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RESILIANCE AND DECLINE: ARE WE AT A TIPPING POINT FOR ENDANGERED ACROPORA SP. CORALS IN BELIZE?

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INTRODUCTION

Coral Gardens, Belize has been a home for thriving *Acropora* spp coral communities even at a time of Caribbean-wide collapse of these threatened species. Up to 98% of acroporids are thought to have perished in the wider Caribbean-Atlantic since the 1980's or before due to synergistic factors including warming temperatures, White Band Disease, collapse of herbivore species, overfishing, and eutrophication (Gladfelter, 1982; Lessios, 1988; Aronson and Precht, 2001; Pandolfi and Jackson, 2006; Randall and Van Woesik, 2015; Cramer et al., in press). While *Acropora palmata* and *Acropora cervicornis* have been declining, there is some evidence that their F1 hybrid *Acropora prolifera* may be increasing in their stead, giving rise to hopes that this species may help provide a similar habitat for the reef ecosystem (Vollmer and Palumbi, 2002; Fogarty et al, 2012; Nylander-Asplin et al., in review).

Since 2011, live *A. cervicornis* coral tissue has been monitored annually along 5 established transects at Coral Gardens using m^2 scaled quadrat photographs. In 2014-2015, a team of eleven students and three faculty members completed an Advanced Keck project at Coral Gardens that included assessments of additional environmental and conditional parameters at Coral Gardens (Greer et al, 2015), including coral genetics, geochemical records of environmental change, herbivore dynamics, and ages of fossil coral material. This set the stage for the current project, providing a robust comparative dataset.

The current project also expanded the scope of study at Coral Gardens by including three-dimensional modeling of coral morphology using photogrammetry techniques and opportunistic assessment of massive *Sargassum* spp. seaweed blooms landing on Ambergris Caye beaches.

Although live coral cover has been declining at Coral Gardens since the 2014-2015 Keck project, the site still remains one of the better sites for extant *Acropora* spp. in the Caribbean. One aim of this project was to assess how resilient *A. cervicornis* has remained in the face of massive Caribbean-wide decline and to explore the connections between living coral, algae, and herbivore dynamics at this site. The project took place inshore of the MesoAmerican Barrier reef off Ambergris Caye in June and July 2019 (Figure 1).

METHODS

This study utilized multiple methods to investigate three separate projects off Ambergris Caye, Belize. We used high resolution photo-documentation and field measurements at Coral Gardens to examine relationships between live coral cover and herbivore abundance. We collected pH, Dissolved Oxygen, and temperature data to investigate the impacts of incoming Sargassum blooms on the near shore environments off Ambergris Caye. We also collected detailed overlapping photographic data from individual *Acropora cervicornis*, *Acropora palmata*, and *Acropora prolifera* colonies to create three-dimensional models of each species to assess the degree to which *A. prolifera* morphology provides a similar habitat to that of its parent species. We used multiple computer software programs in each facet of this work.

