Southeast Florida reef-wide Post-Irma coral disease surveys

Florida Department of Environmental Protection
Coral Reef Conservation Program

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Final Summary Report

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Executive Summary

Florida's coral reefs are currently experiencing a multi-year outbreak of coral disease that have resulted in the mortality of millions of corals across southeast Florida, Biscayne National Park, and the Upper and Middle Florida Keys. In early September 2017, Hurricane Irma impacted the entire FRT. The purpose of this project was to conduct field surveys to identify the current state of the coral reefs in southeast Florida and coordinate with other concomitant reef tract efforts to improve the regional understanding of the extent of the disease outbreak and identify recent hurricane injury to direct future restoration. Through a broader partner network, 62 sites from Key Biscayne to St. Lucie Reef were targeted for survey. Twenty-nine sites were chosen based on previous data that indicated high coral values of richness, density, and/or cover at those locations. Thirty-three sites were chosen with FDEP reef managers where there were previous data gaps. A new protocol was developed, which was a modification of the Florida Reef Resilience Program (FRRP) Disturbance Response Monitoring (DRM) methodology. This included collecting additional disease and injury metrics in transects and by rover diver to prioritize sites for triage and restoration activities.

The analyses showed that hurricane impacts on corals were quite low where 82.3% (51/62) of the sites were listed as Tier 3 (minimal impact/triage not needed). There were nine sites listed with at least some Tier 2 damage (moderate impact/secondary priority if resources allow). Site 33 was listed as 100% Tier 2 and Site 30 was 100% Tier 1 (triage recommended). Site 30 had some impressive impacts including large (2 - 5 m) slabs of fractured hardbottom lifted and thrown several meters eastward atop other hardbottom affecting a ~ 2 m *Orbicella faveolata* colony that was mostly covered leaving only the very top exposed. One day of triage was conducted at a dense *Acropora cervicornis* patch to stabilize many coral fragments and collect loose debris (mostly gorgonians). Lack of capacity and weather deterred further triage attempts for several months. It was eventually decided that triage efforts were not a priority for SE Florida because of the ongoing disease.

Coral disease prevalence was high. The rover diver surveys found 11.4% total disease prevalence across all sites (243/2130) infecting 43.3% of the species found, and prevalence at the southern sites was higher. Mean density and richness at sites with previous relatively high values were considerably lower than their historic values with a 57.2% and 42.2% decrease respectively, indicating profound changes in the coral populations. Perhaps the most striking result was the low density of *Eusmilia fastigiata*, *Meandrina meandrites*, *Dichocoenia stokesi*, *Colpophyllia natans*, *Pseudodiploria strigosa*, *Diploria labyrinthiformis*, and *Orbicella annularis*. We found 36 individuals of all these species combined out of 1,165 colonies (3.1%). A comparison of the percentages of each species to the total in the southern sites to those of the 2004 annual monitoring data in Broward County showed drastic differences in the populations that likely go beyond any bias in survey differences.

These data support the idea that the Florida Reef Tract is becoming more homogenous and dominated by eurytopic, generalist species that can tolerate a wider range of environmental conditions. However, this disease event contradicts the notion that the present assemblages

are stable because they have "withstood a number of recent perturbations, including thermal stress and disease". After moving through the more vulnerable species, the disease is now affecting hardier species thought to be more resistant to stress like *Montastrea cavernosa* and *Siderastrea siderea*.

It is important that actions are taken to curtail this disease quickly so that the remaining population can stabilize and recovery and restoration efforts can begin. There should be continued focus on the remaining corals because they are apparently resistant to the disease and perhaps better acclimated to the stressful conditions over the past several years.

Acknowledgements

Thank you to the Florida Department of Environmental Protection's Florida Coastal Office and Coral Reef Conservation Program (FDEP CRCP) and the Environmental Protection Agency for supporting this effort. A special thanks to all of our partners involved in the data collection including the FDEP CRCP, Restoration & Enhancement Section of the Miami-Dade Department of Regulatory and Economic Resources Environmental Resources Management, NOAA Fisheries Southeast Regional Office, The Center for Marine Ecosystem Health and Robertson Coral Reef Program at Harbor Branch Oceanographic Institute, Florida Atlantic University, the Florida Fish and Wildlife Conservation Commission, Palm Beach County Department of Environmental Resources Management, and Coastal-Eco Group, Inc. I also thank Cory Ames, Shelby Eagan, Alysha Brunelle and Liz Fromuth of the Nova Southeastern University Oceanographic Center (NSUOC) Geographic Information Systems and Spatial Ecology lab for data management and QA/QC. Thanks to FDEP CRCP staff including Kristi Kerrigan for contract and report-review coordination.

Table of Contents

List of Figures

List of Tables

List of Acronyms

DRM	Disturbance Response Monitoring
FDEP	Florida Department of Environmental Protection
FRRP	Florida Reef Resilience Program
FRT	Florida Coral Reef Tract
NOAA	National Oceanic and Atmospheric Administration
SD	Standard Deviation

1. BACKGROUND

Florida's coral reefs are currently experiencing a multi-year outbreak of coral disease. While disease outbreaks are not unprecedented, this event is unique due to the presence of multiple diseases that have affected at least 21 species of coral across the Florida Reef Tract (FRT). These diseases are highly prevalent and are estimated to have resulted in the mortality of millions of corals across southeast Florida, Biscayne National Park, and the Upper and Middle Florida Keys. Hurricane Irma recently impacted the entire FRT in early September 2017. Now that the system was impacted by a major storm event, it is important to know the current state of coral reef communities including disease and injury. The work herein focuses on southeast Florida and is part of a larger effort to survey the entire FRT with one consistent methodology.

1.1. Project Goals & Objectives

The purpose of this project is to lead the coordination, implementation, data analysis, and reporting relevant to a field survey effort to identify the current state of the coral reefs in southeast Florida and coordinate with other concomitant reef tract efforts. This information will improve understanding of the current spatial extent of the disease outbreak, prevalence, species affected, and the gradient of impact. It will also identify reef injury and areas to direct future restoration. The outcomes of this project will contribute to an on-going coral disease response effort which seeks to improve understanding about the scale and severity of the Florida Reef Tract coral disease outbreak, identify primary and secondary causes, identify management actions to remediate disease impacts, restore affected resources and, ultimately, prevent future outbreaks. They will also contribute to the present reef-wide assessment on Hurricane Irma impacts.

2. METHODOLOGY

The Nature Conservancy, Fish and Wildlife Research Institute, and NOAA, in conjunction with FDEP staff, developed an initial disease/injury monitoring protocol, which is a modification of the existing Florida Reef Resilience Program (FRRP) Disturbance Response Monitoring (DRM) methodology. Through a broader partner network, 62 sites from Key Biscayne to St. Lucie Reef were targeted for survey (Figure 1). Twenty-nine sites were chosen based on previous data that indicated high coral values of richness, density, and/or cover at those locations. These data came from a database compiled by John Fauth of a variety of sources collected between 2005 and 2014 and subsequently used for the Our Florida Reefs Marine Planner. This included sites from FRRP, Broward County annual monitoring, Town of Palm Beach nearshore mapping, Alternate breakers, Port Miami, southeast Florida nearshore mapping, and the Southeast Florida Coral Reef Monitoring Program. Thirty-three sites were chosen with FDEP reef managers where there were previous data gaps.

