Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, Florida, 7-11 July 2008
Session number 18

Population status of *Acropora* corals in the Florida Keys

S.L. Miller[1], M. Chiappone[1], L.M. Rutten[1], D.W. Swanson[2]

1) University of North Carolina-Wilmington, CMS, 515 Caribbean Drive, Key Largo, FL 30337, USA
2) University of Miami, RSMAS-MBF, 4600 Rickenbacker Causeway, Miami, FL 33149, USA

Abstract. Population declines of staghorn coral (*Acropora cervicornis*) and elkhorn coral (*A. palmata*) are often-cited examples of Caribbean reef change since the 1970s, due, in part, to disease and localized effects from storms and predation. Both corals were listed as threatened on the U.S. Endangered Species List based upon range-wide decline and poor recovery. A spatially intensive survey undertaken in the Florida Keys of *Acropora* corals quantified habitat distribution, colony abundance, size, and condition at 235 sites spanning over 200 km in 2007. A two-stage stratified sampling design using belt transects incorporated cross-shelf habitats and no-fishing management zones from < 1 m to 15 m depth. *A. cervicornis* was widely distributed among sites and habitats and was particularly abundant on patch reefs, with up to 1.22 colonies/m^2 and surface area coverage of 2%. *A. palmata* was abundant on shallow spur and groove reefs, with up to 1.25 colonies/m^2 and surface area coverage of 25%. Although the prevalence of disease is relatively low, both species continue to suffer predation, as well as physical impacts from lost fishing gear. Predicting the future of these corals in Florida requires information about both their present-day ecology and geologic history in Florida.

Key words: *Acropora*, benthic, coral, marine protected area, population, stratified sampling.

Introduction

The declines in abundance of two of the principal Caribbean reef-building corals, staghorn coral (*Acropora cervicornis*) and elkhorn coral (*A. palmata*), are often-cited examples of the changes in western Atlantic reefs that have occurred during the past several decades (Bruckner 2002; Gardner et al. 2003). The causes of these declines, which began in the late 1970s, include large-scale factors such as coral bleaching and disease, especially white band disease (Gladfelter 1982), as well as smaller-scale effects from storms and predation by corallivorous snails and damselfishes (Miller et al. 2002). Both coral species were under consideration for addition to the U.S. Endangered Species List since the early 1990s and were determined to be "threatened" based upon range-wide population declines and poor recovery (*Acropora* Biological Review Team 2005).

Although there is increased awareness of the fragility of Atlantic *Acropora* corals to further potential population decline, there is surprisingly little information on density structure, size, and population abundance for wider Caribbean reef areas. Notable exceptions to this pattern include recent population assessments of *A. palmata* in the U.S. Virgin Islands, southern Caribbean, and in the Florida Keys at one reef (Miller et al. 2002; Mayor et al. 2006; Zubillaga et al. 2008). While some recovery is apparent in localized areas, populations of both species remain depressed well-below historical levels, including the Florida Keys (Dustan and Halas 1987; Porter and Meier 1992), and threats continue that will potentially inhibit population recovery (*Acropora* Biological Review Team 2005).

To ascertain the current population status of both *Acropora* species, we conducted an intensive assessment of the spatial distribution, colony abundance, size, and condition of both species throughout the Florida Keys, including a large area of the Florida Keys National Marine Sanctuary (FKNMS) and Biscayne National Park (BNP) during 2007. The surveys were an outgrowth of previous efforts conducted by the authors dating back to 1999 to quantify the abundance and condition of coral reef benthos throughout the FKNMS. Data obtained from these earlier efforts, together with existing habitat mapping information for the FKNMS, were used to guide the sampling of *Acropora* corals along ~200 km of the Florida Reef Tract. The goals of the survey were to determine patterns in habitat distribution, coral colony density, colony size, condition, and total population abundance estimates (Miller et al. 2007).

Material and Methods

During June-August 2007, surveys at 235 sites were completed along ~200 km of the reef tract from northern Biscayne National Park to SW of Key West (Fig. 1). Previous surveys dating back to 1999 aided in optimizing a sampling plan for obtaining abundance and size distribution estimates for the two *Acropora* corals. A two-stage stratified random sampling design incorporated nine unique habitat

types (Table 1), as well as areas inside and outside of FKNMS no-take zones. The statistical design features are detailed in Smith et al. (in press).

