Reef-scale trends in Florida Acropora spp. abundance and the effects of population enhancement

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Since the listing of Acropora palmata and A. cervicornis under the U.S. Endangered Species Act in 2006, increasing investments have been made in propagation of listed corals (primarily A. cervicornis, A. palmata to a much lesser extent) in offshore coral nurseries and outplanting cultured fragments to reef habitats. This investment is superimposed over a spatiotemporal patchwork of ongoing disturbances (especially storms, thermal bleaching, and disease) as well as the potential for natural population recovery. In 2014 and 2015, we repeated broad scale (>50 ha), low precision Acropora spp. censuses (i.e., direct observation by snorkelers documented via handheld GPS) originally conducted in appropriate reef habitats during 2005-2007 to evaluate the trajectory of local populations and the effect of population enhancement. Over the decade-long study, A. palmata showed a cumulative proportional decline of 0.4 – 0.7x in colony density across all sites, despite very low levels of outplanting at some sites. A. cervicornis showed similar proportional declines at sites without outplanting. In contrast, sites that received A. cervicornis outplants showed a dramatic increase in density (over 13x). Indeed, change in A. cervicornis colony density was significantly positively correlated with cumulative numbers of outplants across sites. This study documents a substantive reef-scale benefit of Acropora spp. population enhancement in the Florida Keys, when performed at adequate levels, against a backdrop of ongoing population decline.
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ABSTRACT: Since the listing of Acropora palmata and A. cervicornis under the U.S. Endangered Species Act in 2006, increasing investments have been made in propagation of listed corals (primarily A. cervicornis, A. palmata to a much lesser extent) in offshore coral nurseries and outplanting cultured fragments to reef habitats. This investment is superimposed over a spatiotemporal patchwork of ongoing disturbances (especially storms, thermal bleaching, and disease) as well as the potential for natural population recovery. In 2014 and 2015, we repeated broad scale (>50 ha), low precision Acropora spp. censuses (i.e., direct observation by snorkelers documented via handheld GPS) originally conducted in appropriate reef habitats during 2005-2007 to evaluate the trajectory of local populations and the effect of population enhancement. Over the decade-long study, A. palmata showed a cumulative proportional decline of 0.4 – 0.7x in colony density across all sites, despite very low levels of outplanting at some sites. A. cervicornis showed similar proportional declines at sites without outplanting. In contrast, sites that received A. cervicornis outplants showed a dramatic increase in density (over 13x). Indeed, change in A. cervicornis colony density was significantly positively correlated with cumulative numbers of outplants across sites. This study documents a substantive reef-scale benefit of Acropora spp. population enhancement in the Florida Keys, when performed at adequate levels, against a backdrop of ongoing population decline.
INTRODUCTION:

Caribbean coral reefs are home to two species of fast-growing, habitat-forming species of Acropora spp. corals; staghorn (A. cervicornis) and elkhorn (A. palmata). Both are listed as Critically Endangered by IUCN and threatened under the US Endangered Species Act (ESA).

Their endangered status accrues from a litany of factors which have caused extensive mortality combined with inadequate recruitment to sustain populations throughout their range (Acropora Biological Review Team 2005; Aronson & Precht 2001; Bright et al. 2013). ESA listing carries a legal mandate to ‘recover’ imperiled species. The Recovery Plan for A. palmata and A. cervicornis (NMFS 2015) describes the need for ongoing monitoring and evaluation to track the status of populations, as well as the need to curb ongoing threats (e.g., disease, land-based sources of pollution, and thermal stress due to global climate change) and implement proactive population enhancement measures to jumpstart population recovery (NMFS 2015). Growing effort has been dedicated to implementing population enhancement throughout the Caribbean (Young et al. 2012), largely following the ‘coral gardening’ model (Epstein et al. 2003; Rinkevich 2015).