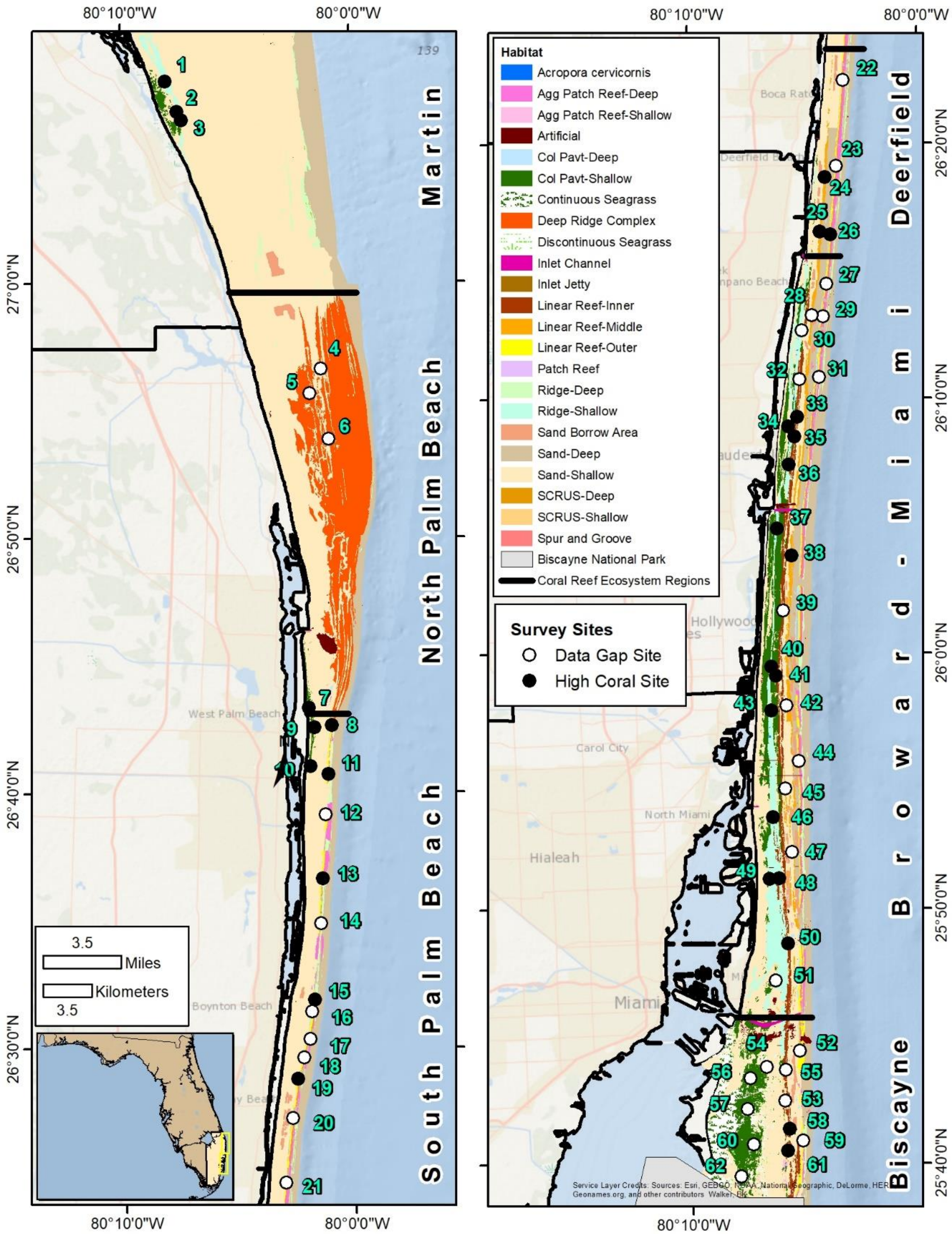

Figure 1. Southeast Florida disease and Irma-impact survey site map. White sites were chosen to fill data gaps and black sites were previously surveyed sites with high coral values.

2.1. DRM Surveys

The DRM surveys consisted of two 10-m transects laid taut across reef substrate about 5 m apart. Within 1-m along the transect, corals greater than four cm in diameter were identified to species and assessed for tissue cover, size and condition. Any coral larger than 4 cm that fell within the belt transect, even if the live or recently dead tissue itself was not within the belt transect was included.

The maximum diameter (largest width perpendicular to the axis of growth) and maximum height (the largest height parallel to the axis of growth) of each colony was recorded to the nearest centimeter. The percentage of old mortality and recent mortality of the whole colony surface was estimated to the nearest 5% unless it was very small or very large, in which case it was rounded to the nearest whole number (e.g. 1%, 97%). “Old dead” was defined as any non-living parts of the coral in which the corallite structures were either gone or covered over by organisms that are not easily removed. “Recently dead” was defined as any non-living parts of the coral in which the corallite structures were either white and still intact or slightly eroded but identifiable to species.

Any coral disease was noted by general descriptors (e.g. Dark spot, White plague). Paling and bleaching were also noted utilizing the following codes to indicate the severity of discoloration. Bleaching or paling directly associated with a disease (next to a margin of recent mortality) was not recorded as paling/bleaching, but this was difficult to distinguish in many cases of diffuse bleaching without decaying tissue. Any discoloration of coral tissue was considered Pale. Patches of fully bleached or white tissue were considered Partially Bleached. And, totally white tissue with no visible zooxanthallae was considered Bleached. Milleporid species (*Millepora alcicornis* and *Millepora complanata*) that were 4 cm or greater within the belt transect were tallied separated based on number of non-bleached colonies (NB), pale colonies (P), partially bleached colonies (PB) and bleached colonies (BL).

2.2. Roving Diver Surveys

Roving diver surveys were also conducted at each site to record a broader understanding of disease prevalence and coral impacts from hurricane Irma across the site. For 20 minutes, a diver(s) swam around the site where the DRM transects occurred within eyesight of the other divers and collected two sets of data. For coral disease, the rover counted every coral species greater than 10 cm in diameter from the list of species in Table 1. These corals were tallied as either diseased or not diseased. Concomitantly, all corals greater than 25 cm on the target list in Table 2 were tallied into injury types by size classes. The size classes were Medium (25-50 cm), Large (51-150 cm), and Gigantic (>150 cm). The injury types were as follows:

- No Breakage = no visual indicator of recent injury to colony;
- Dislodged = colonies detached from their former fixed attachment to the substrate;

- Sheared = components are partially removed, and a portion remains attached to the substrate;
- Fractured = crushed, cracked or fragmented stony coral. The colony may be dislodged or attached to the substrate;
- Fractured hard substrate: the hard substrate, including but not limited to reef framework, is fragmented, crushed, flattened, dislodged, or otherwise altered;
- Burial = hard substrate and benthic community is covered with sediment &/or fractured hard substrate.