To control for spatial variation in population abundance metrics, we divided the Florida Keys survey domain into strata based upon: 1) habitat class; 2) geographic region; and 3) management zones of the Florida Keys National Marine Sanctuary (FKNMS) and Biscayne National Park (BNP). Cross-shelf habitats were designated using regional benthic habitat maps (FDEP 1998). The habitat classification scheme accounted for features that correlate with benthic fauna distributions, including cross-shelf position, topographic complexity, and the proportion of sand interspersed among hard-bottom structures. A geographic regional stratification variable was used to account for oceanographic and geological features in the Florida Keys that influence the distribution, community dynamics, and biotic composition of reefs (Marszalek et al. 1977; Shinn et al. 1989). FKNMS no-take zones were incorporated as a third stratification variable that delineated areas open and closed to consumptive activities.

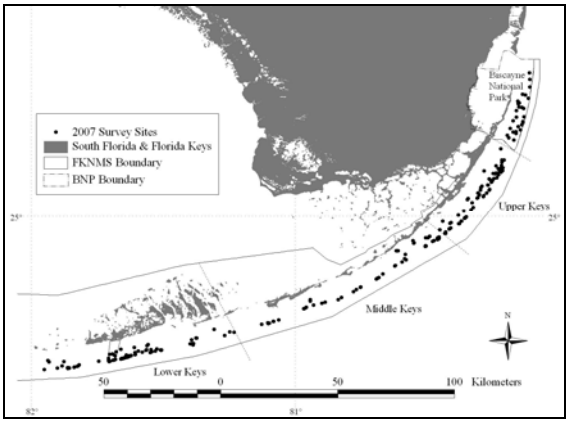

Figure 1: *Acropora* coral sampling locations in the Florida Keys.

A geographic information system (GIS) containing digital layers for benthic habitat (FDEP 1998), bathymetry, and no-take marine reserve boundaries was used to facilitate delineation of the sampling survey domain, strata, and sample units. Map resolution was such that the survey domain was divided into a grid with individual cells of size 200 m by 200 m (40,000 m^2) that defined unique habitat classes (Table 1). A two-stage sampling scheme following Cochran (1977) was employed to control for spatial variation in population metrics at scales smaller than the grid cell minimum mapping unit. Grid cells containing targeted reef and hard-bottom habitats were designated as primary sample units. A second-stage sample unit was defined as a belt transect of fixed area (15-m x 1-m in dimension) within a primary sample unit. The size of an individual primary sampling unit allowed divers to swim to the location of any given second-stage sampling unit from a moored or anchored vessel.

Table 1: Characteristics of study sites in the Florida Keys sampling domain. Available sites reflect the number of 200 m x 200 m cells containing particular habitat types based upon FDEP (1998)

Habitat	Depth (m)	Sites (% effort)	Sites available
Mid-channel patch reef (MPR)	0.9-2.7	36 (15.3)	3,532
Offshore patch reef (OPR)	2.1-14.6	42 (17.9)	1,170
Hard-bottom matrix	2.7-5.8	4 (1.7)	79
Shallow hard-bottom (LHBS)	2.7-7.0	25 (10.6)	972
Inner line spur and groove (IRT)	1.5-6.1	8 (3.4)	87
High-relief spur and groove (HSG)	0.6-9.4	51 (21.7)	238
Deeper hard-bottom (LHBD)	6.7-13.7	15 (6.4)	1,962
Patchy hard-bottom (PHBD)	4.6-11.3	21 (8.9)	956
Low-relief spur and groove (LSG)	7.6-16.2	33 (14.0)	2,825
Sampling Design Total	0.6-14.6	235 (100)	11,821

The underwater surveys consisted first of locating randomly selected, pre-determined coordinates with a differential global positioning system. The original sampling list included 180 sampling locations, with an additional 145 alternate sites. If the original waypoint was not the intended habitat, we sampled the closest alternate site. Once on-site, a two-person benthic diver team oriented four transect tapes 15 in length, marked in 1-m increments, along the bottom, and surveyed an area 0.5-m out from each transect side. Transects were placed in a haphazard fashion, but in a way that adequately represented the habitat at the randomly selected site coordinates. Once transects were deployed, divers determined the depth range along the transect using a digital depth gauge, as well as the maximum vertical relief using a 50-cm scale bar. Any *Acropora* corals that were observed within the 15-m x 1-m belt transects were counted, measured, and assessed for colony condition. For this study, a colony was defined as a patch of continuous live tissue (ramet). In cases where a skeletal unit, possibly representing a single genet, was divided into one or more patches of tissue with clearly defined boundaries, each patch was considered a separate ramet. Measured dimensions of ramets were used to estimate colony surface area using applicable surface area formulas. The condition measurements included an assessment of bleaching, disease, predation, and overgrowth by algae, sponges, and other biota.

