Characterize the condition of previously known and newly identified large dense *Acropora cervicornis* patches in southeast Florida

Florida Department of Environmental Protection
Coral Reef Conservation Program
Reef Resilience Project #3

Characterize the condition of previously known and newly identified large dense *Acropora cervicornis* patches in southeast Florida

Final Report

Prepared By:

Brian K. Walker PhD

Nova Southeastern University
Halmos College of Natural Science and Oceanography
8000 N. Ocean Drive
Dania Beach, FL 33004-3078

June 30, 2017

Completed in Fulfillment of PO AF19EE for

Florida Department of Environmental Protection
Coral Reef Conservation Program
1277 N.E. 79th Street Causeway
Miami, FL 33138

This report should be cited as follows:
Walker, B. 2017. Characterize the condition of previously known and newly identified large dense *Acropora cervicornis* patches in southeast Florida. Florida DEP. Miami, FL. Pp. 1-35.

This report was prepared for the Florida Department of Environmental Protection, Florida Coastal Office by Nova Southeastern University. Funding was provided in part by the Coastal Zone Management Program from the U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA) National Ocean Service Award No. NA14NO24190053, and by the Department, through its Florida Coastal Office. The total cost of the project was $24,288.34. The views, statements, findings, conclusions and recommendations expressed herein are those of the authors and do not necessarily reflect the views of the State of Florida, NOAA or any of its sub-agencies.

Cover photo: Brian Walker, Nova Southeastern University

Executive Summary

Historically, *Acropora spp.* are the major reef building corals seen throughout the Caribbean and parts of the Western Atlantic that can grow relatively rapidly in dominant mono-specific stands. Their rapid growth and fragmentation allows them to out compete other benthic organisms and form the major framework for entire reef zones. They are the most abundant and important species for reef accretion. Their branching morphologies provide important habitat for many other reef species and no other Caribbean coral species fills these ecosystem functions. Acroporids were once the dominant reef builder in the Caribbean and provided the majority of live coral cover, but have had extensive population declines. Despite the recent declines, dense patches of Acropora have been reported in several areas throughout the Caribbean. Perhaps the most surprising of these locations is southeast Florida (SE). SE Florida reefs are a higher latitude system that transitions from a subtropical to temperate climate and is in close proximity to about 6 million people. These are some of, if not, the largest dense patches of *A. cervicornis* in the continental United States and offer a unique opportunity to evaluate population demographic structure and condition in a growth form (dense patches) which was once dominant but now rare.

In the 1990's seven large high-cover Acropora patches were identified and characterized at 6 meters depth or less in Broward County. In 2014, an additional twenty-eight new patches were found covering an area of approximately 110,000 m^2. The patch delineations were not ideal due to mapping resolution and that they need to be mapped with higher precision. The threatened ESA status requires a plan to facilitate the recovery of the species back to historical levels. Thus, understanding the current population extents and condition is necessary to establish a reference baseline condition. These data were needed to determine if management strategies are necessary, which to employ, and reasonable success criteria for management actions. Hence, this study was conducted to provide these data.

Mean total cover between all patches was 56.5% ± 14.9. Live and dead cover were similar. Mean rubble was 12.5% (± 9.2). Mean disease cover was low (0.8% ± 0.7). Mean fireworm predation density was 1.4 m^{-2} ± 1.09. On average, there was one damselfish garden every 5.9 square meters (0.17 m^{-2} ± 0.14). And the mean density of disease occurrences was 0.91 m^{-2} ± 0.84. Multivariate analyses of percent live, dead, rubble, and disease *Acropora cervicornis* at the densest portion of each patch indicated three main categories: Good (2 sites) – high amounts of live tissue; Moderate (20 sites) – similar amounts of live tissue and standing dead framework; Poor (13 sites) – high amounts of dead framework and rubble. The Poor group had an average of 26% cover of dead framework, 21% rubble, and 10% live cover. The Moderate group had an average of 20% cover of dead framework, 8% rubble, and 26% live cover. The Good group had an average of 13% cover of dead framework, 4% rubble, and 62% live cover.

Twenty-three perimeters were mapped around 35 dense patches. The imagery indicated that the dense patches are still distinctly different, however, the *in situ* surveys indicate that several dense patches are spread out and connected to adjacent patches. The diver GPS perimeter mapping yielded a total patch area of approximately 826,609 m^2 (204 acres).

This study found that six percent of the dense patches are in Good condition, fifty-seven percent in Moderate condition, and thirty-seven percent in Poor condition. Without having previous data on most of the patches, not much can be said about their condition trajectories or what caused their declines into the Moderate and Poor states. Little disease was recorded during this study indicating that disease was not a big factor of present patch condition. However, the large amounts of dead framework measured in our study indicate a relatively recent decline in condition. Due to the lack of frequent monitoring, it is unknown how much past disease events contributed to the amount of the present dead framework and rubble cover. Although not significant, Gillliam and Larson (2014) previously found that Rapid Tissue Loss (RTL) disease coincided with decreases in live cover, especially after hurricane Sandy and tropical storm Isaac. Presumably, this could have affected the condition of many of the SE FL dense patches. The cause of increased RTL after these storms is unknown and should be established to mitigate for future impacts to *A. cervicornis* live cover.

Glimpses at patch condition trajectories were possible for a few sites based on historical data from a few longer-term studies. Vargas-Angel et al. (2003) patch categorization contained three groups: A, B, and C. Group A, their mostly-dead site (Coral Ridge), which has since disappeared, was not evident in recent aerial photographs. The exact timing of its disappearance is unknown, but it was before 2007 and is thought to have been due to a strong storm event; perhaps Hurricane Wilma. Group B, defined by relatively high coral cover and greatest *A. cervicornis* density (Commercial I, Commercial II, and Dave), have persisted through time. The Dave patch was renamed as FTL6 in the Broward County annual reef monitoring and BCA in the Southeast Coral Reef Evaluation and Monitoring Program. This patch has been studied extensively. Group C patches (Oakland I, Cervicornis II, and Oakland II) have increased in *A. cervicornis*. The Oakland I patch was renamed Scooter and has been monitored at least semi-annually since 2007.

SE FL is presently in a hurricane drought. The last strong storm to hit the direct area was hurricane Wilma in 2005. Hurricanes Sandy and Matthew came close along the eastern seaboard but they were mostly rain events for south Florida. Increases in live cover have been measured over periods in between storms that may be related to low storm activity (Gilliam and Larson 2014). This needs more investigation as the correlation is not obvious and it is unknown if this is due to lower RTL prevalence or reduced physical impacts. Events like hurricane Sandy and tropical storm Isaac may have catalyzed RTL outbreaks (Gilliam and Larson, 2014), but were not strong enough to move large amounts of framework. A direct hit from a hurricane could spread the patches of mostly dead framework off the reefs leaving little to no live fragments behind to maintain dense patch status similar to the Coral Ridge patch. This scenario could drastically affect the number of dense patches, their condition, and extents.

The patch mapping efforts, funded by NSU, show that spreading continues at both BCA and Scooter however, the densest areas in the patches still exist in the original locations. These patches are in Poor condition. In terms of the percent live cover to total Acropora measured in each patch, Scooter ranked 26 out of 35 sites and BCA ranked 34 out of 35. We estimated live cover at 9.7% which is similar to other recent results. After revisiting

BCA and mapping the perimeter during this study, it is clear that live cover has decreased and not just moved away.

Scooter was a similar story to BCA in that live cover had decreased through time at the densest areas in the patch to about 15% and did not significantly change from 2011 to 2013 (Gilliam and Larson, 2014). Changes in live cover occurred between 2008 and 2011 where the majority of live cover shifted away from the densest framework areas. After visiting Scooter it was obvious the densest portions were degraded, however because the site is so large, shifting of live cover to a new area was not obvious or investigated. A visual comparison of 2013 aerial photography and 2017 ESRI satellite imagery do not show obvious differences, but the ESRI imagery cannot be statistically analyzed.

The perimeter surveys showed that most of the patches are much larger than originally visualized in the 2013 aerial imagery. It appears they have also spread across the reef-scape through time. The densest areas are still the areas with the most concentrated colonies, but many of the perimeters span between these areas.

This study elucidated new data on the extent and condition of the dense patches of *Acropora cervicornis* in SE FL**.** Approximately 20% of the dense patches were previously known before Walker and Klug (2014) and only two were previously mapped. This study statistically analyzed dense patch conditions and binned them into three groups based on the amount of live, dead, disease, and rubble cover. The GPS diver mapping identified the spreading of dense patches and increased total area of dense *A. cervicornis* to 826,609 m² (204 acres), an increase of over 500% from previous estimates. This new information highlights more critical gaps in our knowledge of regional *A. cervicornis* distributions and population distribution, demographics, and status.

Below are a series of recommendations to help fill those knowledge gaps:

Conduct A. cervicornis *mapping and condition assessments more frequently to determine cause of live tissue declines.*

Establish a cause of increased RTL after storm events to mitigate for future impacts to live cover.

Analyze historical imagery to determine the timing of dense A. cervicornis *patch inception and persistence over time.*

Collect regular, periodic regional standardized imagery to elucidate the dynamics of dense patches and document the current extent of nearshore resources.

Investigate the genetic diversity of the dense A. cervicornis *patches to determine if they are genetically similar to each other and other local populations.*

Monitor fecundity and reproduction to identify if environmental factors and patch conditions are related to reproductive success.

Acknowledgements

Thank you to the Florida Department of Environmental Protection's Florida Coastal Office and Coral Reef Conservation Program (FDEP CRCP), and the Coastal Zone Management Program from the U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA) National Ocean Service for supporting this effort.

I especially thank Ryan Hoyt, Cory Ames, and Kristen Cumming of the Nova Southeastern University Oceanographic Center (NSUOC) Geographic Information Systems and Spatial Ecology lab for data collection, entry, and management. Thank you to Dr. David Gilliam for funding the initial dense patch monitoring and continued collaborative support for SE FL Acropora research. Thanks to FDEP CRCP staff including Kristi Kerrigan for coordinating and reviewing the products.

Table of Contents

List of Figures

List of Tables

List of Acronyms

ANOSIM	Analysis of Similarity
CRCP	Coral Reef Conservation Program
DAP	Dense Acropora Patch
ESA	Endangered Species Act
ESRI	Environmental Systems Research Institute
FDEP	Florida Department of Environmental Protection
FRT	Florida Coral Reef Tract
GPS	Global Positioning System
MDS	Multi-Dimensional Scaling
NOAA	National Oceanic and Atmospheric Administration
NSUOC	Nova Southeastern University Oceanographic Center
RTL	Rapid Tissue Loss disease
SECREMP	Southeast Coral Reef Evaluation and Monitoring Program
SE FL	Southeast Florida
SFWMD	South Florida Water Management District
SIMPER	Similarity Percentages
USACE	United States Army Corps of Engineers

1. INTRODUCTION

Coral reefs are rich in biodiversity (Odum and Odum, 1955, Alvarez-Filip et al., 2009, Carpenter et al., 2008, Connell, 1978, Hoegh-Guldberg et al., 2007, Knowlton, 2001, Moberg and Folke, 1999), provide a storm barrier that protects the habitats behind them from eroding and being destroyed, as well as provide cultural influences and aesthetics (Moberg and Folke, 1999, Smith, 1978, Done et al., 1996, Spurgeon, 1992). They are also an invaluable resource for fishing and eco-tourism (Kuhlmann, 1988, Smith, 1978, Hoegh-Guldberg et al., 2007, Hughes et al., 2003, Spurgeon, 1992, Done et al., 1996, Moberg and Folke, 1999). In some areas, coral reefs are the primary economic income and provide billions of (U.S.) dollars in revenue (Done et al., 1996, Birkeland, 1997, Jameson et al., 1995). With increasing human populations in coastal areas comes increased anthropogenic impacts to coastal systems such as nutrient loading, pollution runoff, overfishing, sedimentation, (Aronson et al., 2003, Moberg and Folke, 1999, Hodgson, 1999, Goldberg and Wilkinson, 2004, Hughes et al., 2003, Knowlton, 2001, Gardner et al., 2003, Bruno et al., 2007) in addition to rising ocean temperatures from global climate change due to the increased CO_2 and methane emissions (Moberg and Folke, 1999, Alvarez-Filip et al., 2009, Hughes et al., 2003, Hoegh-Guldberg et al., 2007, Carpenter et al., 2008). These anthropogenic influences have caused a sharp decline in major reef-building corals in the Caribbean and Western Atlantic in recent times (Hughes et al., 2003, Wilkinson, 2002, Aronson et al., 2003, Moberg and Folke, 1999, Richmond, 1993, Burke et al., 1998).

Historically, *Acropora spp.* are the major reef building corals seen throughout the Caribbean and parts of the Western Atlantic. There are three species in this region: *Acropora cervicornis* (staghorn coral), *Acropora palmata* (elkhorn coral), *and Acropora prolifera* (fused staghorn coral/F1 Hybrid). These species can be dominant mono-specific stands or can co-exist with each other. They have very rapid branching growth and reproduce both sexually (spawning) and asexually (fragmentation) with the exception of the hybrid species which can only reproduce asexually (Highsmith, 1982, Wallace, 2012). Their rapid growth and fragmentation allows them to out compete other benthic organisms and form the major framework for entire reef zones (Connell et al., 2004, Wallace, 1999, Wallace, 2012). Acroporids were once the dominant reef builder in the Caribbean and provided the majority of live coral cover (Veron, 2000, Veron, 2008, Aronson et al., 2003, Precht and Aronson, 2004). They are the most abundant and important species for reef accretion and their branching morphologies provide important habitat for many other reef species and no other Caribbean coral species fills these ecosystem functions (Acropora Biological Review Team, 2005).

Acropora spp. have had extensive declines (Pandolfi, 2002). Recently, Carpenter et al. (2008) performed a global assessment on reef-building corals to investigate the extent of the sharp decline in coral cover. They found that out of the 704 species examined, 231 are considered threatened and 407 total are in either the near threatened, or threatened categories. Out of all of the coral families examined in the study, Acroporidae is the most at risk with 50% of the species in the threatened category (Guzman, 1991, Aronson and Precht, 2006, Hoegh-Guldberg et al., 2007, Rinkevich, 2005, Young et al., 2012). In 2006, all three Caribbean Acropora species (*A. cervicornis, A. palmata*, and *A. prolifera)* were listed as Threatened under the Endangered Species Act.

Despite the recent declines, dense patches of Acropora have been reported in several areas throughout the Caribbean including Roatan, Honduras; Veracruz, Mexico; Belize; the Dominican Republic; and Southeast Florida (Larson et al., 2014, Macintyre et al., 2000, Lirman et al., 2010, Riegl et al., 2009). Perhaps the most surprising of these locations is southeast Florida (SE). SE Florida reefs are a higher latitude system that transitions from a subtropical to temperate climate (Walker and Gilliam, 2013) and is in close proximity to about 6 million people. Historically, Acropora was a major component of the SE Florida offshore reefs in the Holocene (Lighty et al., 1978). Extant dense patches of *A. cervicornis* have been known to exist along the Florida coast for many years (Jaap, 1984); however, their sizes, distributions, and persistence have not been sufficiently elucidated (Vargas-Ángel et al., 2003, Walker et al., 2012). These are some of, if not, the largest dense patches of *A. cervicornis* in the continental United States and offer a unique opportunity to evaluate population demographic structure and condition in a growth form (dense patches) which was once dominant but now rare.

In the 1990's seven large Acropora patches were identified and characterized at 6 meters depth or less in Broward County (Walker et al., 2012, Vargas-Ángel et al., 2003, Walker and Klug, 2014, Vargas-Ángel et al., 2006). These localized patches were observed to have 87 – 97% *A. cervicornis* cover, but only 25% were alive at their most staghorn abundant site. In 2014, Walker and Klug (2014) delineated 35 *A. cervicornis* patches using aerial photography (Figure 1). They estimated the area of the seven previously studied patches at approximately 46,000 m^2 and the area of 28 new patches at approximately 110,000 m^2. Walker and Klug (2014) acknowledged that the patch delineations were not ideal due to mapping resolution and that they need to be mapped similar to the methods described in Walker et al. (2012). Using small-scale mapping techniques, two of the seven previously studied patches were monitored for patch perimeter movement and percent cover changes (Walker et al., 2012). They found that the coral patches were dynamic at a local scale. During a three-year observation period, the patches increased up to 7.5 times their original size and moved up to 51 meters. The patches also had a 50% decrease in live coral cover during the study period. These findings led to several questions. First, if the patches were mobile, then permanent transects cannot reliably monitor the coral populations. Was there a 50% drop cover in the population or did that cover move outside of the permanent monitoring stations? Second, if the patches move, then they do not build up on top of older framework. How old are the patches? Are they relatively recent or do they just appear that way because of their mobility? Third, without a regional mapping approach, how do we know if the dense patches are more numerous now than in the past? These are all important questions for management to answer. The threatened ESA status requires a plan to facilitate the recovery of the species back to historical levels. Thus, understanding the current population extents and condition is necessary to establish a reference baseline condition. Their patchy and dynamic nature precludes traditional monitoring and assessment strategies in order to quantify populations at a regional level.

The identification of these new, large dense patches highlights a critical data gap in our knowledge of *A. cervicornis* distributions and population distribution, demographics, and status. No other location along the Florida Reef Tract are known to have these dense patches, and therefore, detailed patch mapping, characterization, and long-term monitoring addresses the very significant gap in knowledge on how this species survives and grows in a form which was once dominant. Because a reference baseline condition has not been established, there is no way to determine if management strategies are necessary, which to employ, and reasonable success criteria for management actions. Currently, the only management action for recovery in SE FL is colony propagation and out-planting. Although evidence is lacking, some studies have speculated that the existence of these patches is relatively new and may be the result of climate change (Precht and Aronson, 2004). Evaluating the effect of climate change on population distribution is a challenging task, but evaluating condition of currently monitored patches and mapping, characterizing and monitoring new patches provides critical information on the persistence and condition of these patches over time. In the last ten years, some large patches have disappeared (Coral Ridge in Vargas-Ángel et al. (2003)), whereas previous imagery showed that at least one new site did not exist in 2000 (Figure 2). Walker et al. (2012) suggested that the lack of framework may give the appearance the patch is recent, however asexual fragmentation caused two of the patches to spread out considerably over a three-year period leading them to the question whether the coral is lost or just moving outside of the monitoring frame.