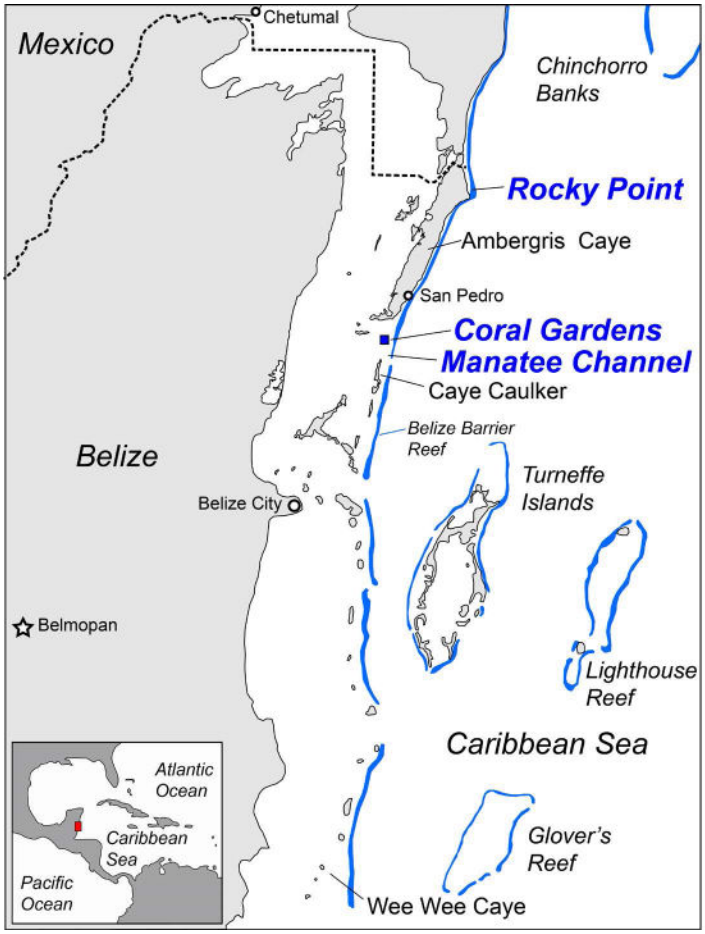

Figure 1. Location map of field sites in Belize.

RESEARCH

This research involved nine rising sophomore students, a rising senior peer mentor, and two faculty from ten different institutions. Together, we quantified 2-dimensional live coral cover from 141 individual quadrat photos. Unfortunately, our work documented a decrease in live A. cervicornis coral cover per m^2 at all 5 transect locations from 2013 to 2019 (Figure 3). While T5 still has the highest percentage of live coral, it showed the greatest decrease in percent over the study period. The remainder of our work was divided into three different areas of inquiry, described below.

The response of algae and herbivores to *Acropora cervicornis* decline

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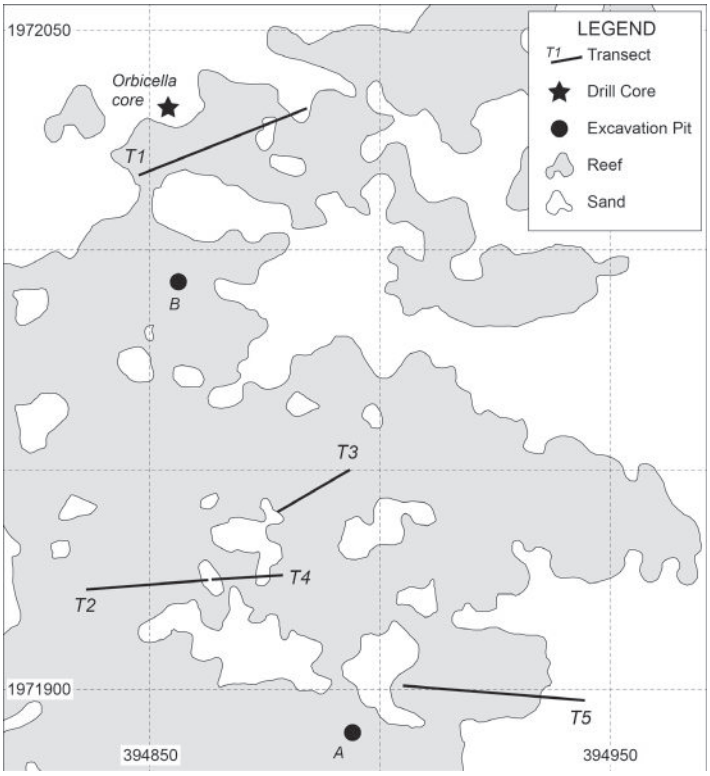

Figure 2. Map of Coral Gardens showing all 5 semi-permanent transect locations (T1-T5).

A decline in live *A. cervicornis* coral cover has been documented at Coral Gardens over the past few years and in particular since the 2014-2015 Keck Advanced project took place. Elsewhere in the Caribbean, *A. cervicornis* has been replaced by macroalgae that has often outcompeted new coral recruits for space on the reef. At some Caribbean locations, it is the suite of coral species that has changed, from the fast-growing and branching acroporids to 'weedier' species like *Agaricia* and *Porites* spp. It has been