Statistical estimation procedures for population abundance metrics (proportional transect frequency, density, total abundance) for a two-stage stratified random sampling design were adapted from Cochran (1977), and computations were carried out using SAS statistical software. Domain-wide mean and variance estimates of density were obtained from weighted averages of strata means and variances. A stratum weighting factor was the proportion of the stratum area relative to the overall survey domain (see Table 1). Similar procedures were used to estimate proportions such as frequency of transect occurrence. Stratum abundance (absolute number of colonies) was estimated by multiplying stratum density by stratum area. The same principle was used to estimate the variance of stratum abundance. Domain-wide abundance and associated variance were obtained by summing the respective strata estimates over the entire survey domain. Design estimation of means, proportions, totals, and their associated variances does not depend on the probability distribution of the underlying observations (Cochran 1977). As such, statistical testing for differences is done by constructing confidence intervals directly from standard errors of either a stratum-specific or domain-wide metric. Statistical comparisons of means were conducted by calculating confidence intervals (CI) based upon the equation CI = mean ± t[α, df] * SE (standard error), with SE estimated by the two-stage stratified sampling design (Cochran 1977). Confidence intervals were adjusted for multiple comparisons using the Bonferroni procedure. While this adjustment made for relatively conservative statistical testing, it reduced the probability of spurious significant pair-wise comparisons. The experiment-wise error rate was held at α = 0.05 and the comparison-wise error rate was adjusted based on the number of multiple comparisons (comparison-wise error rate = α /c, where c = k (k-1)/2). Colony abundance estimates structured by habitat and by colony surface area size were computed using the two-stage design (Cochran 1977).

Results

Staghorn coral (*Acropora cervicornis*) was observed in the general survey area at 55 of the 235 sites (23%) and was recorded within belt transect boundaries at 45 sites (19%). The habitat distribution of *A. cervicornis* was broader than *A. palmata*, with colonies found in all but one of the nine habitats (Fig. 2). *A. cervicornis* was frequently encountered on mid-channel and offshore patch reefs, as well as inner line reef tract sites, and by comparison was infrequently encountered on the deeper fore reef. Statistical comparisons of proportional transect frequency yielded a significance difference (P < 0.002, Bonferroni-adjusted α) between offshore patch reefs and low-relief spur and groove. A total of 508 *A. cervicornis* ramets were counted and mean (± 1 SE) colony density (no. ramets per m^2) ranged from 0.094 ± 0.030 on offshore patch reefs to ≤ 0.01 in four of the lower-relief fore reef habitats (Fig. 2). The greatest mean (± 1 SE) site level densities (0.683-1.217) occurred on mid-channel and offshore patch reefs. Despite this variation, no significant differences (P > 0.002, Bonferroni-adjusted α) in mean colony density among habitats were detected. Abundance estimates indicate that there are perhaps ~13.8 ± 12.0 million *A. cervicornis* colonies in the sampling domain, with nearly 90% on mid-channel and offshore patch reefs (Table 2).

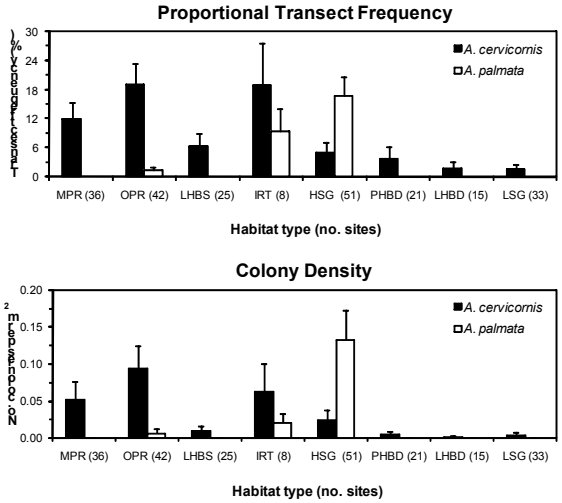

Figure 2: Mean proportional transect frequency (% of transects present) and colony density (no. colonies per m^2) for *Acropora cervicornis* and *A. palmata* in the Florida Keys. Error bars are +1 SE and numbers in parentheses on the x-axis are the number of sites sampled in each habitat. See Table 1 for habitat abbreviations.