Walker and Klug (2014) provided a list of recommendations regarding the dense Acropora patches. They recommended periodic monitoring of the condition of these patches to understand their live tissue cover and the amount of diseases affecting them, analyzing historic images to identify the timing of patch inception and movement, and periodically collecting a regional set of imagery to identify new patches and document temporal patch dynamics. Without a regional mapping approach, including *in situ* work and aerial photography, there is no way of knowing when new dense patches form, if they are increasing in number, and if they are moving or dissipating through time.

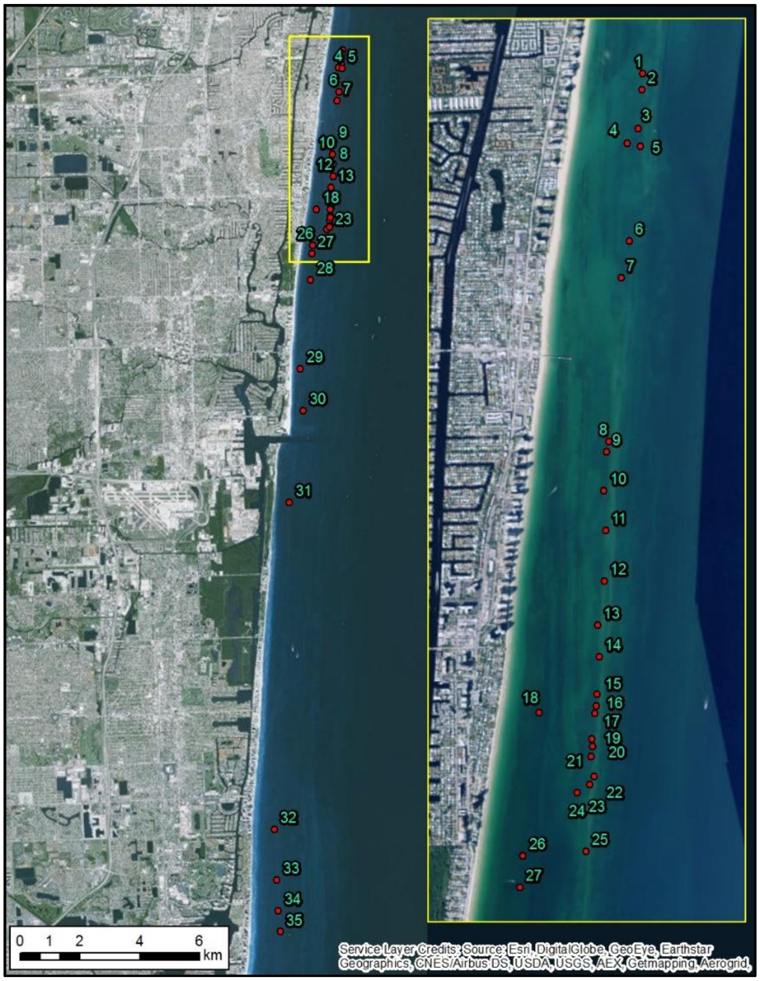


Figure 1: The location of the 35 known dense *A. cervicornis* patches along the northern FRT.

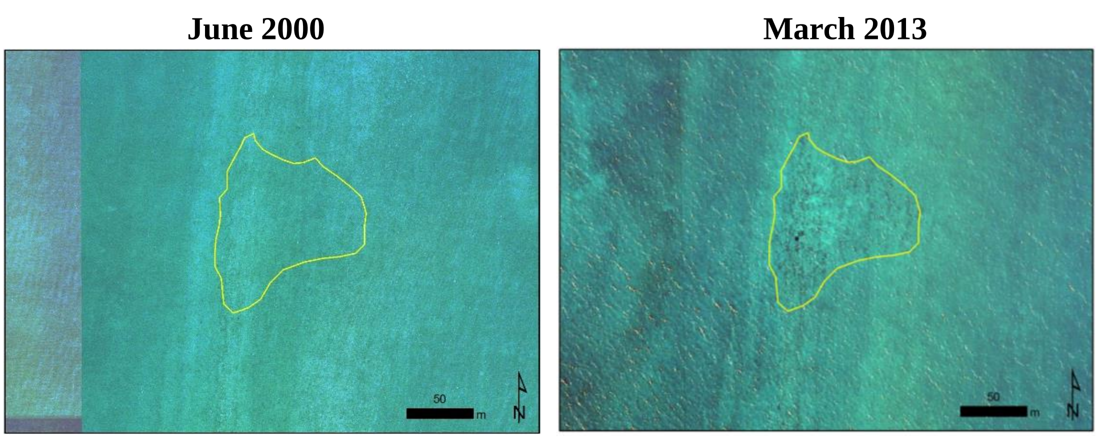


Figure 2: A newly discovered *A. cervicornis* site in the March 2013 aerials (right) that was not evident in June 2000 (left). The yellow polygon is a rough aerial estimate of the site totaling 9,284 m².

1.1. Project Goals & Objectives

Although dense patches of *A. cervicornis* were once ubiquitous throughout the Caribbean, such dense patches are now unique, and mapping, characterizing, and monitoring these rare growth type occurrences begins to fill a critical data gap in our understanding of population dynamics. The primary objective of this project is to characterize previously known and newly identified large and dense patches of *Acropora cervicornis* on the northern Florida Reef Tract (FRT), document their current condition, and map their boundaries.

Demographic data collected from these dense areas will facilitate prioritizing specific areas used by the species requiring habitat conservation, a current NOAA Recovery Plan Outline action. Dense patch inventories will enable the identification of new patches in light of climate change and data on the dynamics and drivers of growth and mortality will aid in design of restoration activities. This project meets the following high priority Florida Reef Tract (FRT) management needs:

- Promote conservation of coral reef ecosystems through identification of areas that are potentially resilient to climate change and vulnerable areas where actions are likely to increase resistance. Encourage and promote management actions necessary to avoid of minimize impacts and spread the risk due to climate change and ocean acidification.
- Characterize physical and chemical changes in coral reef environments by enhancing question-based monitoring to fill gaps in our current observations. This both establishes a baseline to assess climate change impacts on coral reef ecosystems and reveals changes through time.
- Identify areas of perceived resilience and areas of high vulnerability (which may or may not contain high coral cover/abundance) with the FRT and provide additional protection to those areas via appropriate marine zoning and reduction of existing stressors.
- Characterize physical and chemical changes in coral reef environments by enhancing and refining monitoring to fill gaps in our current observations. This both establishes a baseline to assess climate change impacts on coral reef ecosystems and reveals changes through time which are essential to understanding observed and forecasted impacts.
- Identify, characterize and rank priority areas for protection within Florida, including (but not limited to): spawning site, nursery habitats, or other areas critical to particular life-history stages; biodiversity hotspots; areas with greatest resilience or potential for restoring resilience; areas facing the greatest threats.
- Identify larval sources, spawning areas and aggregations. Understand sources of coral and reef larvae so that these can be conserved for necessary regeneration and restoration.
- Identify and prioritize those coral reef ecosystems … that will benefit the most from implementing management conservation strategies to reduce land-based sources of pollution.
- Create a full inventory of status, trends and threats to coral reef resources across the entire FRT within five years.

2. METHODOLOGY

This study acquired population and condition data in the densest location of all thirty-five dense patches. At each site we conducted four non-overlapping 30 m transects where allowable by patch size. Where patches did not accommodate the full transect length (Sites 16, 18, 23, and 29), the transects were cut short and the number of assessed quadrats was noted. In a 1 m² quadrat placed at meter intervals along each transect we estimated % live Acropora, % dead Acropora, % disease/recent dead Acropora, % Acropora rubble, number of live Acropora fragments, prevalence of Acropora disease, fireworm predation, and damselfish gardens (Figure 3). Care was taken not to double count incidences of disease, fireworm predation, and damselfish gardens between quadrats. All other stony coral species >4 cm diameter were identified and measured. In the rare occasion that the transects had an extreme density of small *Porites astreoides* colonies, only three transects were assessed for other stony corals. Qualitative video footage and photographs were collected.

Figure 3. Diver collecting Acropora data in the 1 m² quadrat along the 30 m transect tape.

3. DATA ANALYSES

All site data were pooled (all transects combined into one sample) and standardized into percentages of the survey area for each site. Data were analyzed using JMP 12 for univariate statistics and Primer v7 for multivariate analyses. JMP 12 was used to obtain descriptive statistics (mean, standard deviation, minimum value, and maximum value) and linear regressions for continuous variables. The amount of live, dead, and diseased Acropora and rubble data were analyzed in Primer v7 to evaluate the similarities of Acropora condition between sites. Specific multivariate tests run were nonmetric, multi-dimensional scaling plots constructed using Bray-Curtis similarity indices to examine differences in community structure between dense patches (PRIMER v7); analysis of similarity to test if differences in community structure were present between factor groups; and similarity percentage analysis to identify those variables most responsible for the differences seen among different factor groups. All multivariate data were square root transformed to reduce the effect of zeros in the similarity matrix.

4. RESULTS

Mean total cover between all patches was 56.5% ± 14.9 (Table 1). Live (22% ± 14%) and dead cover (22% ± 10.1) were similar. Mean rubble was 12.5% (± 9.2). Mean disease cover was low (0.8% ± 0.7). Mean fireworm predation density was 1.4 m^{-2} ± 1.09. On average, there was one damselfish garden every 5.9 square meters (0.17 m^{-2} ± 0.14). And the mean density of disease occurrences was 0.91 m^{-2} ± 0.84.

Site eight contained the highest total *Acropora cervicornis* cover (85.7%) and highest total live cover (68.9%) (Figure 4). Site 34 had the lowest total *A. cervicornis* cover (22.5%) and Site 32 had the lowest live *A. cervicornis* cover (0.5%). Site 27 had the most dead cover (49.9%) and Site 1 had the lowest (7.3%). Site 19 had the highest rubble cover (38%) and Site 30 had the lowest (1.6%). Site 32 had no disease (lowest) while Site 16 had the highest disease cover (2.5%).

Site 32 had the lowest density of *A. cervicornis* fragments (0.1 m^{-2}), fireworm predation (0.03 m^{-2}), and disease (0% m^{-2}) (Figure 5). Whereas Site 1 had the highest fragment density (2.2 m^{-2}), Site 11 had the highest fireworm predation density (5 m^{-2}), Site 3 had the highest damselfish garden density (0.7 m^{-2}), and Site 16 had the highest density of disease occurrences (2.8 m^{-2}).

Table 1. Descriptive statistics of all dense patch metrics. Density metrics are per square meter.

Statistic	***Total Acropora***	***Total Live***	***Total Dead***	***Total Diseased***	***Total Rubble***	***Fragment density***	***Fire worm density***	***Damselfish Garden Density***	***Density of Disease Occurrences***
Mean	56.83%	21.90%	21.80%	0.84%	12.30%	0.90	1.44	0.17	0.91
Standard Error	2.69%	2.37%	1.74%	0.11%	1.55%	0.09	0.18	0.02	0.11
Standard Deviation	15.90%	14.04%	10.30%	0.65%	9.17%	0.54	1.09	0.14	0.66
Minimum	22.73%	0.47%	7.28%	0.00%	1.66%	0.01	0.03	0.01	0.00
Maximum	86.12%	68.88%	49.85%	2.51%	37.96%	2.18	4.99	0.66	2.78
Count	35	35	35	35	35	35	35	35	35

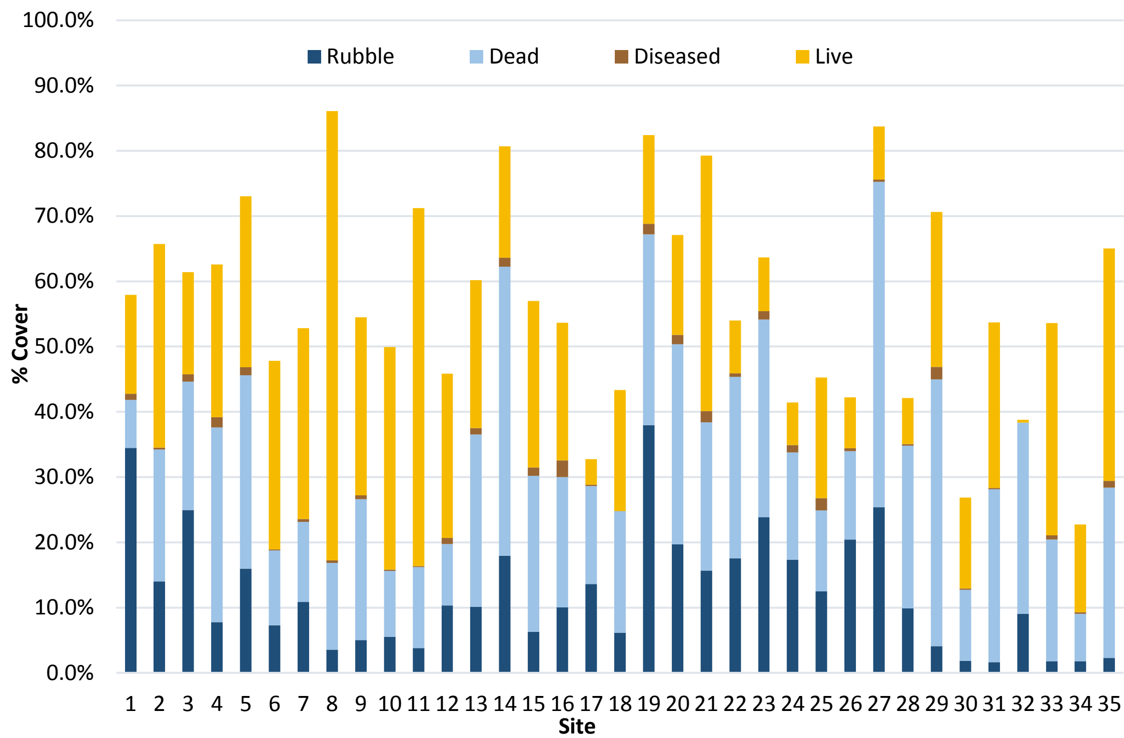


Figure 4. Percent cover of *A. cervicornis* metrics by site.

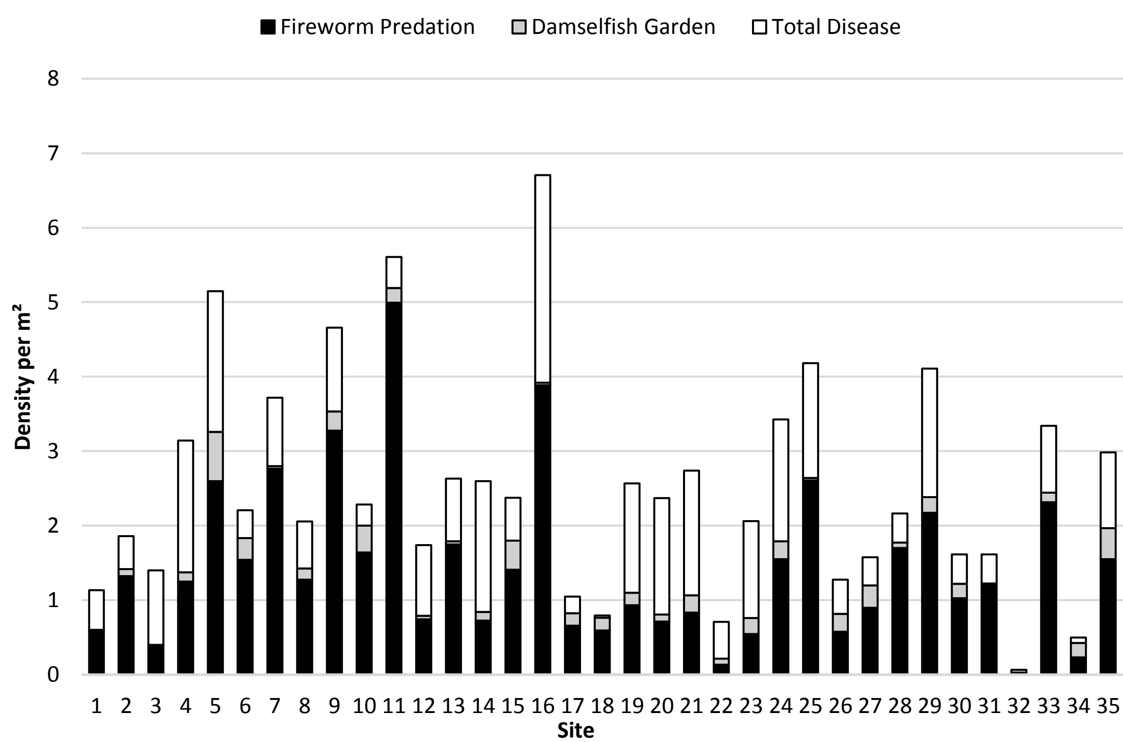


Figure 5. Density of *A. cervicornis* impact metrics by site.

Acropora cervicornis cover data (live, dead, rubble, and disease) were analyzed to determine similarities in all cover metrics between sites and to determine the sites' condition class. A cluster analysis of a Bray-Curtis resemblance matrix in Primer 7 showed that sites split out into several groupings at the 64% similarity level indicating that the clusters are relatively different (Figure 6). These differences were related to the relative amounts of live, standing dead, diseased, and rubble cover. From these groupings, we chose three main categories: Good (2 sites) – high amounts of live tissue; Moderate (20 sites) – similar amounts of live tissue and standing dead framework; Poor (13 sites) – high amounts of dead framework and rubble. There were two outliers from the main groupings, Site 34 and Site 1. These were separated because they had significantly less overall coral cover than all other sites; however, the ratio of cover metrics indicated they belonged to the moderate and poor groups respectively.