Impacted sites were also categorized into percentages of the following tiers to help prioritize triage efforts:

Tier 1 = severe impact/top priority for stabilization/triage;
Tier 2 = moderate impact/secondary priority if resources allow after Tier 1;
Tier 3 = minimal impact/ triage not needed.

Table 1. List of target coral species > 10 cm for the disease roving diver surveys.

Disease Target species
Colpophyllia natans
Dendogyra cylindrus
Dichocoenia stokesi
Diploria labyrinthiformis
Eusmilia fastigiata
Meandrina meandrites
Montastraea cavernosa
Orbicella annularis
Orbicella faveolata
Orbicella franksi
Pseudodiploria clivosa
Pseudodiploria strigosa
Siderastrea spp.

Table 2. List of target coral species > 25 cm for the injury roving diver surveys.

Impact Target species
Acropora cervicornis
Acropora palmata
Dendogyra cylindrus
Colpophyllia natans
Diploria labyrinthiformis
Meandrina meandrites
Montastraea cavernosa
Orbicella annularis
Orbicella faveolata
Orbicella franksi
Pseudodiploria strigosa

2.3. QA/QC

All site data were entered into Excel where QA/QC and data summaries were performed. Once entered data were reviewed to ensure they matched the data sheets. Then summary tables and charts were created. During the summary table creation, the data were reviewed for consistency between teams especially for coral species and disease identifications. In some cases, site pictures were reviewed to help this QA/QC process. Then summary data were entered into a GIS file to create maps for data visualization across the region.

3. RESULTS

3.1. Disease

Diseased corals were found in the disturbance response monitoring (DRM) surveys and the roving diver surveys, which covered more area. There were 1,165 corals greater than or equal to 4 cm measured and assessed in the DRM transects for all sites (Table 1). Of these, 5.2% were diseased, 1.2% bleached, 7.1% partially bleached, and 8.3% with some paling. The rover diver surveys found 11.4% total disease prevalence, the percentage of a population that was affected by disease, across all sites and species (243/2130). Thirteen out of the thirty species identified in this study (43.3%) were affected. Total disease prevalence varied between regions with 4.9% (55/1121) affected corals in the north and 18.6% (188/1009) affected corals in the south. Since this project was focused on disease and surveys were conducted after peak bleaching, this summary report focuses on the disease aspects.

Coral condition varied by species (Figure 2). Only one colony of *Oculina sp*. was recorded in all transects resulting in a 100% disease prevalence. Another oddity in the prevalence calculations was a dense patch of *Madracis auretenra* (formerly mirabilis) at Site 18 (Figure 3). This was a single patch too large to measure. This growth form is difficult to capture in a density metric because distinguishing separate colonies is nearly impossible. The total number of colonies was reflective of the number of quadrats in which it occurred and two small pieces were diseased. This resulted in a prevalence of 20%, however images of the colony do not illustrate a large amount of disease.

Aside from these outliers, the DRM survey data showed that *Pseudodiploria clivosa* had the highest overall prevalence (28.6%) followed by *Siderastrea siderea* (15.7%), *Orbicella faveolata* (11%), and *Montastraea cavernosa* (6.4%). These results agree with other reports on the current state of the disease in SE FL. Disease prevalence differed within species between regions. In the north region (Martin and West Palm Beach counties), 60% of *P. clivosa* were affected (
Figure 4) versus 11.1% in the south (Broward and Miami-Dade counties) (Figure 5). Conversely, 18.5% of *S. siderea* were affected in the south versus 2.8% in the north, and *O. faveolata* was affected at 14.3% in the South versus 0% in the North. *Montastraea cavernosa* was about the same between regions, 4.9% in the south versus 7.5% in the north.

The roving diver disease surveys, which targeted a specific list of species >10cm diameter, showed that *Orbicella annularis* had the highest overall prevalence (66.7%) followed by *Colpophyllia natans* (33.3%), *Pseudodiploria clivosa* (25%), *Orbicella faveolata* (20.9%), *Siderastrea spp.* (20.6%), *Orbicella franksi* (14.3%), and *Montastraea cavernosa* (10.2%) (Figure 6). *Pseudodiploria clivosa* (44.4%) and *Orbicella faveolata* (25%) had high prevalence in the north (Figure 7). *Orbicella annularis* (66.7%), *Colpophyllia natans* (40%), *Siderastrea spp.* (24.1%), *Orbicella faveolata* (20.7%), *Montastraea cavernosa* (17.5%), and *Orbicella franksi* (14.3%) had high disease prevalence in the south (Figure 8).

It has been reported that the recent disease event has significantly reduced the regional coral population (Precht et al. 2016). The combined DRM surveys found a mean coral density of 0.94 corals/m² (±0.715 SD) (Table 4), which also differed between the north sites (0.636 ± 0.36 corals/m²) and the south sites (1.11 ± 0.805 corals/m²).

Twenty-nine of the survey sites were previously known to have relatively higher coral cover values from surveys performed between 2005 and 2014. We calculated the mean densities and richness of the 29 sites from their previous survey data and compared it to the 2018 survey to get an understanding of how they have changed through time. The mean coral density of all 29 previous surveys was 2.5 ± 1.31 corals/m² compared to 1.07 ± 0.87 corals/m² in 2018. This equates to a 57.2% decrease in mean coral density among these previous high-coral sites (Table 5). Figure 9 shows the data comparison per site indicating almost all sites have decreased in coral density. No spatial patterns were obvious in density loss. The eleven northern sites with previous data declined 60.9% (

Table 6) versus 55.7% in the eighteen southern sites (Table 7).

The mean richness of the 29 previous surveys was 8.3 ± 3.1 species between 2005 and 2014 compared to 4.8 ± 2.0 species in 2018 (Table 8). This equates to a 42.2% decrease in the number of species among these previous high-coral sites. Figure 10 shows the data comparison per site indicating almost all sites have decreased in coral richness. Spatial patterns of declining richness were evident between the north and south. The eleven northern sites with previous data declined 30.5% (Table 9) versus a 46.5% decline in the eighteen southern sites (Table 10).

3.2. Hurricane Irma Impacts

Irma impact prevalence on corals, the percentage of a population that was affected by recent impacts, varied between the DRM and rover diver surveys. The DRM surveys yielded total impact prevalence or 5.75% (67/1165) (Table 11). Most of the impacts were from sedimentation (33) and dislodging (23) across thirteen species. *Acropora cervicornis* was impacted the most (77.8%), followed by *Dichocoenia stokesi* (28.6%), *Pseudodiploria strigosa* (18.2%), *Porites porites* (15.8%), and *Orbicella faveolata* (11.1%).

The rover diver surveys, which covered a much larger area than the DRM, but focused on large colonies of fewer species, found 11.3% total coral impact prevalence (Table 12). Total coral impact was dominated by dislodged colonies (48.7%; 57/117) and buried colonies (31.6%; 37/117). There were regional differences in impact prevalence. The north region prevalence (2.7%) (Table 13) was much lower than the south (17%) (Table 14). The low prevalence in the north was driven by high numbers of *Montastraea cavernosa* (198) and *Pseudodiploria clivosa* (47) with very low impacts (10 total).