Most *Acropora cervicornis* colonies were relatively small (< 0.5 m in max. diameter), although there were some mid-channel and offshore patch reefs with larger thickets. The percentage of live tissue surface area per m^2 of substratum was greatest on several mid-channel and offshore patch reefs, with upwards of 2% cover at individual sites. Mean ± 1 SE percent cover by habitat type was < 0.2% for all habitats, with offshore patch reefs (0.16 ± 0.06%), inner line reef tract (0.11 ± 0.06%), and mid-channel patch reefs (0.10 ± 0.05%) yielding the greatest habitat-level cover, albeit at very low values. Population abundance estimates structured by ramet surface area indicate that ~67% of the *A. cervicornis* colonies in the Florida Keys are less than 150 cm^2 in surface area (Fig. 3). Of the colonies assessed for condition, there were no obvious signs of white band disease, white plague, tissue necrosis, or *Coralliophila* predation.

Nine colonies (2.2%) had obvious signs of damselfish predation. Entanglement with lobster trap rope was common, especially on patch reefs, and of the 78 patch reefs sampled, more than 90% of sites, including Sanctuary no-take zones, contained remnant lobster trap debris. There were several instances where *A. cervicornis* colonies were entangled and obvious tissue damage and colony breakage resulted.

Table 2: Population abundance estimates (95% CI) for *Acropora cervicornis* and *A. palmata* in the Florida Keys sampling domain partitioned by habitat type. See Table 1 for habitat abbreviations

Habitat	*A. cervicornis*	*A. palmata*
MPR	7,391,961 (6,586,650)	0 (0)
OPR	4,656,900 (2,955,347)	295,989 (545,865)
LHBS	388,849 (406,738)	0 (0)
IRT	217,527 (270,435)	72,509 (80,934)
HSG	224,028 (269,877)	1,266,381 (744,035)
PHBD	237,554 (344,767)	0 (0)
LHBD	106,458 (213,021)	0 (0)
LSG	550,372 (958,157)	0 (0)
Total	13,773,647 (12,004,991)	1,634,879 (1,370,835)

Elkhorn coral (*Acropora palmata*) was observed in the general survey area at 24 of the 235 sites (10.2%) and was recorded within belt transect boundaries at 19 sites (8.1%). The habitat distribution of *A. palmata* was much narrower than its congener, with colonies found along belt transects in three of the nine habitats (Fig. 2). *A. palmata* was most frequent on high-relief spur and groove reefs and statistical comparisons of proportional transect frequency illustrated a significance difference between this habitat and five of the other habitats surveyed ($P < 0.002$, Bonferroni-adjusted α). A total of 403 *A. palmata* ramets were counted and mean (± 1 SE) colony density (no. ramets per m^2) ranged from 0.133 ± 0.039 on high-relief spur and groove to zero in five habitats (Fig. 2). The greatest mean (± 1 SE) site-level densities (0.833-1.250) all occurred in high relief spur and groove; this habitat type yielded a significantly greater mean colony density than five of the other seven habitats ($P < 0.002$, Bonferroni-adjusted α). Abundance estimates indicate that there are perhaps ~1.6 ± 1.4 million *A. palmata* colonies in the sampling domain, with nearly over 80% occurring on high-relief spur and groove reefs (Table 2).