As Acropora population enhancement effort has grown, substantial management and planning effort has been invested into developing risk-averse strategies. These strategies include 1. emphasis on in situ (versus land-based) culture, 2. dispersing individual field nursery operations to limit the geographic distance from which source stocks are drawn and propagated fragments are outplanted, and 3. maximizing and tracking the genotypic diversity of cultured stocks. Acropora spp. are propagated via fragmentation from locally-collected stocks in offshore field nurseries, grown to a viable size and then outplanted to reef habitats with the
goal of re-creating sustainable population patches which can serve as larval sources to
jumpstart population recovery on a broader scale. Common practices and details of
implementation are described in Johnson et al. (2011).

Unfortunately, cultured *Acropora* fragments often behave like their wild counterparts in
Caribbean reef communities as they are subject to ongoing chronic and acute stressors, often
manifesting substantial mortality in the same pattern as the background population (Miller et
al. 2014; Schopmeyer & Lirman 2015). Critics of population enhancement maintain that
potentially high levels of mortality would preclude any long term benefit to population
recovery, and that high cost implies that the scale of effect (e.g., area of reef) will remain trivial.

Substantial published work has documented the remarkable success of these field nursery
culture efforts (Griffin et al. 2012; Lirman et al. 2014; Lirman et al. 2010; Lohr et al. 2015) as
well as the short term fate of individual outplanted colonies (Griffin et al. 2015a; Mercado-
Molina et al. 2015). These evaluations are based on tractable observations and measurements
of individual tagged colonies at a few sites over one to a few years. There is a much greater
challenge in tracking *Acropora* spp. colony abundance at the meso-scale (100’s m² to hectares)
due to fragmentation, displacement, and partial mortality. Consequently, there is little
information available to aid in evaluating the potential for active population enhancement to
‘move the needle’ in affecting reef-scale population trajectories of Caribbean *Acropora* spp.

In this study, we used a broad scale, low-precision census technique (direct observation
by snorkelers documented via handheld GPS; Devine et al. 2005; Walker et al. 2012) to further
this evaluation goal by documenting both the long term (2005 – 2015) reef-scale trajectory of
Florida Keys *Acropora* populations undergoing ongoing acute and chronic disturbances as well
as whether these trajectories are influenced by population enhancement effort. The acute disturbances affecting these populations included multiple tropical storms (2005, 2008, 2012), a severe cold thermal event in 2010, mild bleaching in 2011, and a severe warm thermal mass bleaching event in 2014 as well as chronic and substantial effects of predation and disease (Williams & Miller 2012).

A conservation organization in the upper Florida Keys (Coral Restoration Foundation, CRF) has been propagating and outplanting *A. cervicornis* since 2003 (substantial numbers since 2011) and *A. palmata* since 2012 (substantial numbers since 2014, Suppl. Table 1), although the number of outplants placed on the reef has varied greatly over time according to the factors such as permitting restrictions, damaging storms which required time for recovery of nursery infrastructure and cultured stocks, and funding levels. This sustained effort combined with the availability of historic census information from a range of reef sites in the upper Florida Keys provides a novel opportunity to evaluate potential reef-scale effects of *Acropora* spp. population enhancement against a backdrop of ongoing chronic and acute disturbances in the reef environment. We compared trajectories of *Acropora* spp. density at reef areas which had versus had not received population enhancement efforts over appropriate time frames to evaluate the reef-scale effect of enhancement.

**METHODS:**

Sites targeted for this study were chosen in 2005, prior to the onset of substantial population enhancement efforts. Habitat maps (as described in Lidz et al. 2006; Marszalek 1977) were used to identify shallow (< 5m) coral habitat areas in the upper Florida Keys,
spanning between Carysfort reef in the north to Pickles reef in the south (i.e., 25.2°N to 24.9°N latitude). Targeted reef areas were restricted to less than 5 m depth as observations at deeper depths on snorkel become less reliable. This depth range encompasses the core habitat for A. palmata, though A. cervicornis traditionally occupies a wider depth range. Most, but not all sites were surveyed once in 2005-7, once in 2013 or 14, and once in 2015 (Suppl. Table 2; Miller 2008; Williams 2013). Hence, different numbers of sites are available for different temporal comparisons.