The multidimensional scaling (MDS) plot showed a clear pattern in the similarity of sites by their location in the plot (Figure 7). Site similarities were driven by high amounts of live cover (sites 8 and 11) on the right and high amounts of dead and rubble on the left.

The analysis of similarity (ANOSIM) of the condition groups showed strong differences between categories where the Poor and Good groups were the least similar (Table 2). This result supports the condition classifications. The similarity percentage analysis (SIMPER) shows the main factors contributing to the separation between groups (Table 3). The Poor group had similar cover of dead framework ($\bar{x}$ = 26%) and rubble ($\bar{x}$ = 20%) and low live cover ($\bar{x}$ = 10%). The Moderate group had similar amounts of live ($\bar{x}$ = 26%) and dead cover ($\bar{x}$ = 20%) and lower rubble ($\bar{x}$ = 8%). The Good group had high amounts of live cover ($\bar{x}$ = 62%) and low dead ($\bar{x}$ = 13%), rubble ($\bar{x}$ = 4%), and disease ($\bar{x}$ = 0%). Eleven sites contained a higher percentage of live than dead Acropora cover (Figure 8). The Good sites contained the highest percentages of live cover to total cover whereas the Poor sites had high percentages of dead and rubble cover.

Table 4 shows statistical means and standard errors of the Acropora patch metrics by condition categories. Figures 9 and 10 show these data in chart form. The letters indicate significance ($p < 0.10$) among metrics between conditions.

Twenty-three perimeters were mapped around 35 dense patches (Figure 11). The imagery indicates that the dense patches are still distinctly different, however, the *in situ* surveys indicate that several dense patches are spread out and connected to adjacent patches. The aerial photography delineations estimated total patch area about 156,000 m². The diver GPS perimeter mapping yielded a total patch area of approximately 826,609 m² (204 acres). The difference in area is mostly attributed to the difference in mapping methods (Figure 12). The aerial imagery only detects the densest portions whereas the *in situ* surveys use a criteria of a colony of at least 0.5 m wide and less than 4 m from an adjacent colony. The mapping efforts showed that the northern extent of dense patches has not changed since 1998.

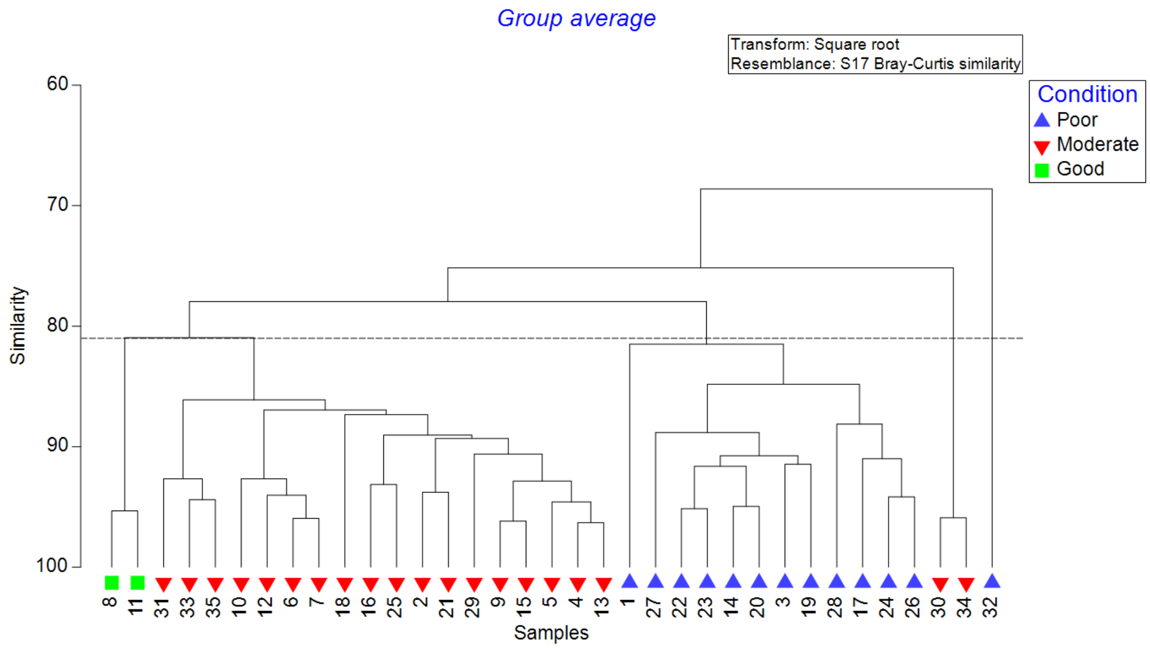


Figure 6. Dendrogram from the cluster analysis showing the relatedness of the sites in their respective condition classes. Dashed line represents the 81% similarity slice.

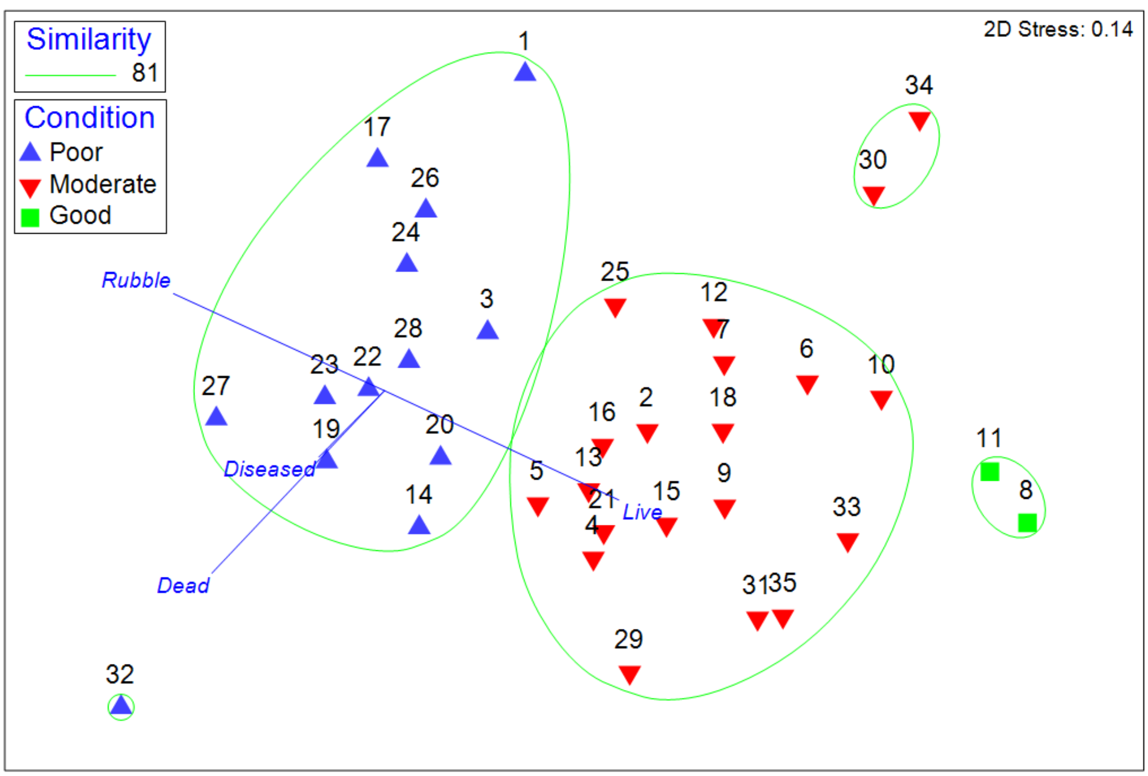


Figure 7. An MDS plot showing the similarity of sites by their location in the plot. The site similarities were driven by high amounts of live cover (sites 8 and 11) on the right and high amounts of dead and rubble on the left. The sites are colored by the condition classifications from the cluster analysis.

Table 2. Analysis of similarity between condition groups.

Pairwise Tests	*R Statistic*	*Significance Level*
Poor, Moderate	0.63	0.1 %
Poor, Good	0.97	1 %
Moderate, Good	0.60	1.7 %

Table 3. Similarity percentages between condition groups.

Poor	*Average similarity: 73.73*				
Condition	*Av. Cover*	*Av. Sim*	*Sim/SD*	*Contrib%*	*Cum.%*
Live	0.1	11.48	1.95	15.61	98.9
Disease	0.01	0.81	1.26	1.1	100
Standing Dead	0.26	33.44	2.69	45.44	45.44
Rubble	0.21	27.85	3.69	37.85	83.3

Moderate	*Average similarity: 77.41*				
Condition	*Av. Cover*	*Av. Sim*	*Sim/SD*	*Contrib%*	*Cum.%*
Live	0.26	40.26	5.6	52.31	52.31
Disease	0.01	0.86	1.17	1.12	100
Standing Dead	0.2	27.16	3.33	35.29	87.6
Rubble	0.08	8.68	1.58	11.28	98.88

Good	*Average similarity: 90.21*				
Condition	*Av. Cover*	*Av. Sim*	*Sim/SD*	*Contrib%*	*Cum.%*
Live	0.62	69.71	SD=0!	77.28	77.28
Disease	0	0.21	SD=0!	0.23	100
Standing Dead	0.13	15.77	SD=0!	17.49	94.76
Rubble	0.04	4.51	SD=0!	5	99.77

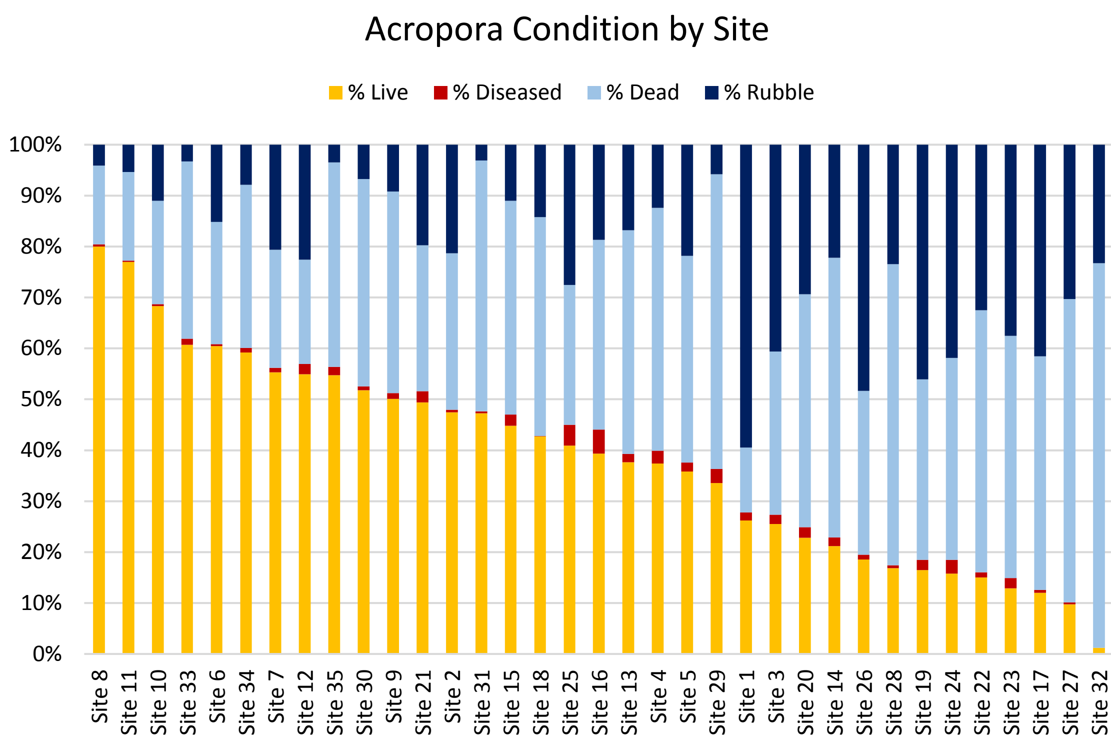


Figure 8. Percentage of *A. cervicornis* cover categories relative to the total amount of *A. cervicornis* at each site.

Table 4. Summary statistics of each dense patch metric by the condition categories.

	Mean			Standard Error		
	Good	*Moderate*	*Poor*	*Good*	*Moderate*	*Poor*
Total A. cervicornis *Cover*	78.39%	54.66%	55.90%	7.35%	2.84%	4.49%
Live A. cervicornis *Cover*	61.85%	26.40%	10.20%	7.02%	1.47%	1.32%
Dead A. cervicornis *Cover*	12.86%	20.10%	26.15%	0.45%	1.95%	3.08%
Diseased A. cervicornis *Cover*	0.28%	0.95%	0.78%	0.11%	0.17%	0.15%
Rubble A. cervicornis *Cover*	3.68%	8.16%	19.55%	0.13%	1.11%	2.59%
Fragment Density	0.492	0.998	0.809	0.008	0.112	0.166
Fireworm Density	3.133	1.773	0.747	1.858	0.218	0.124
Damselfish Garden Density	0.175	0.197	0.135	0.025	0.039	0.022
Occurrences of Disease	0.525	1.016	0.827	0.108	0.166	0.160

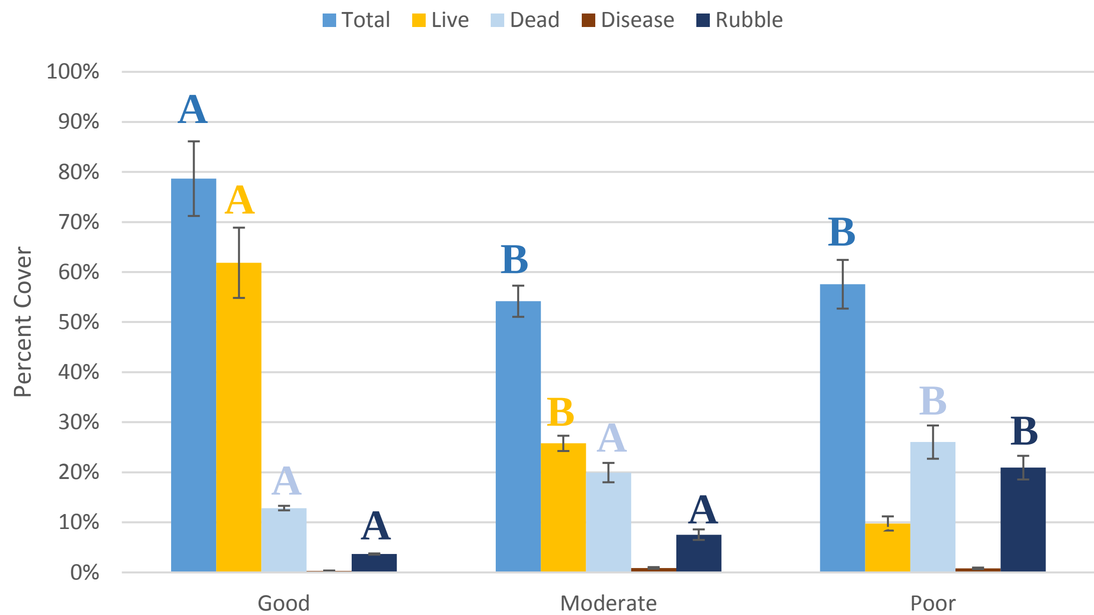


Figure 9. Percent cover of *A. cervicornis* metrics by condition category. Letters denote nonparametric comparisons for each pair using the Wilcoxon Method. Different letters between the same colored bars in the different condition categories indicates a significant difference (p < 0.10). The same letter between bars or no letters means no significance. For example, total cover was significantly higher in the Good sites and the Moderate and Poor sites were not different.

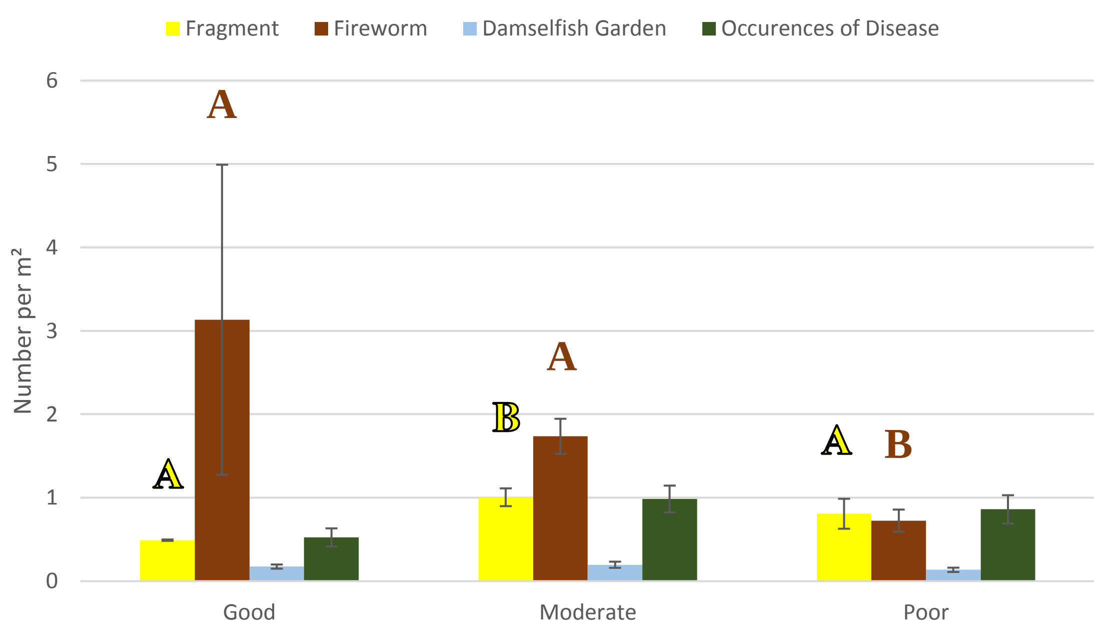


Figure 10. Density of *A. cervicornis* impact metrics by condition category. Letters denote significance within condition categories (p < 0.10). Different letters between the same colored bars in the different condition categories indicates a significant difference (p < 0.10). The same letter between bars or no letters means no significance.