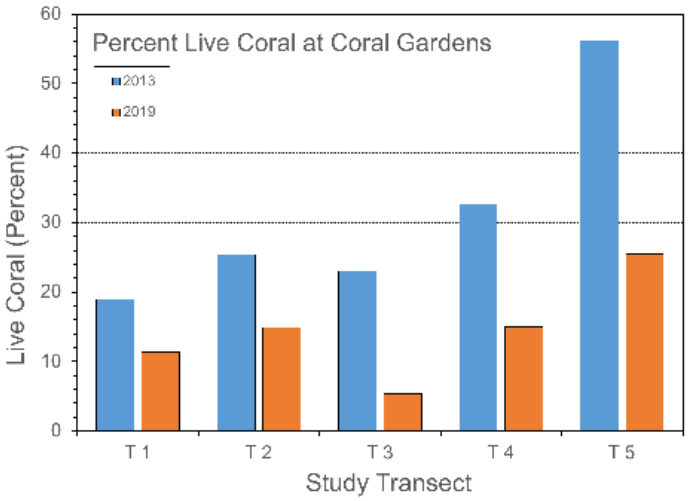

Figure 3. Comparison of mean live coral cover per m2 at transects 1-5 from 2013 to 2019.

well documented that algal cover is often tightly tied to herbivore abundance. This team explored whether the declining coral cover has been accompanied by an increase in macroalgae on the reef, a phase shift in dominant coral species, and/or a change in the abundance of key herbivores at Coral Gardens (Caterham et al., 2019). The team documented the abundance of *Echinometra viridis* urchins, and Damselfish (*Stegastes adustus, Stegastes planifrons, and Microspathodon chrysurus*) within m^2 quadrats across all 5 transects and designated *A. prolifera* patches. They also quantified coral species, live coral, non-living reef framework, sediment, and algae every 0.5 m along each transect with a point-count method. Between 2014 and 2019, they measured a 10.6% absolute increase in non-living framework and a 5.8% increase in algae, noting that the increase in algae was less than non-living rubble surfaces. This could be due in part to the average increase in urchins from 17.4 per m^2 in 2014 to 21.4 per m^2 in 2019. In that time *Agaricia agaricites* increased by 6.3% and damselfish abundance increased by 15%. from 2.0 to 2.3 per m^2. This suggests that damselfish may have some impact on the growth of algae in a declining coral scenario and emphasizes the complexity and importance of ecosystem interactions on coral, algae, and herbivores on the reef.

Browning of the Golden Tide: Impacts of accumulated Sargassum on sea water quality in Ambergris Caye, Belize

Petra Zuñiga (Amherst College), **Will Riley** (Vassar College), **Riley Waters** (Macalester College), **Ginny Johnson** (Washington and Lee University)

We arrived in Belize amidst a massive influx of pelagic *Sargassum* spp., a phenomenon that has only recently occurred in the equatorial Atlantic. Since about 2011, this seaweed has accumulated along Caribbean shorelines, converting from a free-floating 'Golden Tide' offshore to plumes of brown water emanating from the shoreline as the Sargassum rots and decomposes. In addition to aesthetic concerns (sight and smell) for local businesses and residents, the brown water has a measurable impact on water quality nearshore. This team assessed the extent and properties of the browning water offshore of the eastern shore of Ambergris Caye (Zuñiga et al., 2019). They measured dissolved oxygen (DO), pH, temperature, specific conductivity, water color and clarity at 21 locations and along 4 transects perpendicular to the shoreline. They found DO as low as 0.03 mg/L inshore, a 99.5% decrease in DO compared to typical seawater, while DO in free-floating 'Golden' patches averaged 6.0 mg/L. The pH beneath free-floating Sargassum averaged 8.07 but was as low as 6.44 nearshore. Both DO and pH generally increased with distance from shore. The largest brown patch we measured was greater than 265,000 m^2 and extended 200 m from shore, about a quarter of the distance to the reef crest. At another location the brown water extended greater than 800 m from shore. Interviews with local residents suggest these plumes were small in comparison to peak values in recent years. Fish kills, seagrass die-offs near shore, and negative health impacts for humans were all reported by local residents associated with these events. The team noted the importance of continued monitoring and further studies focused on potential remediation efforts for the personal, health, and economic benefits of Belizeans.