Teams of two or three snorkelers addressed each study site with the intent to observe the entire reef surface via swimming sequential, parallel linear transects. The width of each transect was adjusted according to conditions including depth, relief and water visibility, with the intent that the benthos was thoroughly observed with minimal overlap. In practice, this is very challenging to accomplish and enhanced procedures were implemented as the effort progressed to improve the practical coverage, including the visual delineation of the target area (or subset assigned to an individual snorkeler) with weighted dive flags and the use of compasses and pre-agreed headings (generally following the direction of reef spurs) to maintain parallel tracks. In the early censuses, dive scooters (SeaDoo VS Supercharged) were used, but snorkelers performed surveys predominantly under their own power in 2013-15.

Each snorkeler towed a handheld GPS unit (Garmin GPS72 in 2005-7; Garmin eTrex20 for 2013-15) in a waterproof plastic pouch attached to a floating dive flag. The GPS recorded the ‘track’ traversed by the snorkeler. When an Acropora spp. colony was encountered, the snorkeler recorded a waypoint on the GPS for each, and recorded the species for each waypoint on a field data sheet. In some cases, A. palmata colonies were observed growing in high
density patches wherein it was not feasible to demarcate individual colonies. In these cases, the snorkeler would swim around the perimeter of the feature and record waypoints along the outline which were designated on the data sheet as a ‘thicket’. While it is possible that this qualitative definition may have been applied slightly differently by different observers, the disappearance of known thicket areas (e.g., Grecian Rocks and Watsons reef) at later surveys was verified by multiple observers. The area occupied within this ‘thicket’ outline was calculated in GIS for each survey and was compared at each site over time. We did not document any analogous ‘thickets’ for *A. cervicornis*.

After each survey was completed, the GPS-recorded track was saved, waypoints and tracks were downloaded to a personal computer, and then exported to a spreadsheet file where the waypoint attributes were entered from the field data sheet. For each study site, maps were created in ArcGIS plotting the colonies and thickets observed for each census year (Fig 1A-1B, Suppl Fig 1). Lastly, the observational paths followed by the surveyors (i.e. the GPS tracks) were imported to each map to depict the area searched. Using the *Minimum Bounding Geometry* tool, the minimum area covered by the observational path (observed area) was determined for each year*site map.

Temporal comparisons were made for two intervals: a long-term interval from the periods 2005-07 (early; e.g., Fig 1A) to 2013-14 (late; Fig 1B); and a short term interval from 2013-14 (early; Suppl Fig 1A) to 2015 (late; Suppl Fig 1B). For each site, the early and late maps were merged to make temporal comparisons of reef scale density trends (Fig 1C, Suppl Fig 1C). Each temporal comparison was restricted to congruent observed areas of the reef (i.e., covered by the observational paths in both time points) by clipping the area of comparison to the area
of overlap in the observed area for each year using the *Intersect* tool. If the congruent area
consisted of numerous overlapping polygons, then the *Merge Polygon* tool was used. Areas
outlined as *A. palmata* ‘thicket’ were calculated for each survey and the number of colonies in
each thicket area was estimated using a standard density estimate of 1 colony per m$^2$ (based on
independent field estimates using fixed area belt transects within the Horseshoe reef thicket
over four years yielding a mean of 1.01 ± 0.26 SD colonies per m$^2$; M. Miller unpublished data).
Individual colony waypoints and thicket abundance estimates were summed for each species to
obtain the total abundance for each survey year in the overlapping comparison area.

Total colony abundance of each species in each year in the congruent search area of
reef was converted to density (total number of colonies observed / congruent observed area of
reef (m$^2$)) to compare between time points (Mann-Whitney Rank Sum tests). For temporal
comparisons, the proportional change in density between two time points was calculated. This
proportional change in density at each site was calculated for the longest interval observed for
each site, as well as the pre- (2005-6 versus 2014) and post-bleaching (2014 versus 2015)
intervals. Proportional change in density was annualized by dividing by the number of years
between surveys and Mann-Whitney Rank Sum tests were used to test for significant difference
between the pre- and post-bleaching intervals.