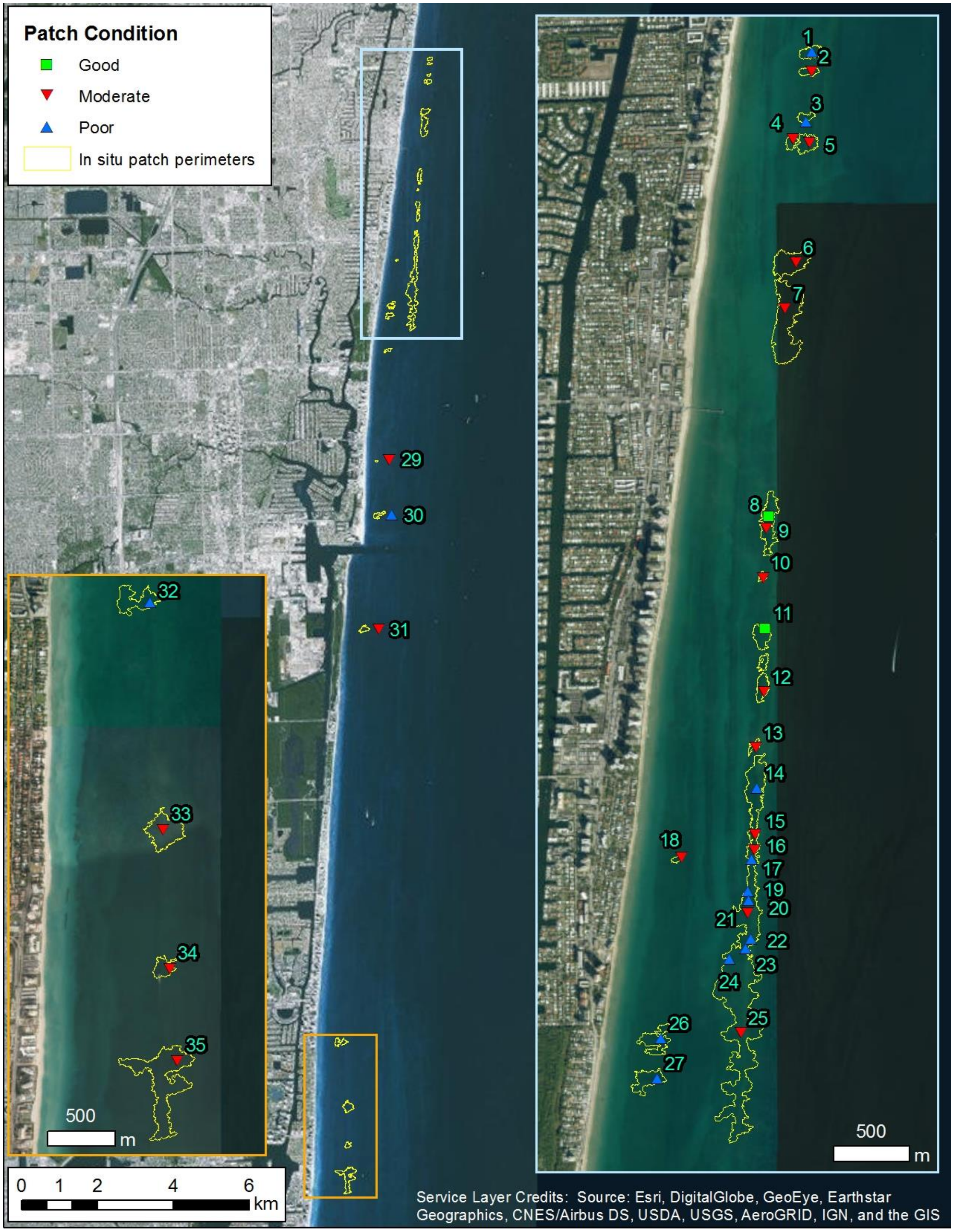


Figure 11. Map of Acropora dense patches showing the original sites locations and the perimeters outlined by the GPS divers (yellow).

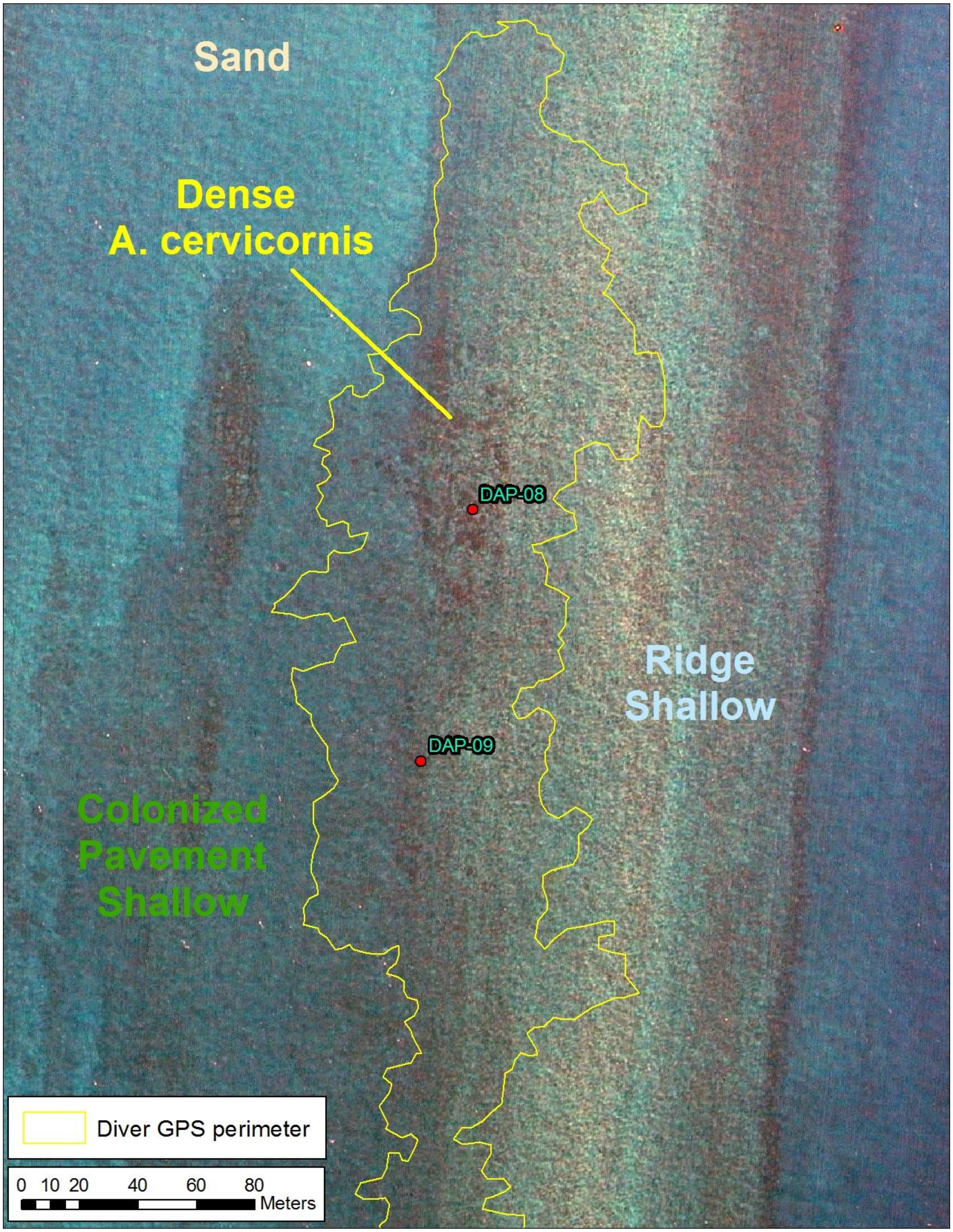


Figure 12. Map of DAPs 8 and 9 showing the transect locations, the dense areas in the 2013 imagery (dark patches on ridge), and the perimeter outlined by the GPS divers (yellow).

5. DISCUSSION

This study achieved its goals to characterize the present condition of *Acropora cervicornis* dense patches in southeast Florida (SE FL) and their perimeters were also mapped as part of a grant from Nova Southeastern University. Together these data give a good indication as to the present state of these patches. Appendix 1 contains a page for each dense patch site including representative site photos, a map of the perimeter, condition ranking and cover data, depth, and survey date.

This study found that six percent of the dense patches are in Good condition (2), fifty-seven percent in Moderate condition (20), and thirty-seven percent in Poor condition (13). Without having previous data on most of the patches, not much can be said about their condition trajectories or what caused their declines into the Moderate and Poor states. Little disease was recorded during this study indicating that disease was not a big factor of present patch condition. Reports of the most recent disease outbreak in SE FL do not include Acropora as one of the affected species (Precht et al., 2016), which supports our disease results. However, the large amounts of dead framework measured in our study indicate a relatively recent decline in condition. Due to the lack of frequent monitoring, it is unknown how much past disease events contributed to the amount of the present dead framework and rubble cover. Gillliam and Larson (2014) monitored select colonies and patches in Broward between 2011 and 2013. They found that Rapid Tissue Loss (RTL) disease coincided with decreases in live cover, but these differences were not significant. The most substantial increases in RTL and decreases in live cover occurred after hurricane Sandy and tropical storm Isaac in the fall of 2012. Presumably, this could have affected the condition of many of the SE FL dense patches. The cause of increased RTL after these storms is unknown and should be established to mitigate for future impacts to *A. cervicornis* live cover.

Mean fireworm, *Hermodice carunculata*, predation density across all patches was 1.4 m^{-2} $\pm$ 1.09 ranging from 0.03 m^{-2} to 4.9 m^{-2}. For comparison, Vargas-Angel et al. (2003) fireworm predation ranged from 0.1 to 2.3 m^{-2}. It is unknown how this equates to the *H. carunculata* at individual sites.

Glimpses at patch condition trajectories are possible for a few sites based on historical data from a few longer-term studies, but direct comparisons are speculative due to differences in methodologies and study purposes. Vargas-Angel et al. (2003) described and compared seven dense patches, six of which spatially coincide with present patches (Figure 13). Because they did not have the mapping information from aerial photography to guide them to the densest areas, they conducted a randomized spatial approach to determining the amount of live and dead cover, hardbottom, and algae in the general areas that contained denser Acropora. These method differences preclude a direct comparison to our data, however their analysis did group patches by their conditions into three main categories: Groups A, B, and C. These groups split out different than ours because they evaluated different metrics. Nonetheless, their patch categorization contained a group of high dead coral cover and rubble (Group A) and one with relatively high coral cover (mostly *A. cervicornis*) (Group B) similar to our study's Poor and Good patch conditions respectively.

Vargas-Angel et al. (2003) Group A was only one site, the Coral Ridge thicket, which is not evident in aerial photographs. Coral Ridge had the highest amount of total *A. cervicornis* of all the patches and the majority of it was dead. This patch disappeared several years later. The exact timing of its disappearance is unknown, but it was before 2007 (*pers. obs*.) and is thought to have been due to a strong storm event, perhaps Hurricane Wilma. Patches in Group B (Commercial I, Commercial II, and Dave), defined by relatively high coral cover and greatest *A. cervicornis* density, have persisted through time. The Dave patch was renamed as FTL6 in the Broward County annual reef monitoring (Gilliam et al., 2010) and BCA in the Southeast Coral Reef Evaluation and Monitoring Program (SECREMP) (Gilliam, 2007). This patch has been studied extensively. Group C patches (Oakland I, Cervicornis II, and Oakland II) have increased in *A. cervicornis* since Vargas-Angel et al. (2003). The Oakland I patch was renamed Scooter and has been monitored at least semi-annually since 2007 (Walker et al. 2012).

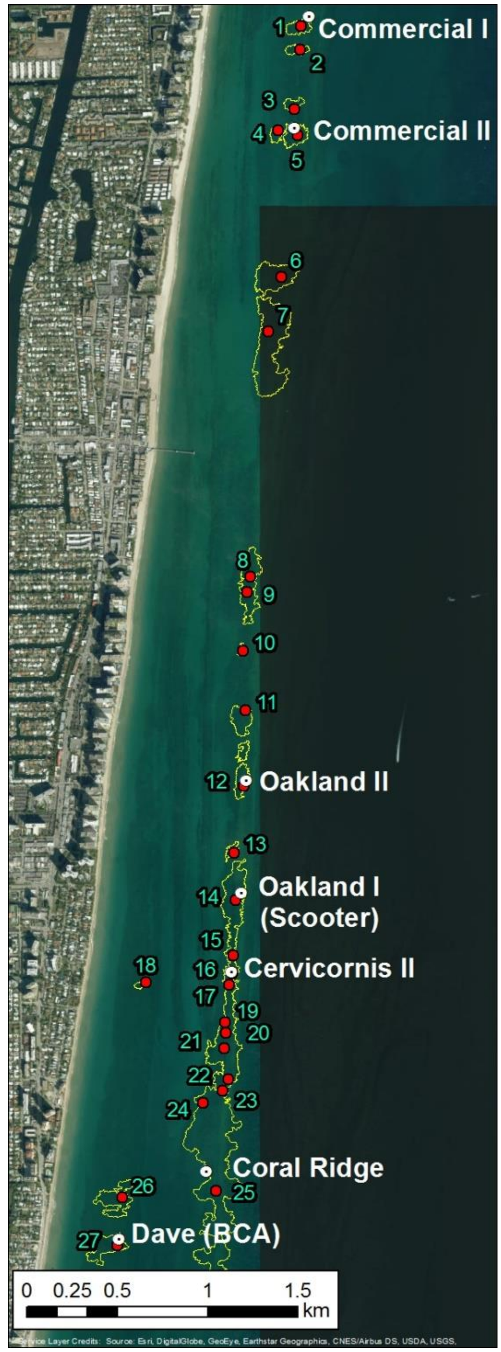


Figure 13. Sites from Vargas-Angel et al. 2003.

Our study found that thirty-seven percent of the dense patches (13) were categorized as Poor (high dead and rubble cover), fifty-seven percent (20) were Moderate (similar live and dead cover), and six percent (2) were Good (high live cover). This raises several questions. Why are these patches in this condition? Is this due to age? What are their trajectories? Will they be able to recover? Will they be expunged after the next hurricane hits the area?

SE FL is presently in a hurricane drought (Hall and Hereid, 2015). The last strong storm to hit the direct area was hurricane Wilma in 2005. Hurricanes Sandy and Matthew came close along the eastern seaboard but they were mostly rain events for south Florida. Increases in live cover have been measured over periods in between storms that may be related to low storm activity (Gilliam and Larson 2014). This needs more investigation as the correlation is not obvious and it is unknown if this is due to lower RTL prevalence or reduced physical impacts. Events like hurricane Sandy and tropical storm

Isaac may have catalyzed RTL outbreaks (Gilliam and Larson, 2014), but were not strong enough to move large amounts of framework. A direct hit from a hurricane could spread the patches of mostly dead framework off the reefs leaving little to no live fragments behind to maintain dense patch status similar to the Coral Ridge patch. This scenario could drastically affect the number of dense patches, their condition, and extents.
One way to track dense patch history is through archived satellite imagery and previous aerial photography surveys (Busch et al., 2016). In images collected in calm, clear conditions, dense patches can be seen against the lighter background of the shallow ridge and colonized pavement habitats. A bank of historical images exist for SE FL. Although patch condition is not measurable, these images could be evaluated to determine when dense patches became visible and/or disappeared. This would give clues as to patch inception and events that caused their demise. This would also facilitate determining temporal changes in dense Acropora patch extents.

BCA and Scooter patches have been studied extensively since the early 2000's. BCA was established as a permanent monitoring station in both Broward County's annual reef monitoring (FTL6) (Gilliam et al., 2010) and the Southeast Coral Reef Evaluation and Monitoring Program (BCA) (Gilliam et al., 2013). These studies monitored the patch's decline for over a decade and reported live cover declines from 40% in 2005 to 14% in 2011. Because these were permanent monitoring stations and *A. cervicornis* is mobile, a plot-based approach to patch monitoring was designed to examine discrete areas outside of the patch for changes in *A. cervicornis* through time (Walker et al. 2012). This approach incorporated permanent plot monitoring stations in a grid design to allow for spatial analyses and concurrent perimeter mapping by GPS divers. The analyses of both datasets elucidated how dynamic these patches are through time. This was done annually in winter and summer at both BCA (DAP-27) and Scooter (DAP-14). Walker et al. (2012) found that total plot live cover varied throughout the year and that it never fully recovered to the previous year's levels through time. They also found clear temporal spatial movements of live cover within patches and those data matched with the mapped perimeters indicating spreading of live colonies (Figures 14 and 15). Therefore it was unknown if live cover at these patches decreased or simply moved outside of the permanent monitoring transects.

The 2017 patch mapping efforts, funded by NSU, show that spreading continues at both BCA and Scooter (Figure 16 and 17) however, the densest areas in the patches still exist in the original locations. This study's condition data show that these patches are in Poor condition. In terms of the percent live cover to total Acropora measured in each patch, Scooter ranked 26 out of 35 sites and BCA ranked 34 out of 35 (Figure 8). There was only one site (DAP-32) with less percent live cover to total cover than BCA and our estimates were on par with SECREMP monitoring. Similarly, the plot mean percent cover data hovered below 10% and did not significantly change from 2011 to 2013 (Gilliam and Larson, 2014). After revisiting BCA and mapping the perimeter during this study, it is clear that live cover has decreased and not just moved away.

Scooter is a similar story to BCA in that live cover had decreased through time at the densest areas in the patch to about 15% and did not significantly change from 2011 to 2013 (Gilliam and Larson, 2014). Changes in live cover occurred between 2008 and 2011 where the majority of live cover shifted away from the densest framework areas (Figure 15). After visiting Scooter it was obvious the densest portions were degraded, however because the site is so large, shifting of live cover to a new area was not obvious or investigated. A visual comparison of 2013 aerial photography and 2017 ESRI satellite imagery do not show obvious differences, but the ESRI imagery cannot be statistically analyzed (Figure 18).