The south rover diver surveys had much higher total impact prevalence (17%) which did not differ much from the impact prevalence of only the target species (15.6%). Impacts in the south were dominated by dislodged (46.2%; 40/106) and buried (34.9%; 37/106) colonies. Appendix 2 provides a series of maps that spatially illustrate the data.

Table 3. Abundance of all corals and diseased, bleached, and paled as well as condition prevalence from the DRM surveys.

		Counts				Prevalence			
Coral Species	Total	Disease	Bleached	Partially Bleached	Paling	Disease	Bleached	Partially Bleached	Paling
Acropora cervicornis	9					0%	0%	0%	0%
Agaricia lamarcki	3			1		0%	0%	33.3%	0%
Colpophyllia natans	1					0%	0%	0%	0%
Dichocoenia stokesi	7					0%	0%	0%	0%
Eusmilia fastigiata	2					0%	0%	0%	0%
Helioseris cucullata	1			1		0%	0%	100%	0%
Madracis auretenra	10	2				20.0%	0%	0%	0%
Montastraea cavernosa	141	9		3	8	6.4%	0%	2.1%	5.7%
Madracis decactis	16				1	0%	0%	0%	6.3%
Meandrina meandrites	5					0%	0%	0%	0%
Mycetophyllia spp	5					0%	0%	0%	0%
Oculina sp.	1	1				100%	0%	0%	0%
Orbicella faveolata	9	1		2	4	11%	0%	22.2%	44.4%
Orbicella franksi	1					0%	0%	0%	0%
Porites astreoides	342	7		13	16	2.0%	0%	3.8%	4.7%
Pseudodiploria clivosa	14	4	1	2	1	28.6%	7.1%	14.3%	7.1%
Porites porites	38		1		2	0%	2.6%	0%	5.3%
Pseudodiploria strigosa	11				2	0%	0%	0%	18.2%
Solenastrea bournoni	18		3	1	1	0%	16.7%	5.6%	5.6%
Scolymia spp.	1					0%	0%	0%	0%
Solenastrea hyades	1					0%	0%	0%	0%
Stephanocoenia intersepta	201	2	2	19	15	1%	1.0%	9.5%	7.5%
Siderastrea radians	66	1	3	3	9	1.5%	4.5%	4.5%	13.6%
Siderastrea siderea	204	32	4	30	35	15.7%	2.0%	14.7%	17.2%
Undaria agaricites	58	2		8	3	3.4%	0%	13.8%	5.2%
Grand Total	**1165**	**61**	**14**	**83**	**97**	**5.2%**	**1.2%**	**7.1%**	**8.3%**

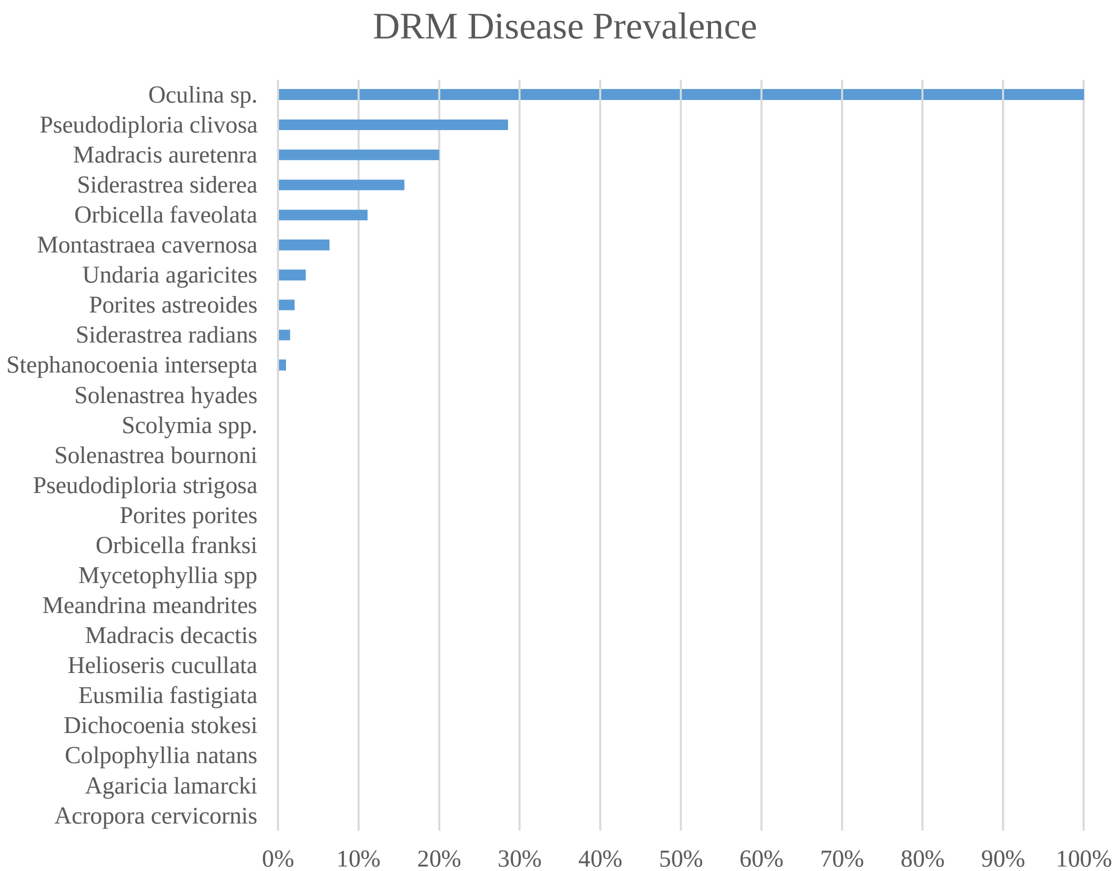

Figure 2. Total disease prevalence from the DRM surveys of all sites by species.