Information on the total number of coral colonies of each species outplanted to each
censused reef site by year was provided by staff of the Coral Restoration Foundation (J. Levy
and K. Ripple; Pers comm; Suppl Table 1). CRF is the only organization undertaking large scale
*Acropora* spp. population enhancement in the study area (additional nurseries operate and
outplant in different sectors of the Florida Reef Tract). The overall change in mean density over
the longest observed interval for each reef (Suppl. Table 3) was used to correlate the overall impact of population enhancement for *A. cervicornis* as outplanting has been ongoing for this species since 2008 and this enabled the use of information from all sites (*n*=14, a few of which had not been surveyed in 2013 or 14). However, substantial outplanting was only conducted for *A. palmata* since 2014 (Suppl Table 1) so the 2014 to 2015 interval only was used to correlate with outplanting effect for this species. For each species, we conducted a Mann-Whitney rank sum test comparing proportional change in colony density between the sites which had and sites which had not received outplants. Also, a simple linear regression was performed for each species between the proportional change in colony density and the cumulative number of outplants among all sites.

**RESULTS:**

The total surveyed area for each census ranged from 55 to 77 hectares while the congruent observed area of reef for temporal comparisons within each site ranged from 1.6 to 15.5 hectares (Table 1). *Acropora palmata* thickets were observed at four sites in 2005-7, two of which had disappeared by 2015 (Fig 2). At these two sites (Grecian Rocks and Watson’s Reef) the aggregation of *A. palmata* colonies in the thicket area had dwindled to where it was no longer designated a thicket, though a few widely-spaced remnant colonies remained. One of the other two sites with thickets showed approximately half decline in area, whereas the last was approximately stable in area (Fig 2). Overall, this represents over two thirds loss in total *A. palmata* thicket area (from 2229 m$^2$ to 713 m$^2$) among these four sites.
When considering the full study duration, both species showed a negative trajectory in the absence of outplanting (40% decline in density for \textit{A. cervicornis}, 70% decline for \textit{A. palmata}, pooled among 7 or 9 sites respectively; Table 2). When considering trends between the pre- and post-bleaching intervals, \textit{A. cervicornis} showed a substantial annualized increase in density when averaged across all sites from 2005 to 2014 (n=8, Table 1A, Fig 3A)) with the most dramatic changes occurring at sites receiving outplants (Table 1A). \textit{A. cervicornis} density increased only slightly on average between 2014 and 2015 (co-incident with a mass thermal bleaching event and a smaller cumulative number of outplants) yielding a significant difference in annualized density change between the two intervals (Mann-Whitney Rank Sum Test p=0.037; Fig 3A). Meanwhile, \textit{A. palmata} showed much smaller proportional changes in density (corresponding with many fewer total outplants; Table 1, Fig 3). While the average trend was substantially negative in the 2005-14 interval and essentially stable in the 2014-15 (bleaching) interval (Fig 3), this difference was not statistically significant (t-test, p=0.824).

To specifically evaluate the hypothesis that outplanting effort had a significant, landscape-scale effect on colony density, we performed two separate tests; for \textit{A. cervicornis} these tests were applied to the full interval of observation at each site (2005-2015, n=14 sites, Suppl Table 3) whereas for \textit{A. palmata}, substantial enhancement effort has only occurred since 2014 so the 2014-2015 interval was used. A Mann-Whitney U-test indicated that sites receiving \textit{A. cervicornis} outplants had significantly different change in density than those that did not (p=0.002). However, no significant difference occurred for \textit{A. palmata} (corresponding to a much smaller cumulative number of outplants, Table 1). Simple linear regression showed a strong and highly significant relationship between change in \textit{A. cervicornis} colony density and
cumulative number of outplants among sites (Fig 4A). The similar regression for *A. palmata* for
the 2014-2015 interval when outplanting (as well as the bleaching event) occurred showed no
significant relationship (Fig 4B).