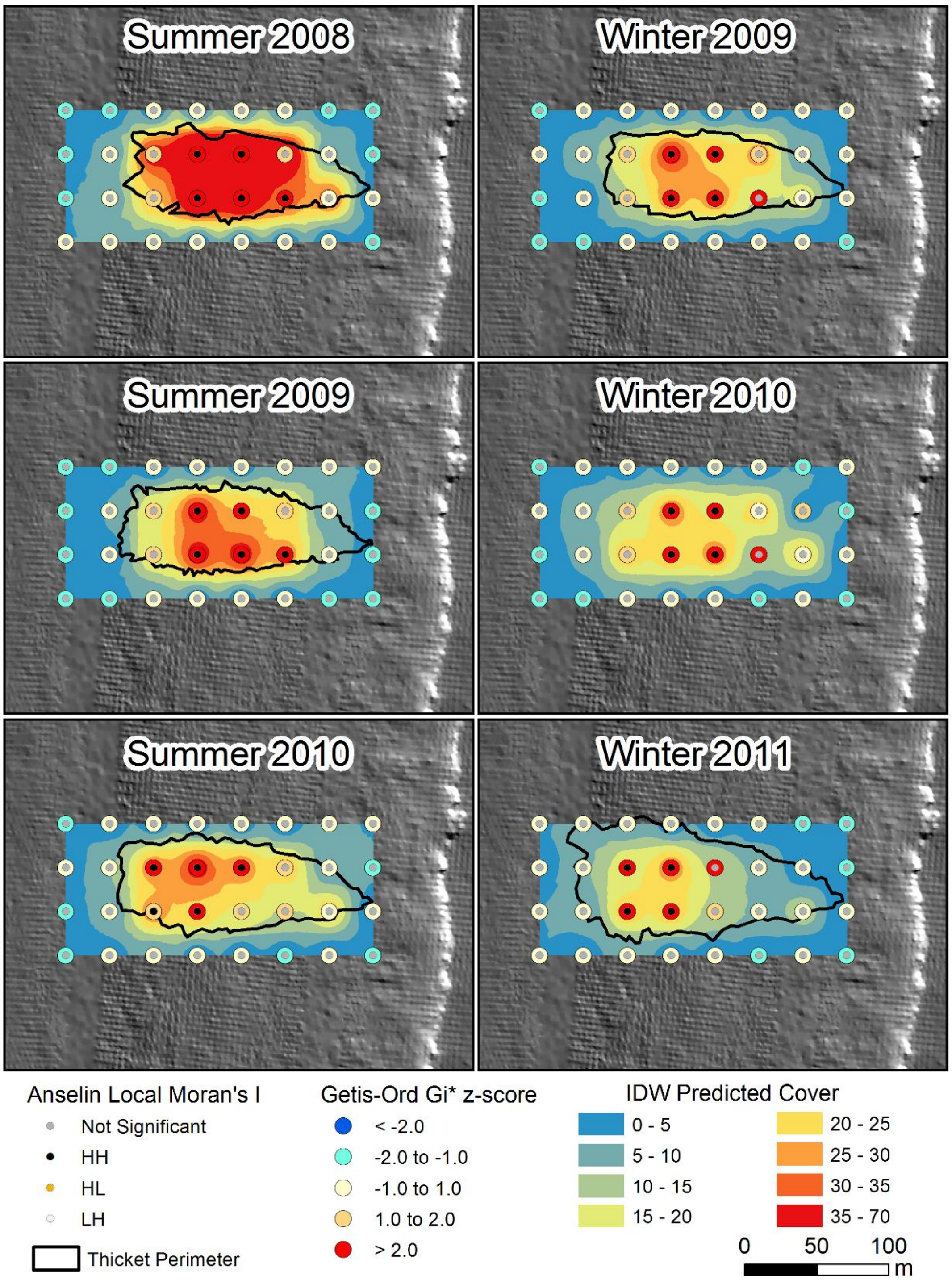


Figure 14. BCA plot cluster analysis and inverse distance weighted interpolation illustrating the temporal changes in live coral cover. Live coral cover decreased during the study period and significantly high clusters (black dots) moved west during the monitoring period supporting the westward expansion seen in the perimeter mapping. Grey surface is a high resolution hillshaded bathymetry. From Walker et al. (2012).

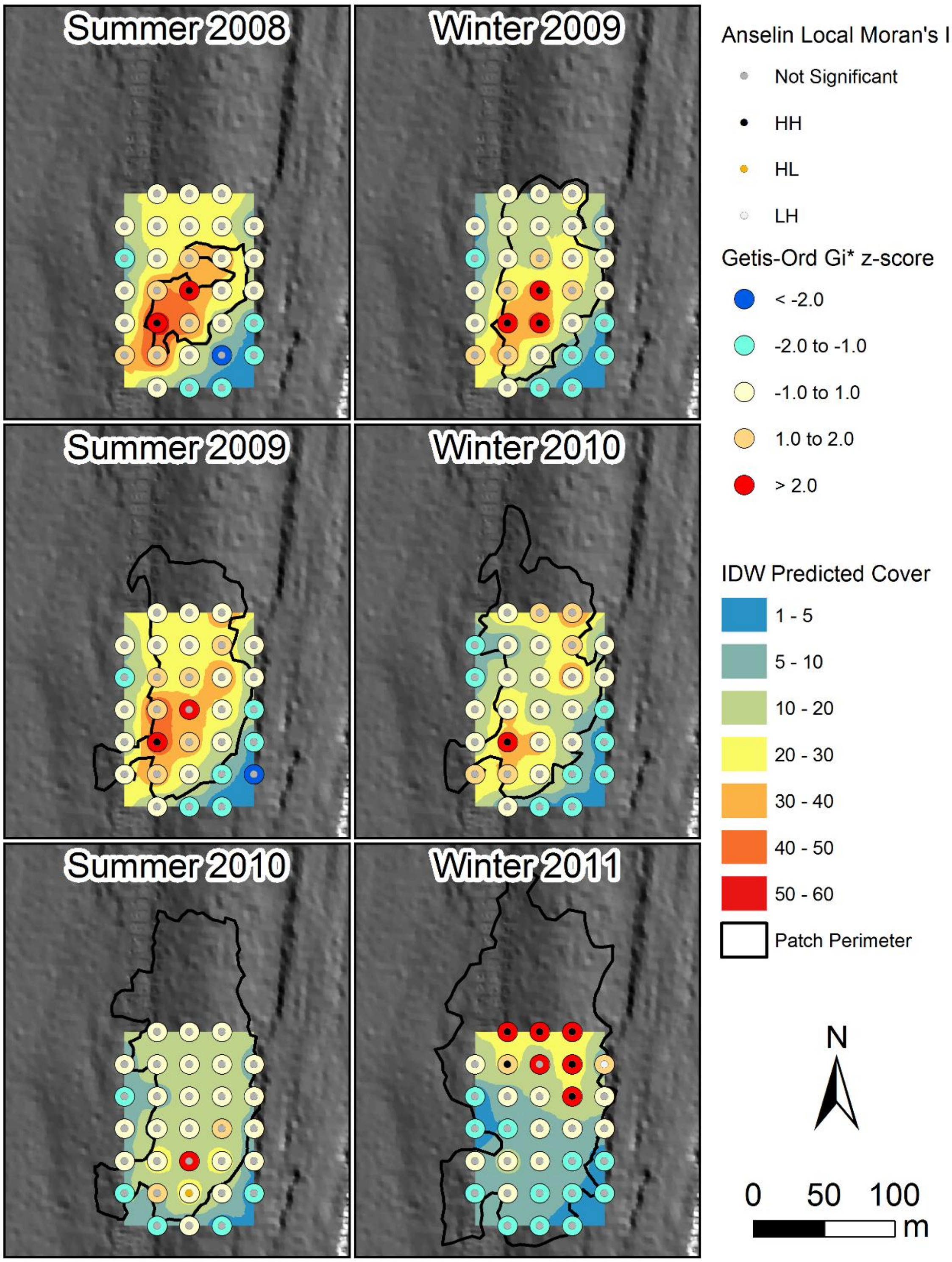


Figure 15. Scooter plot cluster analysis and inverse distance weighted interpolation illustrating the temporal changes in live coral cover. The highest amount of live coral cover moved north during the monitoring period supporting the northward expansion seen in the perimeter mapping. Grey surface is a high resolution hillshaded bathymetry. From Walker et al. (2012).

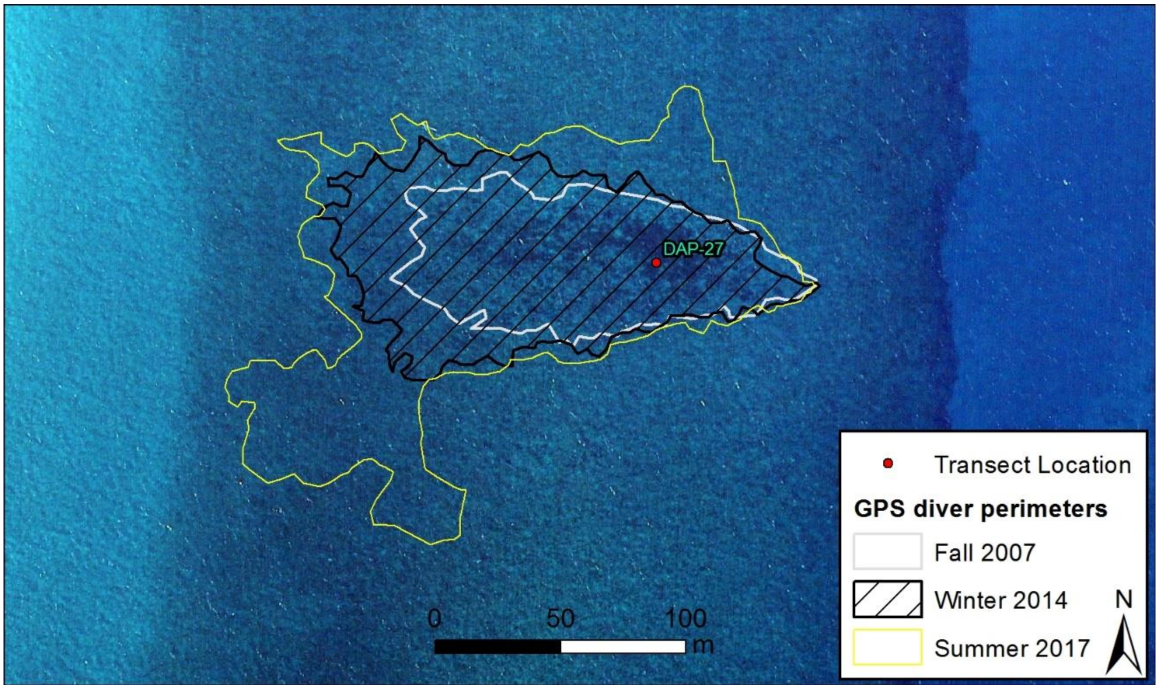


Figure 16. Map of DAP 27 (BCA) showing a few of the previous GPS diver perimeters indicating the patch is still spreading. The imagery is from 2013 and the dark patches on ridge are the visible dense Acropora.

The 2017 perimeter surveys showed that most of the patches are much larger than originally visualized in the 2013 aerial imagery. It appears they have also spread across the reef-scape through time. The densest areas are still the areas with the most concentrated colonies, but many of the perimeters span between these areas. Although we do not know for sure as all patches were not previously mapped and monitored, the Scooter data indicate that spreading is likely the reason why these patches are connected using the GPS diver criteria (at least 0.5m wide colony within 4 m of an adjacent colony) (Figure 17). In 2008, the densest part of the patch was constrained to a relatively small area at DAP-14. In 2014, this area had spread considerably north and south along the ridge using the same criteria. In 2017, it fully connected to DAP-15 to the south and was much closer to DAP-13 to the north.

The presence of *A. cervicornis* is very common in the Broward County shallow ridge and colonized pavement habitats (D'Antonio et al., 2016, Walker and Klug, 2014), and is mostly constrained between Miami Beach and Lauderdale-By-The-Sea (Walker and Klug, 2014). D'Antonio et al. (2016) performed extensive surveys between Port Everglades and Hillsboro Inlet in northern Broward County quantifying the amount and spatial extent of *A. cervicornis*. Their surveys showed significant clustering along the shallow ridge and 1) as distance from the ridge increased, odds of reduced *A. cervicornis* abundance increased; 2) as topographic elevation increased, odds of increased abundance increased; and 3) as mean depth increased, odds of increased abundance increased. These results support the patch perimeter mapping as most of the mapped dense patches occurred on the western side of the shallow ridge (Figure 19).

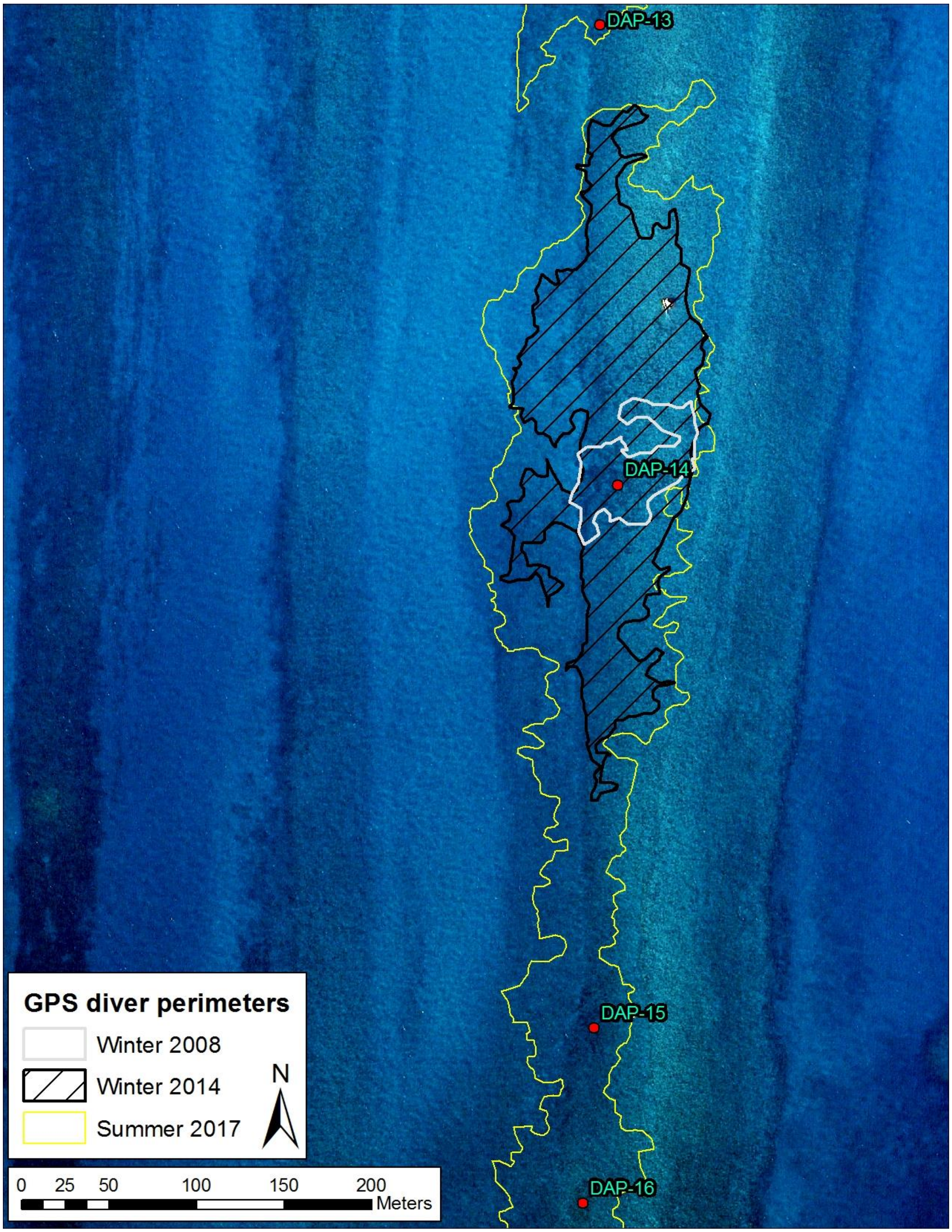


Figure 17. Map of DAP 14 (Scooter) showing a few of the previous GPS diver perimeters indicating the patch is still spreading and is now connected to other adjacent patches. The imagery is from 2013 and the dark patches in the outlines on ridge are the visible dense Acropora.

Figure 18. Visual comparison of Scooter patch (DAP-14) between the 2013 aerial photography (left) and 2017 ESRI satellite imagery (right). Differences are not visually obvious, but statistical comparisons require obtaining new imagery.