Living spaces: Quantifying morphological differences in *Acropora* spp. Corals using 3D Photogrammetry

Mattea Horne (Pomona College), **Jolie Villegas** (Wesleyan University), **Sydney Walters** (Colgate University), **Ginny Johnson** (Washington and Lee University), and in collaboration with **David Pfaff** (Washington and Lee University)

This team investigated the degree to which the morphology of the hybrid *A. prolifera* might produce a similar habitat for herbivores as the parent species *A. palmata* and *A. cervicornis* (Horne et al., 2019). They collected detailed overlapping photographs of coral colonies underwater with a variety of photographic parameters to test which techniques might best facilitate high resolution 3D modeling. They also measured the abundance of *Echinometra viridis* urchins in m^2 quadrats on *A. cervicornis* and *A. prolifera* colonies. They used Agisoft Metashape Professional photogrammetry software to stitch the photos together and measure coral branch height and width. They then used Cinema 4D software to measure the total surface area of live and dead coral substrate,

volume of coral skeleton, and available pore space between branches in each model. They found that *A. prolifera* had 43-49% greater total surface area than *A. cervicornis* with 3.3-3.4 m^2 per square meter (live *A. prolifera*) based on the footprint of the coral colonies. *A. prolifera* had 9-13% higher surface area than *A. palmata*. The available space (accessible habitat) for urchins was measured by subtracting the volume of coral from the volume of the smallest possible polygon constructed to contain the coral colony. *A. cervicornis* had the greatest available space (0.96 m^2 per cubic meter) followed by *A. prolifera* (0.91-0.95 m^2 per cubic meter) and *A. palmata* (0.89 m^2 per cubic meter). Yet total volume does not capture the size distribution of spaces, which is key to determining utility for an urchin. *A. prolifera* exhibits a scrubbier 'bushy' and more compact morphology that is generally distinct from the more open lattice of *A. cervicornis* and the very open canopy of *A. palmata*. Therefore, the available space in an *A. prolifera* colony is distributed more widely but manifest in smaller spaces. Field data showed denser urchin populations in *A. prolifera* patches (31.7 urchins per m^2) than *A. cervicornis* (21.4 urchins per m^2) but the urchins associated with *A. prolifera* appeared smaller on average. The results suggest that the distinct morphologies of these coral species might provide some influence on the size, movement, and available shelter of those that seek food and/or refuge within reef framework.

IMPLICATIONS OF THIS WORK

Is Coral Gardens a refugia?

Although live *Acropora cervicornis* has declined over the last several years at Coral Gardens, it remains one of the largest documented accumulations of extant *A. cervicornis* reported in the literature (Busch et al., 2016). For how long this will continue cannot be resolved at this time. Genetic aging of Coral Gardens acroporids suggests a long-lived and persistent population (Irwin et al., 2017) and age data from the 2014-2015 Keck project confirms persistence over the last 100 years (Greer et al., in prep). This study shows continued growth of *Acropora* spp. at Coral Gardens. At the same time, it seems that declining coral has not resulted in the kind of massive phase shift from coral to algae that other sites in the Caribbean have seen. It is possible that Coral Gardens herbivores are key to keeping the algae at bay.

Are the recent Sargassum blooms detrimental to nearshore Ambergris Caye?

Our data suggest that the browning of the golden tide is potentially a very dangerous phenomenon for humans and nearshore marine communities. While a great deal more work should be done, and our evidence for negative health impacts is anecdotal, it is clear that the decomposing *Sargassum* spp leads to DO far below sustainable levels for marine communities in the shallowest nearshore environments. The decrease in pH levels nearshore is worrisome for carbonate producers (coral and calcareous algae) in those areas closest to shore. Mitigation, while keeping the health of humans interacting with the decaying Sargassum spp. in mind, should be an important consideration moving forward.

Will *Acropora prolifera* provide a similar habitat to its parent species for other reef dwellers?

While *A. prolifera* does seem to provide a framework somewhat similar to *A. cervicornis*, it is not a perfect substitute. It seems to provide more space but for smaller *Echinometra viridis* urchins. More work needs to be done to better assess the degree to which *A. prolifera* provides space and habitat to other reef dwellers.

Should Coral Gardens be protected?

Our data suggest that Coral Gardens remains an exceptional location for extant *Acropora* spp. corals. We continue to suggest that Coral Gardens may benefit from increased conservation efforts and we hope that Marine Protected Area (MPA) designation will be considered for this site. We understand that MPA status does not always result in better coral health against a formidable backdrop of global and regional climate and environmental change. But our data show that Coral Gardens remains a refuge, at least for now, for *Acropora* spp. corals.

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