DISCUSSION:

This study is not intended to provide an overall cost:benefit for *Acropora* spp. population enhancement as many details of stock collection, propagation, and short term
colony-scale outplant success have been previously documented (Griffin et al. 2012; Griffin et
al. 2015b; Johnson et al. 2011; Lirman et al. 2014; Lirman et al. 2010; Lohr et al. 2015; Mercado-
Molina et al. 2015; Young et al. 2012). Rather, we sought, via a low precision but large scale
census approach, to determine if reef-scale effects of population enhancement efforts could be
discerned. We performed repeated censuses over multiple reef sites over a decadal time frame
in which both extensive population enhancement effort and an acute thermal disturbance
(along with several lesser disturbances) occurred. Thus, this approach was designed to detect
large changes at a large spatial scale.

Our surface-based observation method restricted censused areas to generally less than
5m depth. The depth of outplants at each site is not consistently documented, though some
were likely placed deeper than 5 m depths and missed in our surveys, rather than dead.

Although the historic core habitat of *A. cervicornis* likely extended deeper than 5 m depth,
current known distribution of *A. cervicornis* in the Keys is predominated by nearshore
(shallower) habitats (Miller et al. 2008) in contrast to the deeper fore-reef habitats historically
described for this species. Thus, although extensive *A. cervicornis* distribution in deeper areas not covered by our study is possible, current evidence does not support this in the Florida Keys.

Much greater overall enhancement effort (~ an order of magnitude, Table 1, Suppl Table 1) has gone to *A. cervicornis* in comparison to *A. palmata*, and this added effort corresponded to a significant landscape scale effect. *A. cervicornis* density showed a significant and positive relationship with the degree of this enhancement effort across sites over the entire study period (Fig 4A). However, the acute thermal bleaching event appears to have reduced the impact of outplanting between 2014 and 2015 as more than double the number of outplants during that year yielded a much smaller increment of density compared to the earlier interval (Fig 3A). Indeed, we observed extensive bleaching and mortality of outplants during the 2014 bleaching event in a separate study (Miller et al., unpubl). Both the overall densities and the scale of the enhancement effort have been lower for *A. palmata* (Table 1) which shows a clear pattern of declining density over the recent decade both overall (Table 2, Fig 3B) and as represented in the occupation of thickets (Fig 2). This mostly negative population trend has not been substantively overcome by the small outplanting effort to date and is consistent with results of independent plot-scale studies in the Florida Keys (Sutherland et al. 2016; Williams & Miller 2012). We are not aware of other published studies of contemporary trends in Florida Keys *A. cervicornis* populations, although the detrimental effects of individual events on this species are documented (e.g., 2010 winter cold; Kemp et al. 2011). Substantial documentation does exist (Vargas-Angel et al. 2003; Walker et al. 2012) of abundant *A. cervicornis* populations, including extensive thickets, in southeast Florida (over 80 km north of our study area), though little quantitative information on trends in abundance is available in this nearby region.
The precision of our census technique was low, as the challenge of a snorkeler navigating in open ocean as well as variation in depth, visibility, and likely individual observer variation yielded less than perfect observational coverage and detection of colonies that were present. However, we implemented improved field techniques over time which improved the operational coverage of the area surveyed (e.g. the deployment of surface markers to delineate the survey area for each surveyor and the use of compasses; compare coverage of tracks in Fig 1A vs 1B; additional tracks in Suppl Fig. 2). Thus, results suggesting overall decline in densities are conservative as we expect our observational detection was improved in later years. Also, this technique allowed us to evaluate population trends at a hectare scale. More resolved techniques such as photo mosaics provide a much more precise assessment technique, but are still only applicable at meso-scales (hundreds of m²; Lirman et al. 2007).