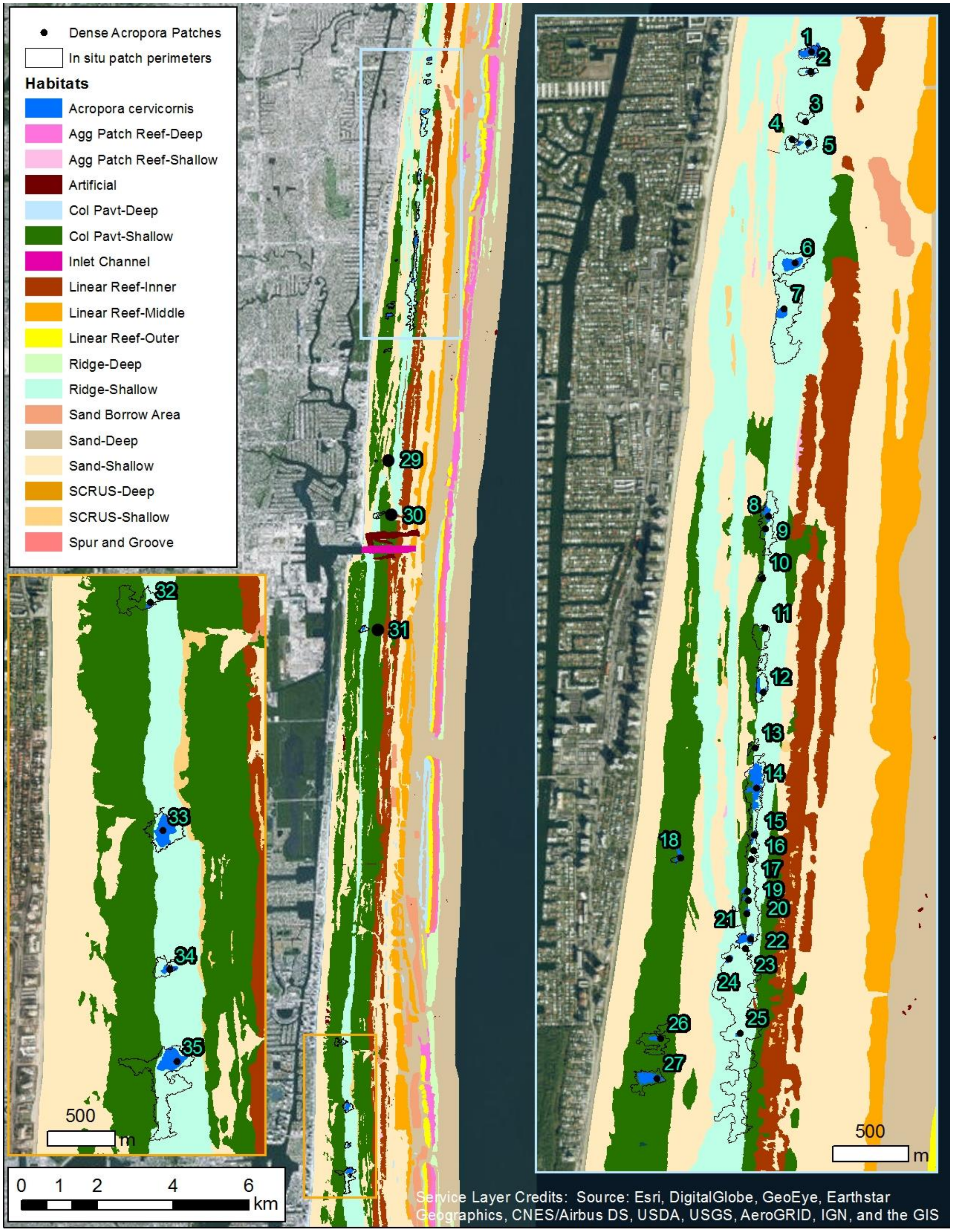


Figure 19. Map of Acropora dense patches and the perimeters outlined by the GPS divers (black outlines) on the benthic habitat map.

6. CONCLUSIONS & RECOMMENDATIONS

This study elucidated new data on the extent and condition of the dense patches of Endangered Species Act threatened coral species, *Acropora cervicornis* in SE FL. Only approximately 20% of the dense patches were previously known before Walker and Klug (2014) and only two (BCA and Scooter) were previously mapped before this study. This study statistically analyzed dense patch conditions and binned them into three groups based on the amount of live, dead, disease, and rubble cover. The GPS diver mapping identified the spreading of dense patches and increased total area of dense *A. cervicornis* to 826,609 m^2 (204 acres), an increase of over 500% from the Walker and Klug (2014) estimates, which were acknowledged to be low. This new information highlights more critical gaps in our knowledge of regional *A. cervicornis* distributions and population distribution, demographics, and status. Below are a series of recommendations to help fill those knowledge gaps.

Recommendation 1: Conduct A. cervicornis *mapping and condition assessments more frequently to determine cause of live tissue declines*. RTL was most prevalent in the fall in Broward County (Gilliam and Larson, 2014). Monitoring semiannually before and during the highest disease prevalence would establish a clear link between loss of live cover and disease and provide a good understanding of the annual patch conditions.

Recommendation 2: Establish a cause of increased RTL after storm events to mitigate for future impacts to live cover. In addition to semiannual monitoring, assessing the patches after several (3 – 5) heavy storm events or water discharges would provide understanding on the link between RTL and environmental parameters. The monitoring should include water collections with standard water quality analyses including salinity and pH and correlations to USACE and SFWMD water management.

Recommendation 3: Analyze historical imagery to determine the timing of dense A. cervicornis *patch inception and persistence over time.* It has been speculated that the abundance of this species is increasing in this region due to climate change (Precht and Aronson, 2004), however no evidence has shown this to be the case. These patches are highly dynamic, moving considerable distance in short periods of time (Walker et al., 2012) and some have formed since 2000. The only way to fully understand if the net amount of dense *Acropora* is increasing is to investigate it on a regional level. A single assessment of archived satellite imagery could determine temporal changes in framework cover. It may also aid in understanding sexual recruitment processes if coupled with genotyping (Recommendation 5). Are all of the patches from a single, special recruitment year? Are they all asexually propagated from each other? This could be seen in imagery based on inception and movement.

Recommendation 4: Collect regular, periodic regional standardized imagery to elucidate the dynamics of dense patches and document the current extent of nearshore resources. This information could be used to evaluate the relationship between storm intensity and frequency and dense patch extents. This would help uncover if possible increasing coverage could be due to the recent hurricane drought. This is especially important after large storm events. The periodicity would depend on available funding. Every year would provide a good dataset to investigate annual changes in *A. cervicornis* dense areas. It would also provide updated data for change detection of other nearshore habitats such as sea grass and reef burial/exposure. Collecting aerials every two or three years is better than nothing, but it reduces the ability to ascribe a specific cause to the changes found.

Recommendation 5: Investigate the genetic diversity of the dense A. cervicornis *patches to determine if they are genetically similar to each other and other local populations.* This one-time survey coupled with spatial investigations would provide better information on the genetic relationship between patches and how sexual reproduction affects local populations.

Recommendation 6: Monitor fecundity and reproduction to identify if environmental factors (temperature, salinity, pH, water quality) and patch conditions (high live cover, high RTL cover, high fireworm predation) are related to reproductive success. Recruitment from sexual propagation is thought to be low in SE FL. Quarterly histology of a subset of patches chosen based on the genotyping data would provide information on gamete production and sexual reproduction. When coupled with environmental (water quality) and patch condition data, their effects on reproductive output could be understood and may enable the development of management strategies to increase sexual reproductive outputs and facilitate regional *A. cervicornis* recovery.

7. LITERATURE CITED

ACROPORA BIOLOGICAL REVIEW TEAM 2005. Atlantic Acropora Status Review Document. National Marine Fisheries Service, Southeast Regional Office.

ALVAREZ-FILIP, L., DULVY, N. K., GILL, J. A., CÔTÉ, I. M. & WATKINSON, A. R. 2009. Flattening of Caribbean coral reefs: region-wide declines in architectural complexity. *Proceedings of the Royal Society B: Biological Sciences*.

ARONSON, R. B., BRUNO, J. F., PRECHT, W. F., GLYNN, P. W., HARVELL, C. D., KAUFMAN, L., ROGERS, C. S., SHINN, E. A. & VALENTINE, J. F. 2003. Causes of coral reef degradation. *Science,* 302**,** 1502-1504.

ARONSON, R. B. & PRECHT, W. F. 2006. Conservation, precaution, and Caribbean reefs. *Coral reefs,* 25**,** 441-450.

BIRKELAND, C. 1997. Symbiosis, fisheries and economic development on coral reefs. *Trends in Ecology & Evolution,* 12**,** 364-367.

BRUNO, J. F., SELIG, E. R., CASEY, K. S., PAGE, C. A., WILLIS, B. L., HARVELL, C. D., SWEATMAN, H. & MELENDY, A. M. 2007. Thermal stress and coral cover as drivers of coral disease outbreaks. *PLoS Biol,* 5**,** e124.

BURKE, L., BRYANT, D., MCMANUS, J. & SPALDING, M. 1998. Reefs at risk: A map based indicator of threats to the world's coral reefs. *World Resources Institute, Washington DC*.

BUSCH, J., GREER, L., HARBOR, D., WIRTH, K., LESCINSKY, H., CURRAN, H. A. & DE BEURS, K. 2016. Quantifying exceptionally large populations of Acropora spp. corals off Belize using sub-meter satellite imagery classification. *Bulletin of Marine Science,* 92**,** 265-283.

CARPENTER, K. E., ABRAR, M., AEBY, G., ARONSON, R. B., BANKS, S., BRUCKNER, A., CHIRIBOGA, A., CORTÉS, J., DELBEEK, J. C., DEVANTIER, L., EDGAR, G. J., EDWARDS, A. J., FENNER, D., GUZMÁN, H. M., HOEKSEMA, B. W., HODGSON, G., JOHAN, O., LICUANAN, W. Y., LIVINGSTONE, S. R., LOVELL, E. R., MOORE, J. A., OBURA, D. O., OCHAVILLO, D., POLIDORO, B. A., PRECHT, W. F., QUIBILAN, M. C., REBOTON, C., RICHARDS, Z. T., ROGERS, A. D., SANCIANGCO, J., SHEPPARD, A., SHEPPARD, C., SMITH, J., STUART, S., TURAK, E., VERON, J. E. N., WALLACE, C., WEIL, E. & WOOD, E. 2008. One-Third of Reef-Building Corals Face Elevated Extinction Risk from Climate Change and Local Impacts. *Science,* 321**,** 560.

CONNELL, J. H. 1978. Diversity in Tropical Rain Forests and Coral Reefs. *Science,* 199**,** 1302.

CONNELL, J. H., HUGHES, T. P., WALLACE, C. C., TANNER, J. E., HARMS, K. E. & KERR, A. M. 2004. A LONG-TERM STUDY OF COMPETITION AND DIVERSITY OF CORALS. *Ecological Monographs,* 74**,** 179-210.

D'ANTONIO, N. L., GILLIAM, D. S. & WALKER, B. K. 2016. Investigating the spatial distribution and effects of nearshore topography on Acropora cervicornis abundance in Southeast Florida. *PeerJ,* 4**,** e2473.

DONE, T. T., OGDEN, J. J., WIEBE, W. & ROSEN, B. 1996. Biodiversity and ecosystem function of coral reefs. *Global biodiversity assessment-pages: 393-429*.

GARDNER, T. A., CÔTÉ, I. M., GILL, J. A., GRANT, A. & WATKINSON, A. R. 2003. Long-term region-wide declines in Caribbean corals. *Science,* 301**,** 958-960.
GILLIAM, D., BRINKHUIS, V., RUZICKA, R. & WALTON, C. 2013. Southeast Florida Coral Reef Evaluation and Monitoring Project 2012 Year 10 Final Report. Miami Beach, FL.
GILLIAM, D. S. 2007. Southeast Florida coral reef evaluation and monitoring project 2007 year 5: final report. St. Petersburg, FL: Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, Florida Department of Environmental Protection.
GILLIAM, D. S., DODGE, R. E., SPIELER, R. E., JORDAN, L. K. B. & GOERGEN, E. A. 2010. Marine biological monitoring in Broward County, Florida: Year 9 Annual Report. Prepared for the BC Board of County Commissioners, BC Natural Resources Planning and Management Division.
GILLLIAM, D. & LARSON, E. 2014. Nova Southeastern University Demographic Monitoring of Acropora palmata and Acropora cervicornis. *In:* LUNZ, K. (ed.) *Final, Comprehensive Report For Monitoring and Mapping of Threatened Acroporids in U.S. Jurisdiction: Development of a Multi-State Conservation Program.* St. Petersburg, FL: Florida Fish and Wildlife Research Institute
GOLDBERG, J. & WILKINSON, C. 2004. Global threats to coral reefs: coral bleaching, global climate change, disease, predator plagues and invasive species. *Status of coral reefs of the world,* 2004**,** 67-92.
GUZMAN, H. M. 1991. Restoration of Coral Reefs in Pacific Costa Rica. *Conservation Biology,* 5**,** 189-194.
HALL, T. & HEREID, K. 2015. The frequency and duration of U.S. hurricane droughts. *Geophysical Research Letters,* 42**,** 3482-3485.
HIGHSMITH, R. 1982. Reproduction by Fragmentation in Corals. *Marine ecology progress series,* 7**,** 207-226.
HODGSON, G. 1999. A global assessment of human effects on coral reefs. *Marine Pollution Bulletin,* 38**,** 345-355.
HOEGH-GULDBERG, O., MUMBY, P. J., HOOTEN, A. J., STENECK, R. S., GREENFIELD, P., GOMEZ, E., HARVELL, C. D., SALE, P. F., EDWARDS, A. J., CALDEIRA, K., KNOWLTON, N., EAKIN, C. M., IGLESIAS-PRIETO, R., MUTHIGA, N., BRADBURY, R. H., DUBI, A. & HATZIOLOS, M. E. 2007. Coral Reefs Under Rapid Climate Change and Ocean Acidification. *Science,* 318**,** 1737.
HUGHES, T. P., BAIRD, A. H., BELLWOOD, D. R., CARD, M., CONNOLLY, S. R., FOLKE, C., GROSBERG, R., HOEGH-GULDBERG, O., JACKSON, J. & KLEYPAS, J. 2003. Climate change, human impacts, and the resilience of coral reefs. *science,* 301**,** 929-933.
JAAP, W. C. 1984. Ecology of the south Florida coral reefs: a community profile.
JAMESON, S. C., MCMANUS, J. W. & SPALDING, M. D. 1995. *State of the reefs: regional and global perspectives*, Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, US Department of Commerce.
KNOWLTON, N. 2001. The future of coral reefs. *Proceedings of the National Academy of Sciences,* 98**,** 5419-5425.

KUHLMANN, D. 1988. Sensitivity of Coral Reefs to Environmental Pollution.

LARSON, E. A., GILLIAM, D. S., L̍OPEZ PADIERNA, M. & WALKER, B. K. 2014. Possible recovery of Acropora palmata (Scleractinia: Acroporidae) within the Veracruz Reef System, Gulf of Mexico: a survey of 24 reefs to assess the benthic communities. *Revista de Biología Tropical,* 62**,** 299-308.

LIGHTY, R. G., MACINTYRE, I. G. & STUCKENRATH, R. 1978. Submerged early Holocene barrier reef south-east Florida shelf.

LIRMAN, D., BOWDEN- KERBY, A., SCHOPMEYER, S., HUNTINGTON, B., THYBERG, T., GOUGH, M., GOUGH, T., GOUGH, R. & GOUGH, Y. 2010. A window to the past: documenting the status of one of the last remaining 'megapopulations' of the threatened staghorn coral Acropora cervicornis in the Dominican Republic. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 20**,** 773-781.

MACINTYRE, I., PRECHT, W. F. & ARONSON, R. B. 2000. Origin of the Pelican Cays ponds, Belize. *Atoll Research Bulletin,* 466.

MOBERG, F. & FOLKE, C. 1999. Ecological goods and services of coral reef ecosystems. *Ecological Economics,* 29**,** 215-233.

ODUM, H. T. & ODUM, E. P. 1955. Trophic Structure and Productivity of a Windward Coral Reef Community on Eniwetok Atoll *Ecological Monographs* 25**,** 291-320.

PANDOLFI, J. M. 2002. Coral community dynamics at multiple scales. *Coral Reefs,* 21**,** 13-23.

PRECHT, W. F. & ARONSON, R. B. 2004. Climate flickers and range shifts of reef corals. *Frontiers in Ecology and the Environment,* 2**,** 307-314.

PRECHT, W. F., GINTERT, B. E., ROBBART, M. L., FURA, R. & VAN WOESIK, R. 2016. Unprecedented Disease-Related Coral Mortality in Southeastern Florida. *Scientific Reports,* 6**,** 31374.

RICHMOND, R. H. 1993. Coral reefs: present problems and future concerns resulting from anthropogenic disturbance. *American Zoologist,* 33**,** 524-536.

RIEGL, B., PURKIS, S. J., KECK, J. & ROWLANDS, G. 2009. Monitored and modeled coral population dynamics and the refuge concept. *Marine pollution bulletin,* 58**,** 24-38.

RINKEVICH, B. 2005. Conservation of coral reefs through active restoration measures: recent approaches and last decade progress. *Environmental Science & Technology,* 39**,** 4333-4342.

SMITH, S. 1978. Coral-reef area and the contributions of reefs to processes and resources of the world's oceans. *Nature,* 273**,** 225-226.

SPURGEON, J. P. 1992. The economic valuation of coral reefs. *Marine Pollution Bulletin,* 24**,** 529-536.

VARGAS-ÁNGEL, B., COLLEY, S. B., HOKE, S. M. & THOMAS, J. D. 2006. The reproductive seasonality and gametogenic cycle of Acropora cervicornis off Broward County, Florida, USA. *Coral Reefs,* 25**,** 110-122.

VARGAS-ÁNGEL, B., THOMAS, J. D. & HOKE, S. M. 2003. High-latitude Acropora cervicornis thickets off Fort Lauderdale, Florida, USA. *Coral Reefs,* 22**,** 465-473.

VERON, J. E. 2008. Mass extinctions and ocean acidification: biological constraints on geological dilemmas. *Coral Reefs,* 27**,** 459-472.

VERON, J. V. 2000. *Corals of the World*.

WALKER, B. & KLUG, K. 2014. Southeast Florida shallow-water coral reef community baseline habitat mapping and characterization of mapped communities. Miami Beach, FL: Florida DEP Coral Reef Conservation Program report.

WALKER, B. K. & GILLIAM, D. S. 2013. Determining the extent and characterizing coral reef habitats of the northern latitudes of the Florida Reef Tract (Martin County). *PloS one,* 8**,** e80439.

WALKER, B. K., LARSON, E., MOULDING, A. & GILLIAM, D. 2012. Small-scale mapping of indeterminate arborescent acroporid coral (*Acropora cervicornis*) patches. *Coral Reefs,* 31**,** 885-894.

WALLACE, C. 1999. *Staghorn Corals of the World - A revision of the Genus. Acropora.,* Melbourne, CSIRO Publishing.

WALLACE, C. C. 2012. Acroporidae of the Caribbean. *GEOLOGICA BELGICA,* 15**,** 388-393.

WILKINSON, C. 2002. Status of coral reefs of the world: 2002, Vol. *Australian Institute of Marine Science*.