Figure 3. Pictures of Madracis auretenra *dense patch at Site 18.*

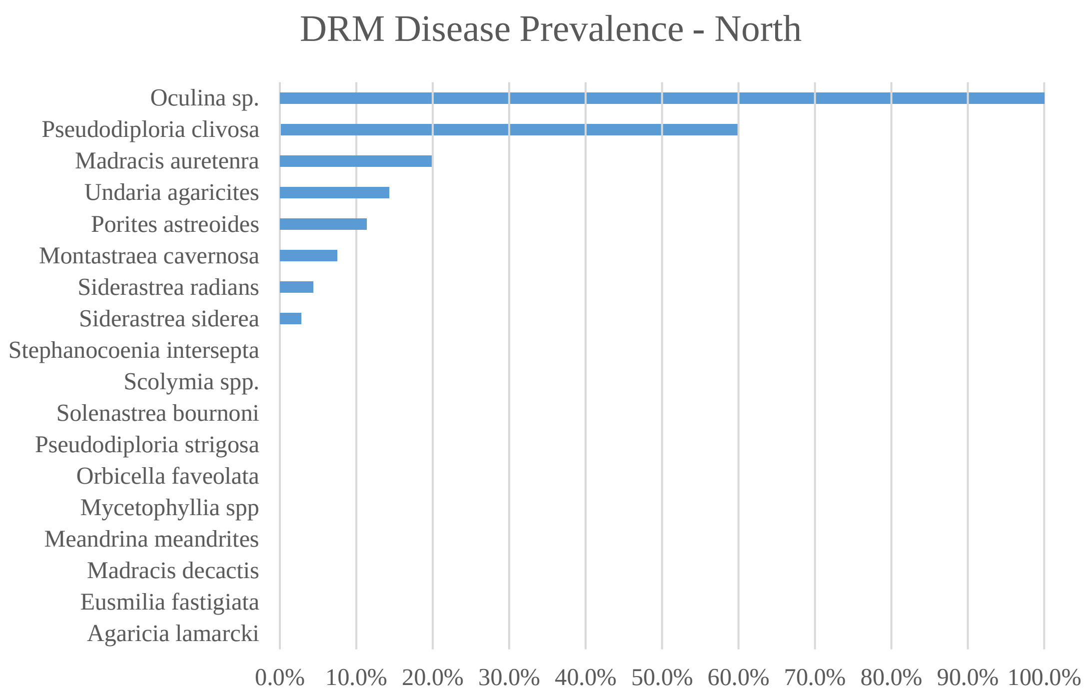

Figure 4. Total disease prevalence from the DRM surveys of North sites (Martin and West Palm Beach counties) by species.

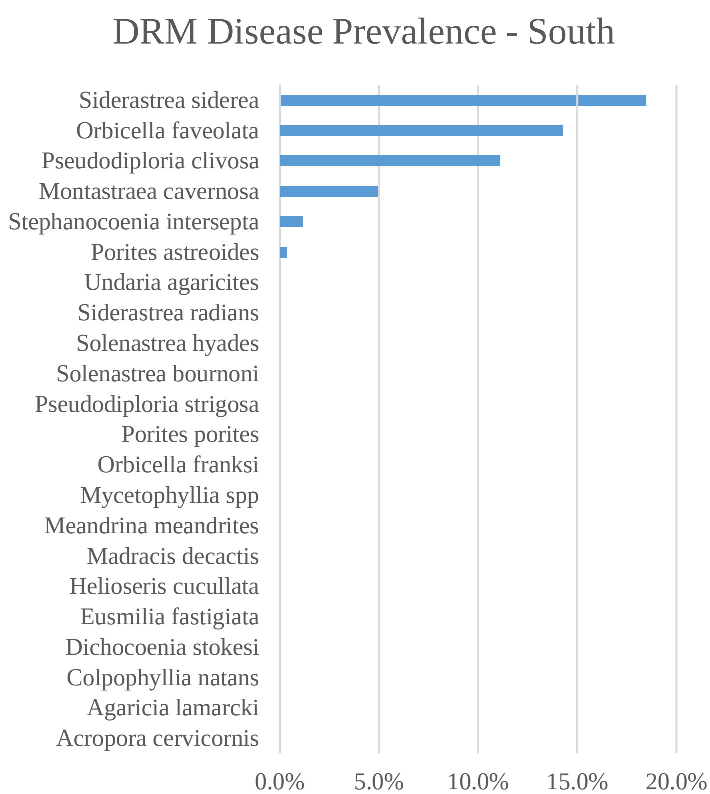

Figure 5. Total disease prevalence from the DRM surveys of South sites (Broward and Miami-Dade counties) by species.

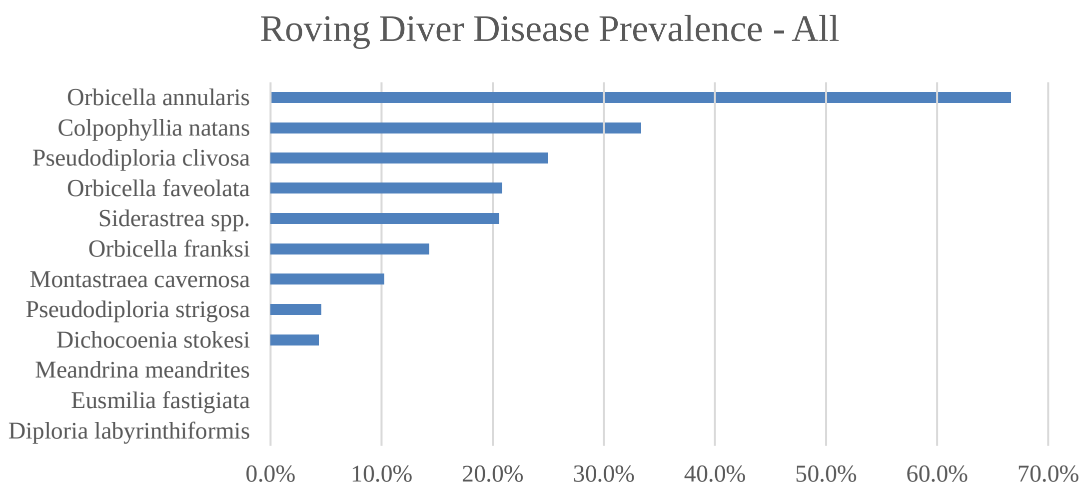

Figure 6. Total disease prevalence from the roving diver surveys of all sites by species.

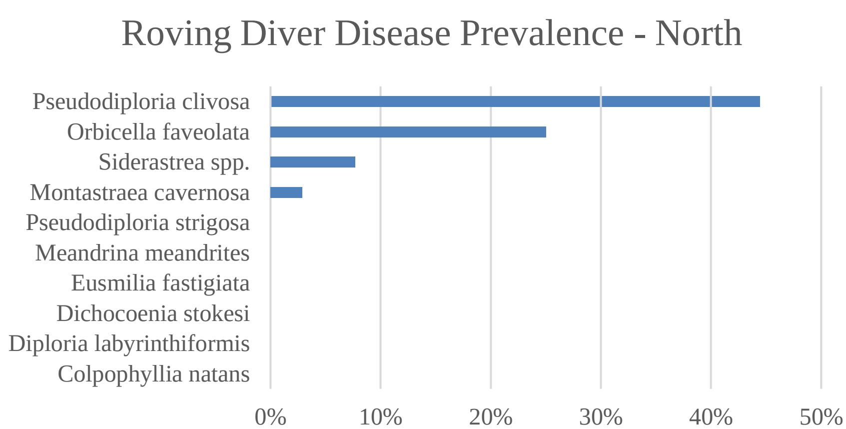

Figure 7. Total disease prevalence from the roving diver surveys of North sites (Martin and West Palm Beach counties) by species.