The substantial loss of *A. palmata* thicket area is a particularly concerning result. *Acropora* thickets are understood to have been the typical configuration on Caribbean reefs prior to the drastic decline of these species starting in the late 1970’s (Gladfelter 1982; Goreau 1959; Jaap 1984) and are functionally important in terms of providing structural habitat both for other reef inhabitants and to facilitate fragment retention (i.e., successful asexual reproduction) for the coral itself. This importance is reflected in the fact that the area of thicket (not just population abundance) has been defined as a key criterion for determining the recovery of these species under the US Endangered Species Act (NMFS 2015). The loss of *A. palmata* thicket area thus represents a trend opposing species recovery. The density of all *A. palmata* colonies also shows negative trends at most sites, both before and during the acute thermal bleaching event (Table 1).
Overall, population enhancement is associated with reef-scale positive trends in *Acropora cervicornis* in the Florida Keys, though a (order-of-magnitude) lower level of outplanting effort (predominantly during a bleaching year) did not appear to be adequate to produce a similar relationship for *A. palmata*. Also, positive effects of outplanting *A. cervicornis* appeared to be damped by a massive thermal stress event in 2014-15. If the intent is to recover these foundation species (as mandated by the Endangered Species Act) and maintain reef ecosystem function, our results point to the need for ongoing population enhancement efforts as a stop-gap strategy to prevent further population declines while the paramount need to curtail climate change is addressed (NMFS 2015).

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Figure Legends:

Fig 1: Component maps and spatial analyses are illustrated for a single site (Grecian Rocks) and interval. A similar sequence of maps was constructed for each site (Supplemental Fig 1,2) and temporal comparison. Observed search tracks and waypoint features mapped for each census year are given in A) 2006 with waypoints as stars and B) 2014 with waypoints as asterisks. *A. palmata* colony waypoints are depicted in yellow, *A. cervicornis* colonies in purple, and *A. palmata* thicktet outline points in red. C) Merged maps for temporal comparison showing the congruent observed area (determined by GIS intersect of the polygons determined by the search tracks for each year) for both years and the overlayed colony distribution observed in both years. Similar year and temporal comparison maps for 2014-2015 are given in Supplemental Fig 2).

Fig 2: Area (m$^2$) of *A. palmata* thickets (i.e. high density aggregations for which mapping individual colonies was deemed infeasible) at four sites over time. Horseshoe was surveyed in both 2005 and 2007 so the point for this time period is a mean of these two. Thickets dropping to zero area likely still contained remnant colonies, but at lower densities such that individual colonies could be mapped (see text for details on methods).

Fig 3: Annualized proportional change in colony density (i.e., proportion change from Table 1 divided by the number of years in the observed interval; mean plus 1 SE) for *Acropora cervicornis* (A) and *Acropora palmata* (B) during two time intervals. Diamonds (right y-axis) show the mean number of fragments of each species outplanted per year over the same intervals. Note the differences in axis scales.
Fig 4: Scatterplot showing linear regressions for proportional change in colony density relative to the cumulative number of outplants for A) *Acropora cervicornis* (full interval of observation, n=14 sites) and B) *Acropora palmata*. Population enhancement has only occurred for *A. palmata* since 2014, so B) shows proportional change in density for this species from 2014-2015 at n=9 sites (regression is not significant).
Figure 1

Illustration of survey and spatial analysis

Component maps and spatial analyses are illustrated for a single site, Grecian Rocks; a similar sequence of maps was constructed for each site (given in Supplemental Fig 1) and temporal comparison. Observed search tracks and waypoint features mapped for each census year (2006 points as stars, 2014 points as asterisks) are given in A) 2006 with waypoints as stars and B) 2014 with waypoints as asterisks. *A. palmata* colony waypoints are depicted in yellow, *A. cervicornis* colonies in purple, and *A. palmata* thicket outline points in red. C) Merged maps for temporal comparison showing the congruent observed area (determined by GIS intersect of the polygons determined by the search tracks for each year) for both years and the overlayed colony distribution observed in both years. Similar year and temporal comparison maps for 2014-2015 are given in Supplemental Fig 2).
**Figure 2** (on next page)

*Acropora palmata* thickets

Area (m$^2$) of *A. palmata* thickets (i.e. high density aggregations for which mapping individual colonies was deemed infeasible) at four sites over time. Horseshoe was surveyed in both 2005 and 2007 so the point for this time period is a mean of these two. Thickets dropping to zero area likely still contained remnant colonies, but at lower densities such that individual colonies could be mapped (see text for details on methods).
Figure 3 (on next page)