YOUNG, C., SCHOPMEYER, S. & LIRMAN, D. 2012. A review of reef restoration and coral propagation using the threatened genus Acropora in the Caribbean and Western Atlantic. *Bulletin of Marine Science,* 88**,** 1075-1098.

8. APPENDIX

Data, representative photos, and map of each dense Acropora patch (DAP) site.

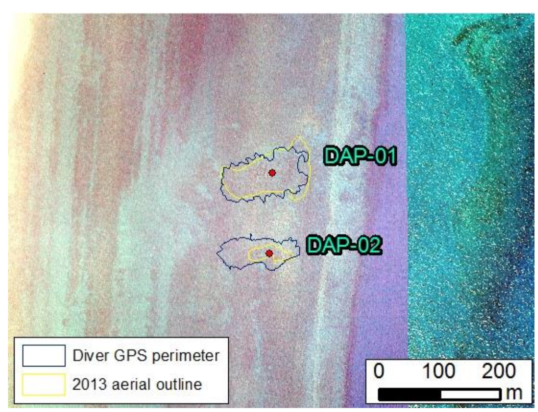
DAP-01

Species: *Acropora cervicornis*

Depth: 12 ft (3.7 m)

Last Survey Date: May 13, 2016

Patch Condition:	*Poor*
% Total:	**57.0**
% Live:	**15.2**
% Dead:	**7.4**
% Disease:	**0.9**
% Rubble:	**34.5**



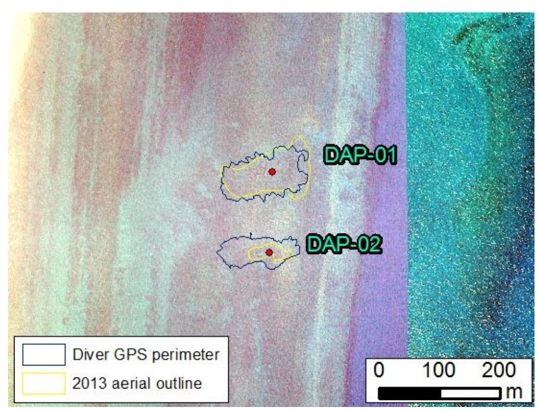
DAP-02

Patch Condition:	Moderate
% Total:	65.3
% Live:	31.1
% Dead:	20.2
% Disease:	0.3
% Rubble:	14.0

Species: *Acropora cervicornis*

Depth: 14 ft (4.3 m)

Last Survey Date: May 13, 2016



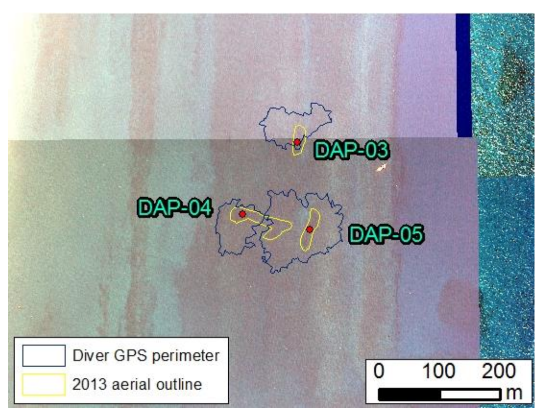
DAP-03

Species: *Acropora cervicornis*

Depth: 18 ft (5.5 m)

Last Survey Date: May 13, 2016

Patch Condition:	*Poor*
% Total:	**60.3**
% Live:	**15.7**
% Dead:	**19.7**
% Disease:	**1.1**
% Rubble:	**25.0**



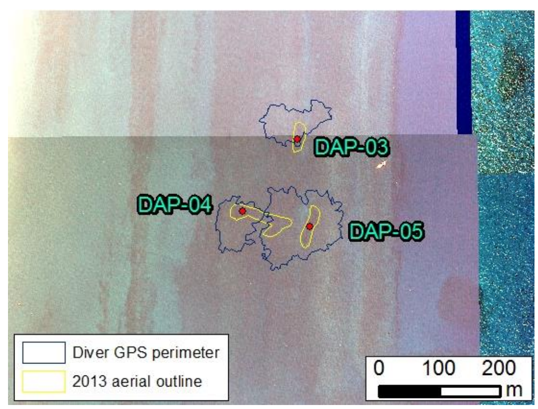
DAP-04

Species: *Acropora cervicornis*

Depth: 15 ft (4.6 m)

Last Survey Date: May 16, 2016

Patch Condition:	*Moderate*
% Total:	**61.0**
% Live:	**23.4**
% Dead:	**29.8**
% Disease:	**1.9**
% Rubble:	**7.8**



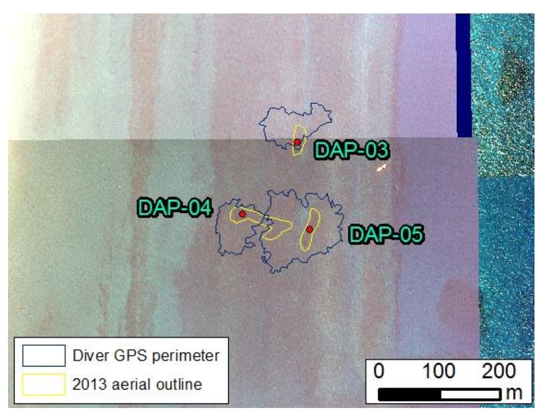
DAP-05

Species: *Acropora cervicornis*

Depth: 14 ft (4.3 m)

Last Survey Date: May 16, 2016

Patch Condition:	*Moderate*
% Total:	**71.8**
% Live:	**26.2**
% Dead:	**27.3**
% Disease:	**1.3**
% Rubble:	**18.3**



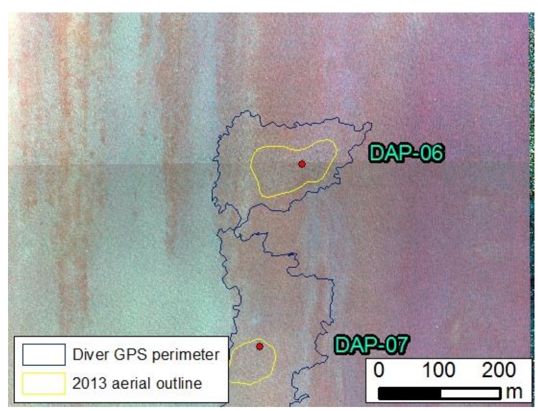
DAP-06

Patch Condition:	Moderate
% Total:	47.7
% Live:	28.9
% Dead:	11.5
% Disease:	0.2
% Rubble:	7.3

Species: *Acropora cervicornis*

Depth: 15 ft (4.6 m)

Last Survey Date: May 16, 2016



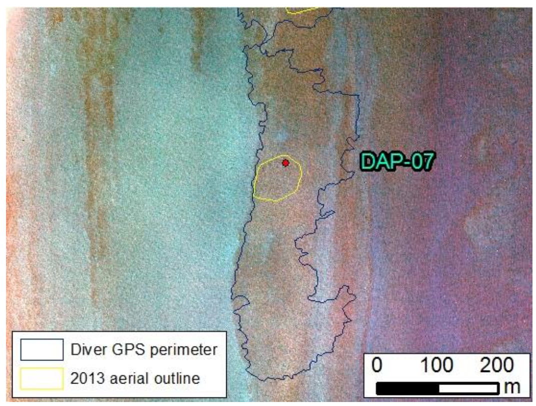
DAP-07

Species: *Acropora cervicornis*

Depth: 15 ft (4.6 m)

Last Survey Date: May 18, 2016

Patch Condition:	*Moderate*
% Total:	**52.4**
% Live:	**29.2**
% Dead:	**12.3**
% Disease:	**0.5**
% Rubble:	**10.9**



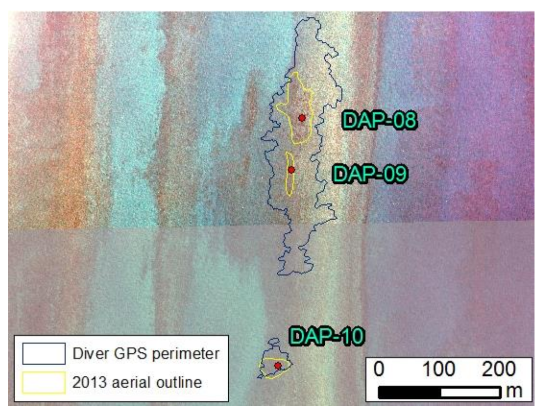
DAP-08

Species: *Acropora cervicornis*

Depth: 11 ft (3.4 m)

Last Survey Date: May 18, 2016

Patch Condition:	*Good*
% Total:	**85.7**
% Live:	**68.9**
% Dead:	**13.3**
% Disease:	**0.4**
% Rubble:	**3.6**



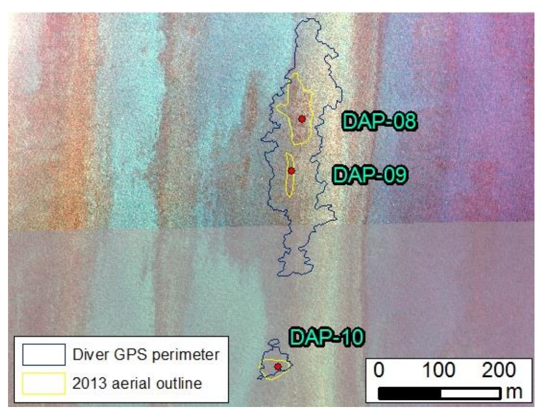
DAP-09

Species: *Acropora cervicornis*

Depth: 14 ft (4.3 m)

Last Survey Date: May 18, 2016

Patch Condition:	*Moderate*
% Total:	**53.9**
% Live:	**27.3**
% Dead:	**17.9**
% Disease:	**0.6**
% Rubble:	**8.7**



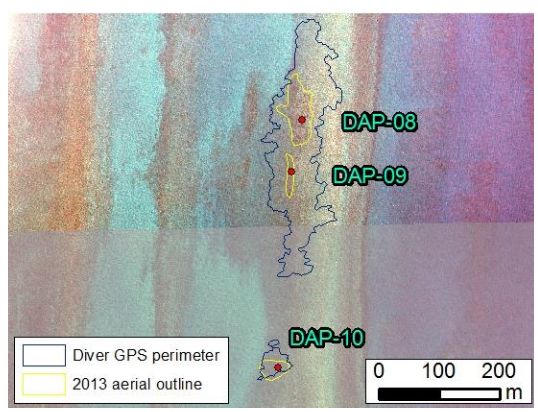
DAP-10

Patch Condition:	*Moderate*
% Total:	**49.7**
% Live:	**34.1**
% Dead:	**10.1**
% Disease:	**0.2**
% Rubble:	**5.5**

Species: *Acropora cervicornis*

Depth: 19 ft (5.8 m)

Last Survey Date: May 24, 2016



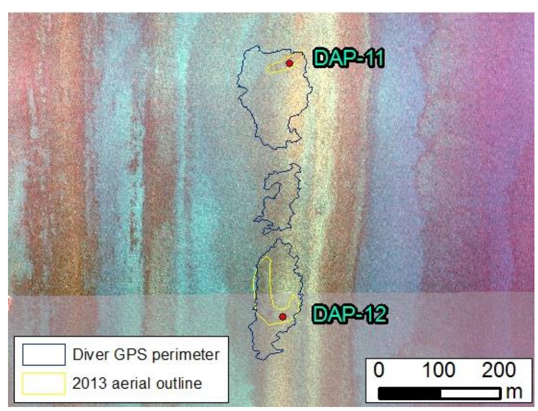
DAP-11

Species: *Acropora cervicornis*

Depth: 12 ft (3.7 m)

Last Survey Date: May 24, 2016

Patch Condition:	*Good*
% Total:	**71.0**
% Live:	**54.8**
% Dead:	**12.4**
% Disease:	**0.2**
% Rubble:	**3.8**



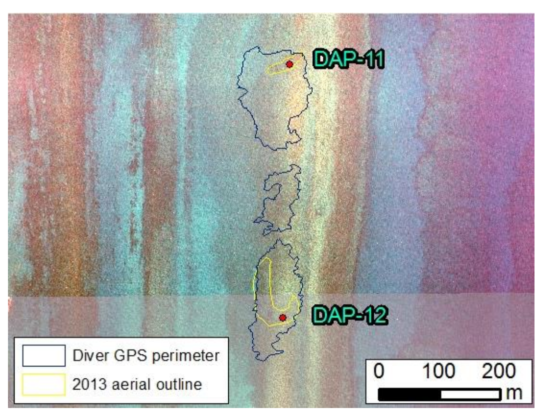
DAP-12

Species: *Acropora cervicornis*

Depth: 11 ft (3.4 m)

Last Survey Date: May 24, 2016

Patch Condition:	*Moderate*
% Total:	**44.9**
% Live:	**25.2**
% Dead:	**9.4**
% Disease:	**0.9**
% Rubble:	**10.3**



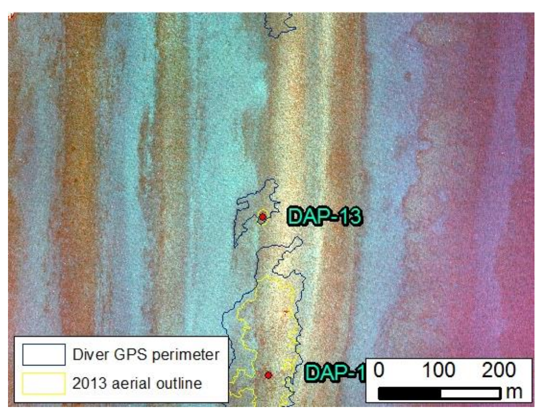
DAP-13

Patch Condition:	Moderate
% Total:	59.2
% Live:	22.6
% Dead:	26.4
% Disease:	1.0
% Rubble:	10.1

Species: *Acropora cervicornis*

Depth: 12 ft (3.7 m)

Last Survey Date: May 31, 2016



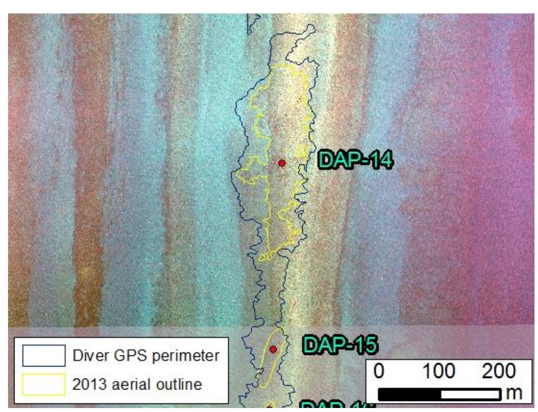
DAP-14

Species: *Acropora cervicornis*

Depth: 11 ft (3.4 m)

Last Survey Date: May 31, 2016

Patch Condition:	*Poor*
% Total:	**79.4**
% Live:	**17.1**
% Dead:	**44.3**
% Disease:	**1.4**
% Rubble:	**17.9**



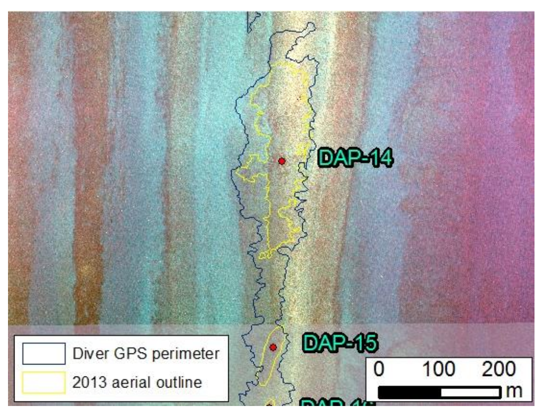
DAP-15

Species: *Acropora cervicornis*

Depth: 15 ft (4.6 m)

Last Survey Date: May 31, 2016

Patch Condition:	*Moderate*
% Total:	**55.8**
% Live:	**25.5**
% Dead:	**23.9**
% Disease:	**1.2**
% Rubble:	**6.3**



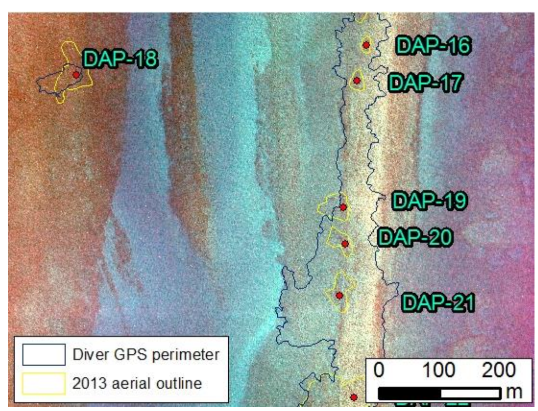
DAP-16

Patch Condition:	Moderate
% Total:	51.1
% Live:	21.1
% Dead:	20.0
% Disease:	2.5
% Rubble:	10.0

Species: *Acropora cervicornis*

Depth: 10 ft (3.0 m)

Last Survey Date: June 1, 2016



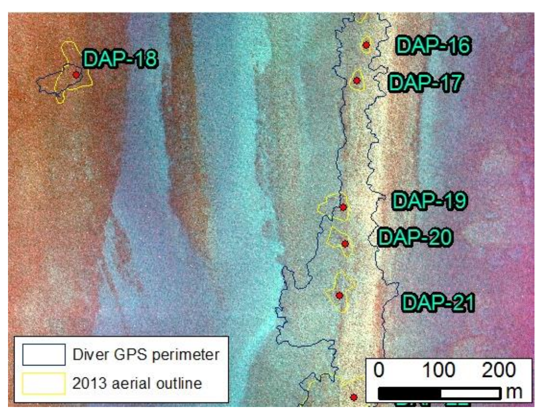
DAP-17

Patch Condition:	Poor
% Total:	32.6
% Live:	3.9
% Dead:	15.0
% Disease:	0.2
% Rubble:	13.6