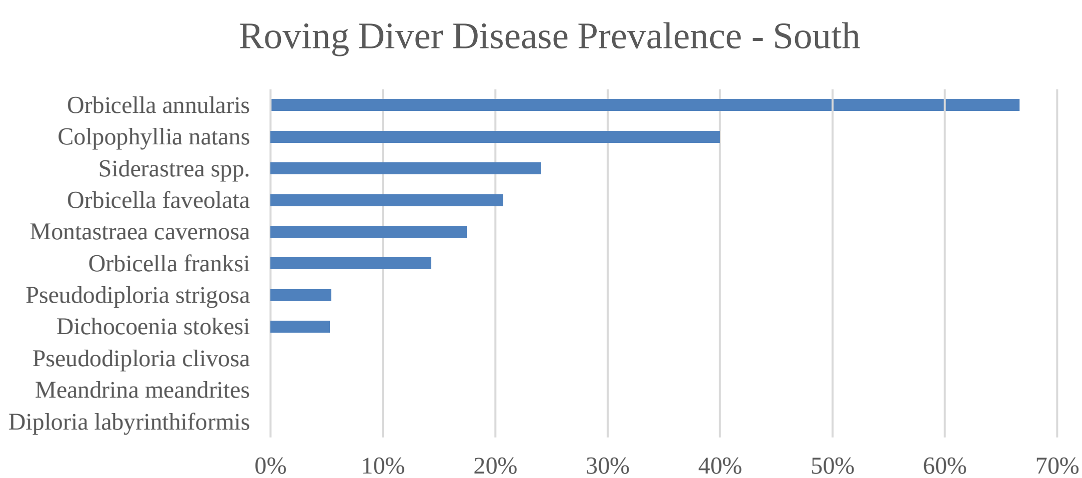

Figure 8. Total disease prevalence from the roving diver surveys of South sites (Broward and Miami-Dade counties) by species.

Table 4. Descriptive stats of 2018 coral density of all sites (left), the North sites only (middle), and the South sites only (right).

2018 Coral Density - All Sites	
Mean	0.939516
Standard Error	0.090763
Median	0.85
Mode	0.35
Standard Deviation	0.714667
Range	4.45
Minimum	0
Maximum	4.45
Count	62

2018 Coral Density - North	
Mean	0.636364
Standard Error	0.076743
Median	0.5
Mode	0.35
Standard Deviation	0.359954
Range	1.5
Minimum	0
Maximum	1.5
Count	22

2018 Coral Density - South	
Mean	1.10625
Standard Error	0.127352
Median	1.1
Mode	1.45
Standard Deviation	0.805445
Range	4.4
Minimum	0.05
Maximum	4.45
Count	40

Table 5. Descriptive stats of the 29 previous site densities (left) and 2018 density of the same sites (right).

Previous Density (2005 – 2014) - All	
Mean	2.50
Standard Error	0.24
Median	2.3
Mode	2.1
Standard Deviation	1.31
Range	5.6
Minimum	0.8
Maximum	6.4
Count	29

2018 Density - All	
Mean	1.07
Standard Error	0.16
Median	0.85
Mode	0.35
Standard Deviation	0.87
Range	4.45
Minimum	0
Maximum	4.45
Count	29

Table 6. Descriptive stats of the 11 previous northern site densities (left) and 2018 density of the same sites (right).

Previous Density (2005 – 2014) - North	
Mean	1.56
Standard Error	0.22
Median	1.1
Mode	1
Standard Deviation	0.73
Range	1.95
Minimum	0.8
Maximum	2.75
Count	11

2018 Density - North	
Mean	0.61
Standard Error	0.13
Median	0.4
Mode	0.35
Standard Deviation	0.44
Range	1.5
Minimum	0
Maximum	1.5
Count	11

Table 7. Descriptive stats of the 18 previous southern site densities (left) and 2018 density of the same sites (right).

Previous Density (2005 – 2014) - South	
Mean	3.07
Standard Error	0.30
Median	2.59
Mode	2.1
Standard Deviation	1.27
Range	4.97
Minimum	1.43
Maximum	6.4
Count	18

2018 Density - South	
Mean	1.36
Standard Error	0.22
Median	1.45
Mode	1.45
Standard Deviation	0.95
Range	4.3
Minimum	0.15
Maximum	4.45
Count	18

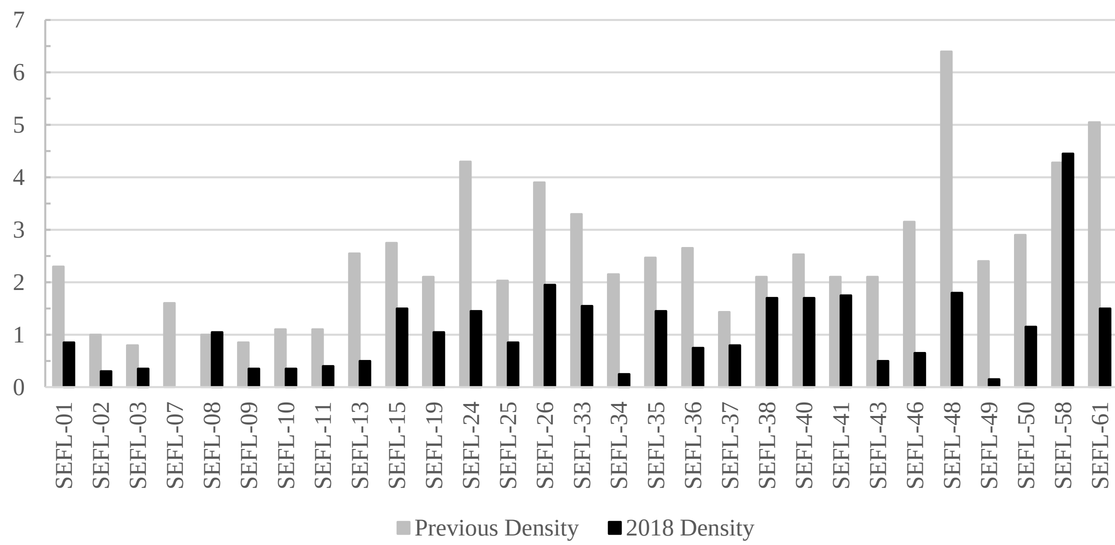

Figure 9. Coral density (/m²) by site from the previous survey (gray) versus the 2018 survey (black).

Table 8. Descriptive stats of the 29 previous site richness (left) and 2018 richness of the same sites (right).

Previous Richness (2005 – 2014) - All	
Mean	8.3
Standard Error	0.57
Median	8
Mode	9
Standard Deviation	3.08
Range	14
Minimum	1
Maximum	15
Count	29

2018 Richness - All	
Mean	4.83
Standard Error	0.38
Median	5
Mode	7
Standard Deviation	2.04
Range	8
Minimum	0
Maximum	8
Count	29

Table 9. Descriptive stats of the 11 previous northern site richness (left) and 2018 richness of the same sites (right).

Previous Richness (2005 – 2014) - North	
Mean	6.27
Standard Error	0.86
Median	7
Mode	7
Standard Deviation	2.87
Range	10
Minimum	1
Maximum	11
Count	11

2018 Richness - North	
Mean	4.36
Standard Error	0.79
Median	5
Mode	7
Standard Deviation	2.62
Range	8
Minimum	0
Maximum	8
Count	11

Table 10. Descriptive stats of the 18 previous southern site richness (left) and 2018 richness of the same sites (right).