*Acropora* spp. change in density

Annualized proportional change in colony density (i.e., proportion change from Table 1 divided by the number of years in the observed interval; mean plus 1 SE) for *Acropora cervicornis* (A) and *Acropora palmata* (B) during two time intervals. Diamonds (right y-axis) show the mean number of fragments of each species outplanted per year over the same intervals. Note the differences in axis scales.
Figure 4 (on next page)

Acropora spp change in colony density with population enhancement

Scatterplot showing linear regressions for proportional change in colony density relative to the cumulative number of outplants for A) Acropora cervicornis (full interval of observation, n=14 sites) and B) Acropora palmata. Population enhancement has only occurred for A. palmata since 2014, so B) shows proportional change in density for this species from 2014-2015 at n=9 sites (regression is not significant).
A) *A. cervicornis*, 2005-2015

![Graph A: A. cervicornis, 2005-2015](image)

R = 0.723, p = 0.008

B) *A. palmata*, 2014-2015

![Graph B: A. palmata, 2014-2015](image)
Table 1 (on next page)

Long-term and short-term *Acropora* spp. changes at sites in the upper Florida Keys.

Summary of congruent observed areas, colony densities, and number of outplants for both species over A) long term interval prior to 2014 thermal bleaching event and B) over the 2014-2015 bleaching event, at sites in the upper Florida Keys. Change in density is represented as a proportion of the initial density. Information on numbers of outplants provided by Coral Restoration Foundation, the only organization performing large-scale population enhancement in this region. ‘Early’ and ‘Late’ refer to the first and last survey year, respectively, of the interval for each site. CF=Carysfort, FR=French, ML=Molasses, NDR= North Dry Rocks, WBDR1/2= White Bank Dry Rocks north/south, LG= Little Grecian, GR = Grecian Rocks, NNDR = North North Dry Rocks, SI= Sand Island.
### A. cervicornis

| Reef  | Years | Congr Area (ha) | #Ac Early | AcDens Early | #Ac Late | AcDens Late | Change AcDens | # Ac Outpl | #Ac Early | AcDens Early | #Ac Late | AcDens Late | Change AcDens | # Ac Outpl | #Ap Early | ApDens Early | #Ap Late | ApDens Late | Change ApDens | # Ap Outpl |
|-------|-------|-----------------|----------|--------------|----------|--------------|---------------|------------|----------|--------------|----------|--------------|---------------|------------|----------|--------------|----------|--------------|---------------|------------|
| CF    | 05 & 14 | 1.6             | 8        | 4.9         | 9        | 5.6          | 0.1           | 370        | 55       | 34.0         | 0        | 0.0          | -1.0          | 0          |
| FR    | 07 & 14 | 8.0             | 8        | 1.0         | 41       | 5.1          | 4.1           | 682        | 185      | 23.2         | 63       | 7.9          | -0.7          | 0          |
| ML    | 06 & 14 | 15.5            | 12       | 0.8         | 1331     | 85.8         | 109.9         | 3071       | 239      | 15.4         | 89       | 5.7          | -0.6          | 0          |
| NDR   | 06 & 14 | 3.9             | 109      | 28.3        | 3        | 0.8          | -1.0          | 300        | 74       | 19.2         | 27       | 7.0          | -0.6          | 0          |
| GR    | 06 & 14 | 14.1            | 42       | 3.0         | 39       | 2.8          | -0.1          | 0          | 408      | 29.0         | 276      | 19.6         | -0.3          | 0          |
| WBDR  | 06 & 14 | 6.4             | 10       | 1.6         | 526      | 82.3         | 51.6          | 1307       | 192      | 63.8         | 109      | 86.1         | 0.3           | 0          |
| WBDR1 | 06 & 14 | 9.3             | 172      | 18.6        | 448      | 48.4         | 1.6           | 0          | 6        | 0.6          | 0        | 0.0          | 0.0           | 0          |
| LG    | 06 & 13 | 2.1             | 1        | 0.5         | 8        | 3.8          | 7.0           | 320        | 153.8    | 270         | 129.8    | -0.2         | 0.0           | 0          |