Species: *Acropora cervicornis*

Depth: 15 ft (4.6 m)

Last Survey Date: June 1, 2016



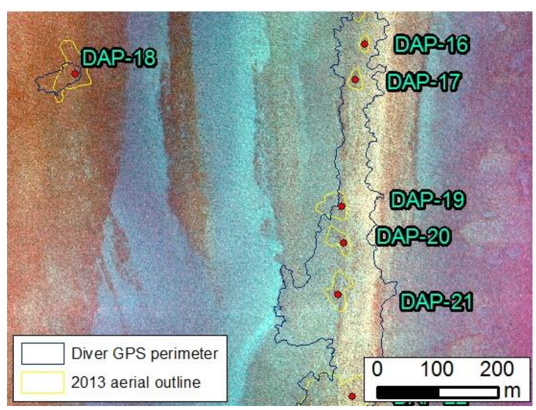
DAP-18

Patch Condition:	Moderate
% Total:	43.3
% Live:	18.5
% Dead:	18.6
% Disease:	0.03
% Rubble:	6.2

Species: *Acropora cervicornis*

Depth: 15 ft (4.6 m)

Last Survey Date: May 12, 2016



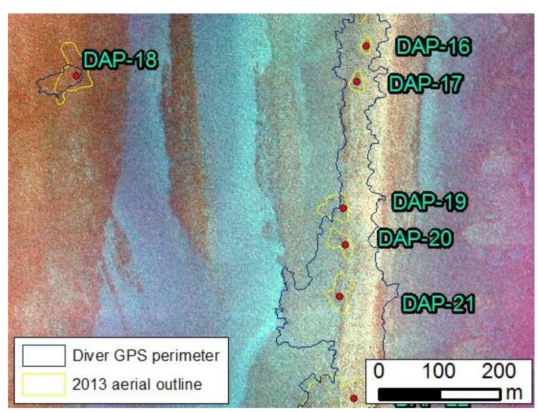
DAP-19

Species: *Acropora cervicornis*

Depth: 15 ft (4.6 m)

Last Survey Date: June 1, 2016

Patch Condition:	*Poor*
% Total:	**80.7**
% Live:	**13.6**
% Dead:	**29.2**
% Disease:	**1.7**
% Rubble:	**38.0**



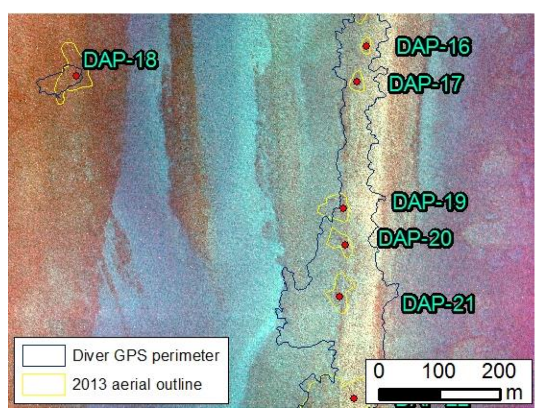
DAP-20

Patch Condition:	Poor
% Total:	**65.7**
% Live:	**15.3**
% Dead:	**30.7**
% Disease:	**1.5**
% Rubble:	**19.7**

Species: *Acropora cervicornis*

Depth: 12 ft (3.7 m)

Last Survey Date: June 2, 2016



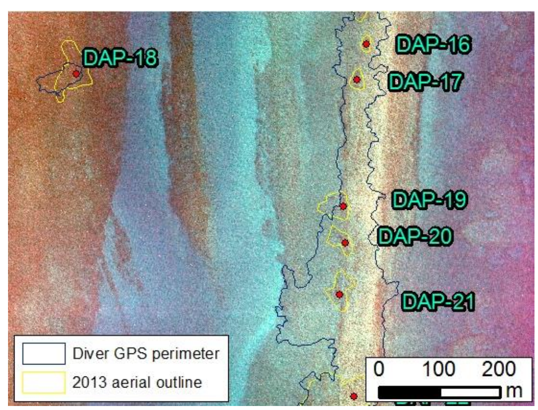
DAP-21

Patch Condition:	Moderate
% Total:	77.5
% Live:	39.2
% Dead:	22.7
% Disease:	1.7
% Rubble:	15.7

Species: *Acropora cervicornis*

Depth: 14 ft (4.3 m)

Last Survey Date: June 2, 2016



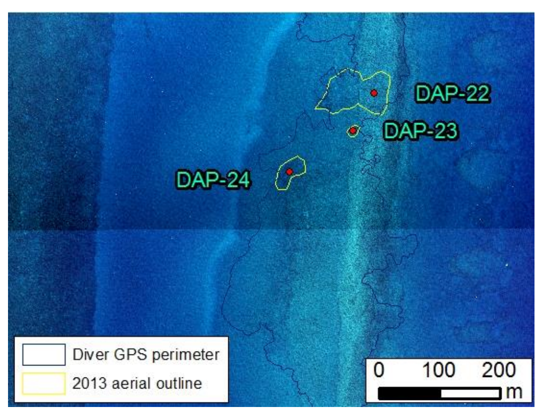
DAP-22

Species: *Acropora cervicornis*

Depth: 10 ft (3.0 m)

Last Survey Date: June 2, 2016

Patch Condition:	Poor
% Total:	53.5
% Live:	8.1
% Dead:	27.8
% Disease:	0.6
% Rubble:	17.6



DAP-23

Patch Condition:	Poor
% Total:	62.4
% Live:	8.2
% Dead:	30.3
% Disease:	1.3
% Rubble:	23.9

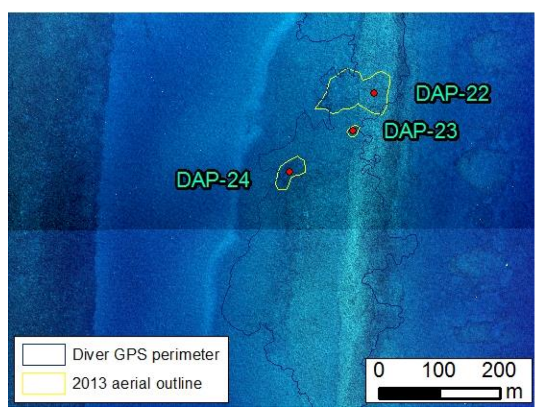
Species: *Acropora cervicornis*

Depth: 14 ft (4.3 m)

Last Survey Date: June 3, 2016





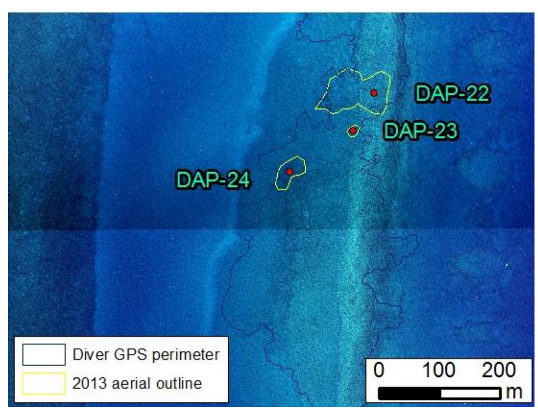
DAP-24

Patch Condition:	Poor
% Total:	42.2
% Live:	8.4
% Dead:	16.4
% Disease:	1.1
% Rubble:	17.4

Species: *Acropora cervicornis*

Depth: 14 ft (4.3 m)

Last Survey Date: June 3, 2016



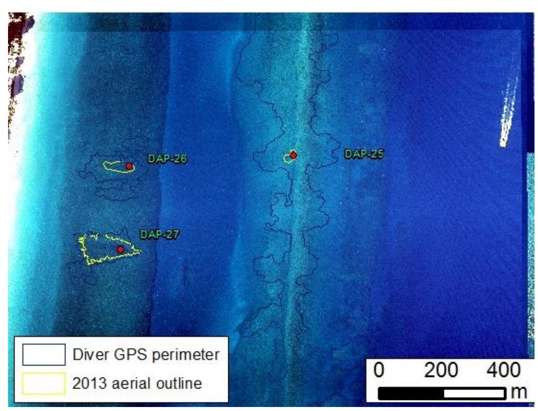
DAP-25

Patch Condition:	Moderate
% Total:	43.4
% Live:	18.5
% Dead:	12.5
% Disease:	1.8
% Rubble:	12.5

Species: *Acropora cervicornis*

Depth: 11 ft (3.4 m)

Last Survey Date: June 3, 2016



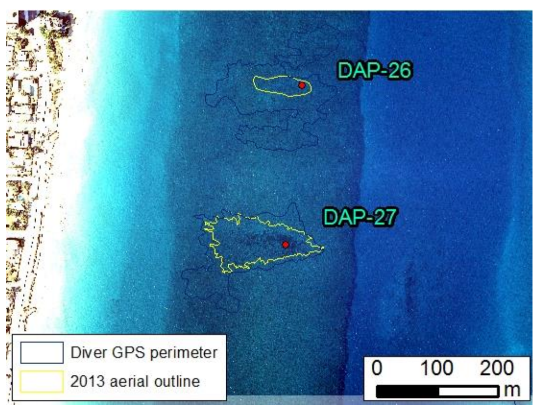
DAP-26

Species: *Acropora cervicornis*

Depth: 18 ft (5.5 m)

Last Survey Date: June 5, 2016

Patch Condition:	Poor
% Total:	41.8
% Live:	7.8
% Dead:	13.6
% Disease:	0.4
% Rubble:	20.4



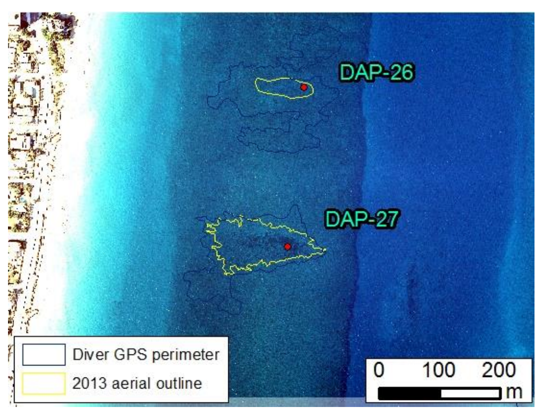
DAP-27

Species: *Acropora cervicornis*

Depth: 16 ft (4.9 m)

Last Survey Date: June 15, 2016

Patch Condition:	*Poor*
% Total:	**83.4**
% Live:	**8.2**
% Dead:	**49.9**
% Disease:	**0.3**
% Rubble:	**25.4**



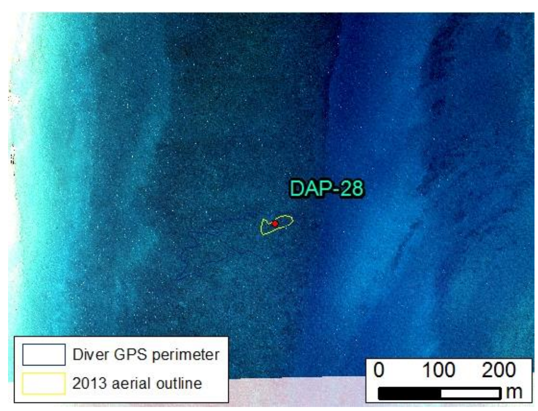
DAP-28

Species: *Acropora cervicornis*

Depth: 18 ft (5.5 m)

Last Survey Date: June 10, 2016

Patch Condition:	*Poor*
% Total:	**41.9**
% Live:	**7.1**
% Dead:	**24.9**
% Disease:	**0.2**
% Rubble:	**9.9**



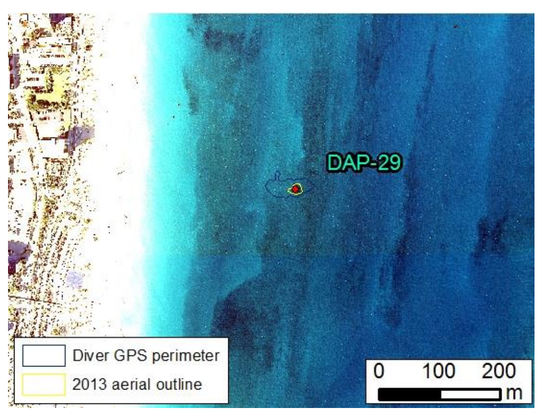
DAP-29

Species: *Acropora cervicornis*

Depth: 18 ft (5.5 m)

Last Survey Date: May 12, 2016

Patch Condition:	*Moderate*
% Total:	**68.7**
% Live:	**23.7**
% Dead:	**40.9**
% Disease:	**1.9**
% Rubble:	**4.1**



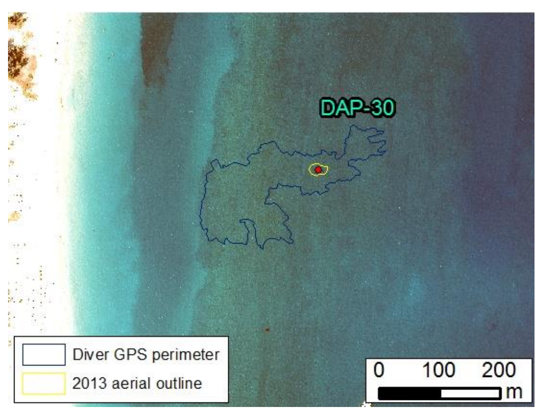
DAP-30

Species: *Acropora cervicornis*

Depth: 13 ft (4.0 m)

Last Survey Date: May 6, 2016

Patch Condition:	*Poor*
% Total:	**43.1**
% Live:	**13.8**
% Dead:	**27.7**
% Disease:	**0.2**
% Rubble:	**1.6**



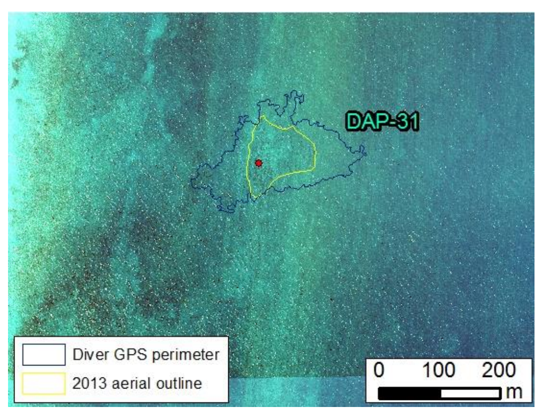
DAP-31

Species: *Acropora cervicornis*

Depth: 15 ft (4.6 m)

Last Survey Date: May 6, 2016

Patch Condition:	*Moderate*
% Total:	**53.5**
% Live:	**25.4**
% Dead:	**26.5**
% Disease:	**0.2**
% Rubble:	**1.7**



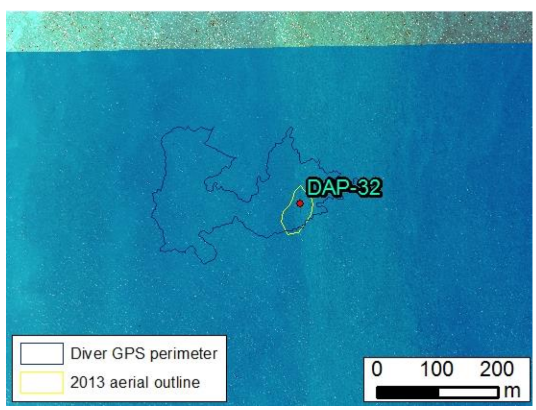
DAP-32

Species: *Acropora cervicornis*

Depth: 18 ft (5.5 m)

Last Survey Date: May 9, 2016

Patch Condition:	*Poor*
% Total:	**38.7**
% Live:	**0.5**
% Dead:	**29.2**
% Disease:	**0**
% Rubble:	**9.0**



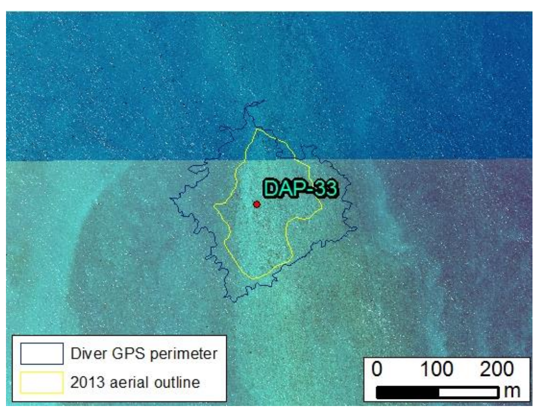
DAP-33

Species: *Acropora cervicornis*

Depth: 17 ft (5.2 m)

Last Survey Date: May 9, 2016

Patch Condition:	*Moderate*
% Total:	**52.9**
% Live:	**32.5**
% Dead:	**18.6**
% Disease:	**0.6**
% Rubble:	**1.8**



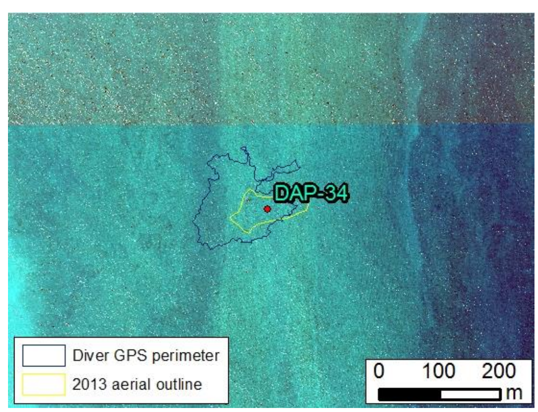
DAP-34

Species: *Acropora cervicornis*

Depth: 18 ft (5.5 m)

Last Survey Date: May 9, 2016

Patch Condition:	*Moderate*
% Total:	**22.5**
% Live:	**13.5**
% Dead:	**7.3**
% Disease:	**0.2**
% Rubble:	**1.8**



DAP-35

Species: *Acropora cervicornis*

Depth: 15 ft (4.5 m)

Last Survey Date: May 12, 2016

Patch Condition:	Moderate
% Total:	64.0
% Live:	35.6
% Dead:	26.1
% Disease:	1.0
% Rubble:	2.3