Previous Richness (2005 – 2014) - South	
Mean	9.56
Standard Error	0.60
Median	9
Mode	9
Standard Deviation	2.55
Range	11
Minimum	4
Maximum	15
Count	18

2018 Richness - South	
Mean	5.11
Standard Error	0.38
Median	5.5
Mode	6
Standard Deviation	1.60
Range	5
Minimum	2
Maximum	7
Count	18

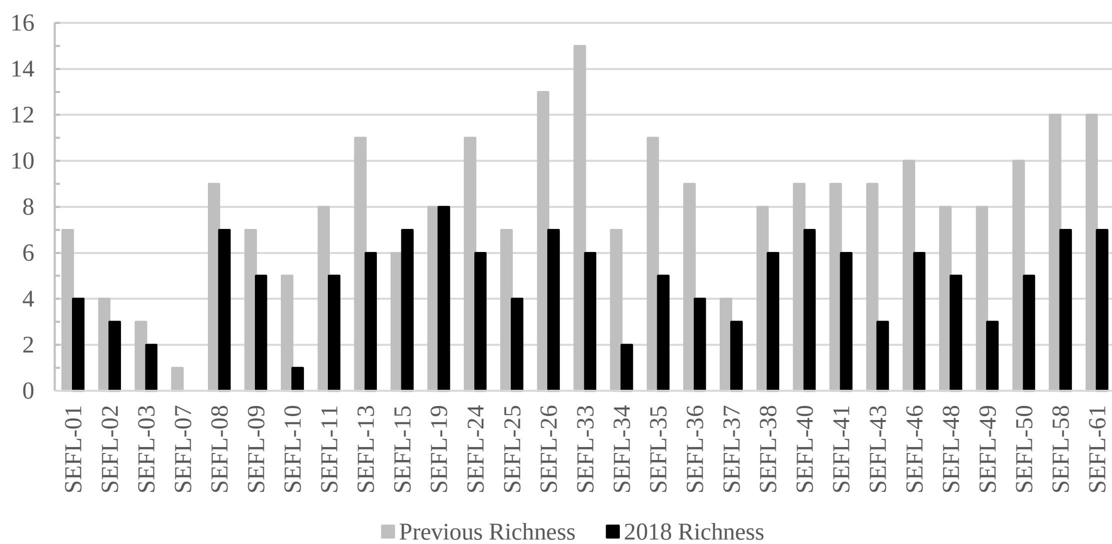

Figure 10. Coral richness (number of species) by site from the previous survey (gray) versus the 2018 survey (black).

Table 11. Total number of corals and the number of hurricane Irma impacts as well as impact prevalence from the DRM surveys.

		Counts				Prevalence				
Coral Species	Total	Abrasion	Dislodged	Broken	Sediment	Abrasion	Dislodged	Broken	Sediment	Total
Acropora cervicornis	9		7			0%	78%	0%	0%	77.8%
Agaricia lamarcki	3					0%	0%	0%	0%	0.0%
Colpophyllia natans	1					0%	0%	0%	0%	0.0%
Dichocoenia stokesi	7				2	0%	0%	0%	29%	28.6%
Eusmilia fastigiata	2					0%	0%	0%	0%	0.0%
Helioseris cucullata	1					0%	0%	0%	0%	0.0%
Madracis auretenra	10					0%	0%	0%	0%	0.0%
Montastraea cavernosa	141				2	0%	0%	0%	1%	1.4%
Madracis decactis	16					0%	0%	0%	0%	0.0%
Meandrina meandrites	5					0%	0%	0%	0%	0.0%
Mycetophyllia spp	5					0%	0%	0%	0%	0.0%
Oculina sp.	1					0%	0%	0%	0%	0.0%
Orbicella faveolata	9		1			0%	11%	0%	0%	11.1%
Orbicella franksi	1					0%	0%	0%	0%	0.0%
Porites astreoides	342	3	3		7	1%	1%	0%	2%	3.8%
Pseudodiploria clivosa	14				1	0%	0%	0%	7%	7.1%
Porites porites	38	1	2	2	1	3%	5%	5%	3%	15.8%
Pseudodiploria strigosa	11				2	0%	0%	0%	18%	18.2%
Solenastrea bournoni	18				1	0%	0%	0%	6%	5.6%
Scolymia spp.	1					0%	0%	0%	0%	0.0%
Solenastrea hyades	1					0%	0%	0%	0%	0.0%
Stephanocoenia intersepta	201	1	5	1	10	0%	2%	0%	5%	8.5%
Siderastrea spp.	270	2	4	0	7	1%	1%	0%	3%	4.8%
Undaria agaricites	58	1	1			2%	2%	0%	0%	3.4%
Grand Total	**1165**	**8**	**23**	**3**	**33**	**1%**	**2%**	**0%**	**3%**	5.8%

Table 12. Total Hurricane Irma impacts of all sites from rover diver surveys. The target species are highlighted in bold.

All				Number of Impacted Colonies by Impact Type			
Species	Total Colonies >25cm	Number of Impacted Colonies	Impact Prevalence	Buried Colonies	Fractured Colonies	Sheared Colonies	Dislodged Colonies
Acropora cervicornis	**16**	**5**	**31.3%**		**4**		**1**
Agaricia lamarcki	1	0	0%				
Colpophyllia natans	**9**	**5**	**55.6%**	**5**			
Diploria labyrinthiformis	**4**	**1**	**25.0%**				**1**
Dichocoenia stokesi	1	1	1				1
Helioseris cucullata	1	0	0%				
Madracis auretenra	100	0	0%				
Montastraea cavernosa	**561**	**42**	**7.5%**	**7**	**7**	**1**	**27**
Madracis decactis	19	0	0%				
Madracis formosa	1	0	0%				
Mycetophyllia lamarckiana	3	0	0%				
Meandrina meandrites	**1**	**0**	**0%**				
Orbicella annularis	**1**	**1**	**100%**				**1**
Orbicella faveolata	**82**	**17**	**20.7%**	**2**	**6**		**9**
Orbicella franksi	**4**	**0**	**0%**				
Porites astreoides	33	3	9.1%	1	1		1
Pseudodiploria clivosa	66	7	10.6%		1		6
Pseudodiploria strigosa	**39**	**12**	**30.8%**	**7**	**2**		**3**
Solenastrea bournoni	35	4	11.4%		1		3
Stephanocoenia intersepta	40	13	32.5%	11			2
Siderastrea radians	1	0	0%				
Siderastrea siderea	15	6	40.0%	4			2
Undaria agaricites	5	0	0%				
Grand Total	**1038**	**117**	**11.3%**	**37**	**22**	**1**	**57**
Target Spp. Total	**717**	**83**	**11.6%**	**21**	**19**	**1**	**42**

Table 13. Total Hurricane Irma impacts of North sites from rover diver surveys. The target species are highlighted in bold.

North				Number of Impacted Colonies by Impact Type			
Species	Total Colonies >25cm	Number of Impacted Colonies	Impact Prevalence	Buried Colonies	Fractured Colonies	Sheared Colonies	Dislodged Colonies
Agaricia lamarcki	1	0	0%				
Dichocoenia stokesi	0	0	-				
Helioseris cucullata	1	0	0%				
Madracis auretenra	100	0	0%				
Montastraea cavernosa	**198**	**3**	**1.5%**		**1**		**2**
Madracis decactis	19	0	0%				
Madracis formosa	1	0	0%				
Mycetophyllia lamarckiana	3	0	0%				
Orbicella faveolata	**2**	**0**	**0%**				
Orbicella franksi	**1**	**0**	**0%**				
Porites astreoides	22	0	0%				
Pseudodiploria clivosa	47	7	14.9%		1		6
Pseudodiploria strigosa	**3**	**0**	**0%**				
Solenastrea bournoni	5	1	20.0%		1		
Siderastrea radians	1	0	0%				
Siderastrea siderea	5	0	0%				
Undaria agaricites	5	0	0%				
Grand Total	**414**	**11**	**2.7%**		**3**		**8**
Target Spp. Total	**204**	**3**	**1.5%**		**1**		**2**

Table 14. Total Hurricane Irma impacts of South sites from rover diver surveys. The target species are highlighted in bold.