### A. palmata

| Reef  | Years | Congr Area (ha) | #Ac Early | AcDens Early | #Ac Late | AcDens Late | Change AcDens | # Ac Outpl | #Ap Early | ApDens Early | #Ap Late | ApDens Late | Change ApDens | # Ap Outpl |
|-------|-------|-----------------|----------|--------------|----------|--------------|---------------|------------|----------|--------------|----------|--------------|---------------|------------|
| CF    | 14 & 15 | 9.4             | 0        | 0.0         | 0        | 0.0          | 0.0           | 815        | 26       | 2.8          | 12       | 1.3          | -0.5          | 66          |
| FR    | 14 & 15 | 7.3             | 60       | 15.9        | 106      | 23.9         | -1.6          | 0          | 63       | 8.6          | 82       | 11.2         | 0.3           | 230         |
| ML    | 14 & 15 | 13.5            | 1260     | 93.2        | 269      | 19.9         | -0.8          | 915        | 89       | 6.6          | 82       | 6.1          | -0.1          | 377         |
| NDR   | 14 & 15 | 3.1             | 109      | 34.7        | 79       | 25.2         | -0.3          | 388        | 74       | 23.6         | 137      | 43.6         | 0.9           | 170         |
| GR    | 14 & 15 | 9.3             | 39       | 4.2         | 231      | 24.8         | 4.9           | 603        | 241      | 25.9         | 50       | 5.4          | -0.8          | 0           |
| WBDR2 | 14 & 15 | 5.6             | 526      | 93.4        | 194      | 34.5         | -0.6          | 0          | 0        | 0.0          | 0        | 0.0          | 0.0           | 0           |
| WBDR1 | 14 & 15 | 6.2             | 446      | 71.7        | 84       | 13.5         | -0.8          | 0          | 0        | 0.0          | 0        | 0.0          | 0.0           | 0           |
| NNDR  | 13 & 15 | 2.6             | 8        | 3.1         | 0        | 0.0          | -1.0          | 0          | 34       | 13.0         | 88       | 33.7         | 1.6           | 0           |
| LG    | 13 & 15 | 3.5             | 18       | 5.1         | 15       | 4.3          | -0.2          | 0          | 60       | 17.1         | 28       | 8.0          | -0.5          | 0           |
| SI    | 14 & 15 | 3.5             | 0        | 0.0         | 0        | 0.0          | 0.0           | 0          | 106      | 30.7         | 35       | 10.1         | -0.7          | 0           |
Table 2 (on next page)

Overall changes in colony density

Cumulative changes in Acropora spp. colony density over the full study duration (2005-07 versus 2014-15) pooled among sites with and without outplanting for each species. Sites and specific durations for each given in Suppl Table 2.
Table 2: Cumulative changes in *Acropora* spp. colony density over the full study duration (2005-07 versus 2014-15) pooled among sites with and without outplanting for each species. Sites and specific durations for each given in Suppl Table 2.

|                     | Total Congr area (ha) | # colonies early | Density early | # colonies late | Density late | Change in density |
|---------------------|-----------------------|------------------|---------------|-----------------|--------------|-------------------|
| **A. cervicornis**  |                       |                  |               |                 |              |                   |
| With Outplants      | 50.8                  | 93               | 1.8           | 1356            | 26.7         | 13.6              |
| (n=7 sites)         |                       |                  |               |                 |              |                   |
| Without Outplants   | 33.2                  | 227              | 6.8           | 144             | 4.3          | -0.4              |
| (n=7 sites)         |                       |                  |               |                 |              |                   |
| **A. palmata**      |                       |                  |               |                 |              |                   |
| With Outplants      | 33.8                  | 620              | 18.3          | 369             | 10.9         | -0.4              |
| (n=5 sites)         |                       |                  |               |                 |              |                   |
| Without Outplants   | 50.2                  | 671              | 13.4          | 178             | 3.5          | -0.7              |
| (n=9 sites)         |                       |                  |               |                 |              |                   |