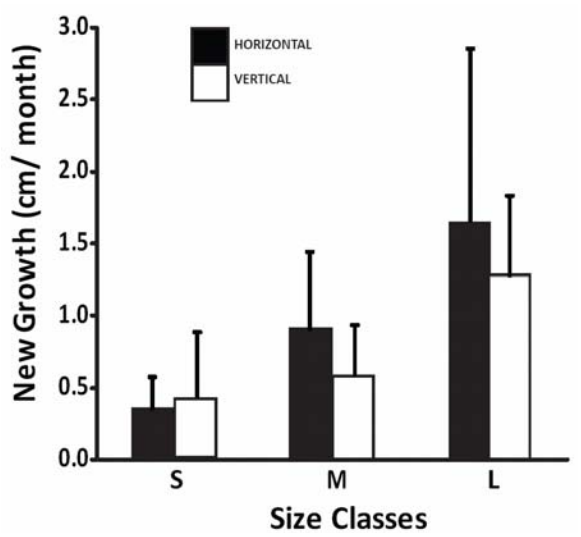

Figure 4: Mean growth (± SD) of transplanted staghorn fragments based on initial size and orientation.

Previous attempts to establish nurseries with staghorn corals provided initial fragment mortality estimates of 22% and 27% (average of 4 sites, recorded 6 and 11 weeks after fragmentation respectively) (Quinn and Kojis 2006). These mortality estimates are comparable to that in our nursery (17.3% after 8 weeks).

In the absence of major disturbances, the highest levels of mortality are commonly recorded during the first observation period following fragmentation, with mortality rates decreasing over time as fragments attach to the substrate and grow (Clark and Edwards 1995; Bowden-Kerby 2001). In agreement with these studies, the largest proportion of the mortality recorded took place within the first few weeks after transplantation (9.2% of fragments died within the first three weeks), and mortality rates decreased thereafter, indicating that the environmental conditions at the nursery site are adequate for fragment survivorship and growth. Likely factors influencing the early mortality patterns observed include stress due to fragmentation and high-temperature impacts. Initial fragmentation for this nursery was done during June and July of 2007, when sea surface temperatures were high (29–30ºC). Based on these observations, we concluded that, when possible, the fragmentation step of coral gardening should be performed when most other extraneous stressors, like high temperature, are minimized. .

The size of fragments is commonly associated with rates of survivorship and growth (Lirman 2000). In this study, fragment mortality was not associated with fragment size (for the range of sizes collected) but larger fragments exhibited faster initial growth rates compared to smaller fragments. This information is

important to determine the minimum size of fragments to collect for a gardening program. The faster growth rates of the horizontal fragments were unexpected because more living tissue from the bottom portion of these fragments was lost initially due to the contact with the epoxy and the cement base. However, fragments placed in a horizontal position have at least two terminal ends for potential new growth and branch development. By being able to extend from the additional growing end (compared to vertical fragments), horizontal fragments grew initially faster than vertical fragments. The continued monitoring of fragment growth will determine whether the initial faster growth rates of horizontal fragments is maintained over time as fragments develop complex branching patterns.

Maximizing growth rates of transplanted corals is a key goal of gardening programs. In this study, the maintenance conducted to remove sediments, macroalgae, and other coral competitors provided enhanced growth conditions for fragments. Under these conditions, the growth rates of staghorn fragments measured in the nursery compared favorably with the linear extension of adult staghorn colonies (10-15 cm/year) reported previously (Gladfelter 1984), indicating that even small fragments are capable of rapid growth rates when potential sources of competition and stress are removed periodically.

The propagation of *Acropora cervicornis* via a coral gardening approach implemented within in-water nurseries using low-cost materials (e.g., cement, epoxy, cinder blocks), can provide an effective method to expand declining stocks of the threatened staghorn coral in Florida. The results that help classify this new program as successful in its early stages include: (1) limited initial fragment mortality (< 20% of fragments were lost in 2 months following fragmentation); (2) rapid decline in subsequent mortality (< 1% between 2 and 4 months); and (3) rapid growth of even the smallest of fragments. The ultimate success of these restoration efforts will depend on the continued growth of fragments as well as the viability of nursery-reared colonies once transplanted back onto natural reef sites.

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