Acropora palmata colony sizes showed a significantly greater range compared to its congener, and we were encouraged to find several sites with relatively large (> 0.5 cm diameter) colonies. High-relief spur and groove reefs yielded the largest colonies and percent cover values. Although mean percent cover on the 51 high-relief spur groove reefs sampled was 1.6 ± 0.6%, site-level cover was greater than 8% at several reefs and ranged up to 25%. These sites yielded the largest colony sizes, with several sites yielding mean surface areas of > 1,000 cm^2 per colony. Population abundance estimates structured by ramet surface area indicate that although ~50% of the *A. palmata* colonies in the Florida Keys are less than 250 cm^2 in surface area, many larger colonies still remain (Fig. 3). Of the *A. palmata* assessed for condition, ~5% were affected by predation by *Coralliophila* snails and damselfishes. We were discouraged to find lobster trap rope entangled in thickets of live colonies, including some within Sanctuary no-take zones, but were encouraged by the absence of visible diseases such as white band and white pox.

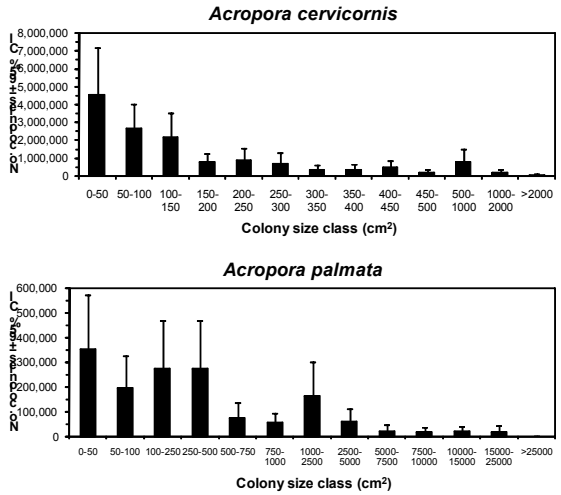

Figure 3: Population abundance estimates by ramet surface area for Florida Keys *Acropora cervicornis* and *A. palmata*. Error bars are 95% confidence intervals. Note the abundance scale change between the two species.

Discussion

This effort is one of the few studies to conduct population estimates of any coral species among a diversity of habitats representing a range in cross-shelf position and depth. For western Atlantic *Acropora* corals in particular, we are aware of only a handful of studies that attempted to derive total colony abundance estimates structured by habitat type and/or colony size (e.g. Miller et al. 2002; Mayor et al. 2006; Zubillaga et al. 2008). Population census results from a large area of the south Florida shelf indicate that both *Acropora* species are aggregated in particular habitat types, especially on the outer platform margin, in habitats noted for historically significant thickets of colonies. However, site-level densities were well below 1 colony/m^2 for both species at most sites sampled, and it is clear that the abundances of these corals are currently far below historical reports in the study area (Dustan and Halas 1987; Porter and Meier 1992). These results are similar to other studies in the region (Bruckner 2002; *Acropora* Biological Review Team 2005).

Acropora colony size distributions were skewed towards mostly smaller (< 100 cm^2) colonies, although larger thickets, especially *A. palmata*, were still present at some locations, especially in high-relief spur and groove habitats. Disease prevalence and evidence of predation from damselfishes and gastropods were low (« 1% of all colonies). We were encouraged to find relatively extensive thickets of *A. palmata* at several bank reefs scattered throughout the Florida Keys, and most of these reefs are currently zoned as no-take marine reserves. However, physical damage from derelict fishing gear, especially trap debris, poses what we believe to be a significant and ongoing impact to extant colonies, even within Sanctuary no-fishing zones.

Population abundance estimates for the Florida Keys illustrate considerable spatial variability, but nonetheless indicate that there are perhaps millions of extant colonies of each species in the study area, not including thickets of *A. cervicornis* to the north of the reef tract offshore of Ft. Lauderdale. At the same time, genetic diversity may be relatively low for both corals and is clearly a research need. Coupled with life history factors, lower genetic diversity may render both corals susceptible to ongoing impacts from storms, disease, and predation, suggesting that current conditions are perhaps not conducive to the recovery of both corals to 1960s or 1970s "baseline" levels (Williams et al. 2008).

What is apparent from these data is that the distribution and abundance patterns of the two species are clearly different, perhaps necessitating different management approaches. Although 34 different spur and groove reefs, including inner line reef tract, were sampled, our results indicate that significant *A. palmata* stands remain at only a handful of sites. While most of these sites are within existing FKNMS no-take zones, predation by snails and damselfishes, as well as physical impacts from lost fishing gear, is prevalent. The distribution pattern of *A. cervicornis* reflects the importance of patch reefs to the possible recovery of this species, which contrasts with historically abundant stands on the deeper fore reef. While there are over 5,000 patch reef sites on the south Florida shelf, *A. cervicornis* is very patchily distributed, and the factors responsible for this pattern are not well known. Promising management options for the recovery of *Acropora* corals have not been well defined, yet there are obvious actions that can be taken at the local level to enhance survival of existing populations that include removing fishing debris and minimizing the potential for further impacts to reefs.

Acknowledgement
Support was provided by the Florida Keys National Marine Sanctuary, NOAA's Coral Reef Conservation Program, and Emerson Associates International. The authors thank NOAA's National Undersea Research Center-UNCW Wilmington, NOAA's National Marine Sanctuary Program (B. Keller and J. Delaney), Biscayne National Park (R. Curry), New World Expeditions, Quiescence Diving Services, A&B Marina, Lost Reef Adventures, Cudjoe Gardens Marina, and Hall's Diving Center. This effort would not have been possible without B. Altmeir, S.G. Smith and J.S. Ault. Research was conducted under National Marine Sanctuary Permit FKNMS-074-98 and National Park Service Permit BISC-2005-SCI-0039.

References

Acropora Biological Review Team (2005) Atlantic *Acropora* Status Review Document. Report to National Marine Fisheries Service, Southeast Regional Office. 152 p

Bruckner AW (2002) Proceedings of the Caribbean *Acropora* workshop: Potential application of the U.S. Endangered Species Act as a conservation strategy. NOAA Tech Mem NMFS-OPR-24, Silver Spring, MD, 199 p

Cochran WG (1977) Sampling techniques, 3rd ed. Wiley, NY

Dustan P, Halas JC (1987) Changes in the reef-coral community of Carysfort Reef, Key Largo, Florida: 1974 to 1982. Coral Reefs 6:91-106

Florida Department of Environmental Protection (FDEP) (1998) Benthic habitats of the Florida Keys. FMRI Tech Rep TR-4. FDEP, St. Petersburg, 53 p

Gardner TA, Cote IM, Gill JA, Grant A, Watkinson AR (2003) Long-term region-wide declines in Caribbean corals. Science 301:948-960

Gladfelter WB (1982) White-band disease in *Acropora palmata*: implications for the structure and growth of shallow reefs. Bull Mar Sci 32:639-643

Marszalek DS, Babashoff G, Noel MR, Worley DR (1977) Reef distribution in south Florida. Proc 3rd Int Coral Reef Symp 2:223-229

Mayor PA, Rogers CD, Hillis-Starr ZM (2006) Distribution and abundance of elkhorn coral, *Acropora palmata*, and prevalence of white-band disease at Buck Island Reef National Monument, St. Croix, US Virgin Islands. Coral Reefs 25:239-242

Miller MW, Bourque AS, Bohnsack JA (2002) An analysis of the loss of acroporid corals at Looe Key, Florida, USA: 1983-2000. Coral Reefs 21:179-182

Miller SL, Chiappone M, Rutten LM (2007) 2007 Quick look report: Large-scale assessment of *Acropora* corals, coral species richness, urchins and *Coralliophila* snails in the Florida Keys National Marine Sanctuary and Biscayne National Park. CMS, UNCW-Wilmington, Key Largo, Florida, 147 p

Porter JW, Meier OW (1992) Quantification of loss and change in Floridian reef coral populations. Am Zool 32:625-640

Shinn EA, Lidz BH, Kindinger JL, Hudson JH, Halley RB (1989) Reefs of Florida and the Dry Tortugas. U.S. Geological Survey, St. Petersburg, 53 p

Smith SG, Swanson DW, Chiappone M, Miller SL, Ault JS (In press) Efficient sampling of coral reefs in the Florida Keys. Limnol Oceanogr

Williams DE, Miller MW, Kramer KL (2008) Recruitment failure in Florida Keys *Acropora palmata*, a threatened Caribbean coral. Coral Reefs 27:697-705

Zubillaga AL, Marquez LM, Croquer A, Bastidas C (2008) Ecological and genetic data indicate recovery of the endangered coral *Acropora palmata* in Los Roques, southern Caribbean. Coral Reefs 27:63-72