South				Number of Impacted Colonies by Impact Type			
Species	Total Colonies >25cm	Number of Impacted Colonies	Impact Prevalence	Buried Colonies	Fractured Colonies	Sheared Colonies	Dislodged Colonies
Acropora cervicornis	**16**	**5**	**31.3%**		**4**		**1**
Colpophyllia natans	**9**	**5**	**55.6%**	**5**			
Diploria labyrinthiformis	**4**	**1**	**25.0%**				**1**
Dichocoenia stokesi	1	1	100%				1
Montastraea cavernosa	**363**	**39**	**10.7%**	**7**	**6**	**1**	**25**
Meandrina meandrites	**1**	**0**	**0%**				
Orbicella annularis	**1**	**1**	**100%**				**1**
Orbicella faveolata	**80**	**17**	**21.3%**	**2**	**6**		**9**
Orbicella franksi	**3**	**0**	**0%**				
Porites astreoides	11	3	27.3%	1	1		1
Pseudodiploria clivosa	19	0	0%				
Pseudodiploria strigosa	**36**	**12**	**33.3%**	**7**	**2**		**3**
Solenastrea bournoni	30	3	10.0%				3
Stephanocoenia intersepta	40	13	32.5%	11			2
Siderastrea siderea	10	6	60.0%	4			2
Grand Total	**624**	**106**	**17.0%**	**37**	**19**	**1**	**49**
Target Spp. Total	**513**	**80**	**15.6%**	**21**	**18**	**1**	**40**

4. CONCLUSIONS

This study achieved its goals to characterize the present condition of corals in southeast Florida (SE FL). This study presents valuable information on how hurricane Irma and the recent coral disease have affected the populations. The analysis with all sites combined shows that hurricane impacts on corals were quite low. This is not a surprising result given the low density and small sizes of corals. That is not to say there were no hurricane impacts. Although 82.3% (51/62) of the sites were listed as Tier 3 (minimal impact/ triage not needed), there were nine sites listed with at least some Tier 2 damage (moderate impact/secondary priority if resources allow after Tier 1). Site 33 was listed as 100% Tier 2 and Site 30 was 100% Tier 1. Site 30 had some especially impressive impacts which included large (2 - 5 m) slabs of fractured hardbottom that was lifted and thrown several meters eastward atop other hardbottom. In at least one case, this affected a 1 – 2 m *Orbicella faveolata* colony that was mostly covered leaving only the very top exposed (Figure 11). The rest of the coral was covered by reef slabs and bleached. It would have cost several thousand dollars to free this one coral and give it a chance to recover amidst other corals with rampant disease. It was decided, however, that triage efforts were not a priority for SE Florida because of the ongoing disease.

Figure 11. Large slabs of reef toppled by hurricane Irma at Site 30.

One day of triage was conducted at a dense *Acropora cervicornis* patch (DAP-08) by Nova Southeastern University and The Florida Aquarium to stabilize many coral fragments and collect loose debris (mostly gorgonians). Lack of capacity and weather deterred further triage attempts for several months.

Coral disease is still present in SE Florida at a relatively high prevalence. The rover diver surveys found 11.4% total disease prevalence across all sites (243/2130) infecting 43.3% of the species found. This differed between the north and south surveys with the south having a higher prevalence. This is not surprising considering the south has more reef area and more corals. Twenty-nine out of the 62 sites were chosen because they had high coral values in past surveys. Mean density and richness at these sites were considerably lower than their historic values with a 57.2% and 42.2% decrease respectively. This indicates that the coral disease has profoundly changed the coral populations throughout the system and continues to do so.

Perhaps the most striking result was the lack of certain species in the 2018 DRM surveys that were previously much larger contributors to the coral population. Precht et al. (2016) recently reported that disease reduced the population densities of *Eusmilia fastigiata*, *Meandrina meandrites,* and *Dichocoenia stokesi* to <3% of their initial densities and *Colpophyllia natans*, *Pseudodiploria strigosa*, *Diploria labyrinthiformis,* and *Orbicella annularis* to <25% of their initial densities. Although not a direct comparison, our study found very low numbers of all of these species. We found 36 individuals of all these species combined out of 1,165 colonies (3.1%). Of course, these percentages are affected by the site allocation and surveyed habitats and vary depending on the distribution of surveys across regions and habitat types. However, a quick comparison of the percentages of each species to the total in the southern sites to those of the 2004 annual monitoring data in Broward County (Gilliam et al. 2004) shows drastic differences in the populations that likely go beyond any bias in survey differences (Table 15).

Since 2004, *Montastrea cavernosa* decreased from contributing 18.8% of the total coral population to 6.9%. *Siderastrea spp*. (*S. radians* and *S. siderea* combined) dropped from 31.8% to 23.8%. *Solenastrea bournoni* dropped from 6% to 1.2%. *Meandrina meandrites* dropped from 3.1% to 0.2%. *Dichocoenia stokesii* dropped from 2.3% to 0.8%. And *Colpophyllia natans* dropped from 0.5% to 0.1%. Conversely, *Porites astreoides* increased from 15.2% of the population to 32.7%. *Stephanocoenia intersepta* increased from 12.2% to 19.7%. *Porites porites* increased from 1.3% to 4.3%. And *Undaria agaricites* increased from 1.7% to 5%.

These data support the idea that the Florida Reef Tract is becoming more homogenous and dominated by eurytopic, generalist species that can tolerate a wider range of environmental conditions (Burman et al. 2012). However this disease event contradicts the notion that the present assemblages are stable because they have "withstood a number of recent perturbations, including thermal stress and disease" (Burman et al. 2012). In each example above, the species that decreased in total percentage of the population were of corals that are known to have been affected by the white plague disease, whereas the species that increased in percentages to the total coral population were unaffected species. After moving through the more vulnerable species, the disease is now affecting hardier species thought to be more resistant to stress like *Montastrea cavernosa* and *Siderastrea siderea*.

Table 15. The percentage of coral species to the total number found in the 2004 Broward Monitoring surveys (Gilliam et al. 2004) and this study.

Species	2004 Broward Monitoring	2018 Disease Surveys
Siderastrea siderea	21.77%	18.98%
Montastrea cavernosa	18.82%	6.89%
Porites astreoides	15.24%	32.66%
Stephanocoenia intersepta	12.23%	19.66%
Siderastrea radians	9.99%	4.86%
Solenastrea bournoni	6.02%	1.24%
Meandrina meandrites	3.07%	0.23%
Dichocoenia stokesii	2.30%	0.79%
Orbicella faveolata	1.98%	0.79%
Madracis decactis	1.92%	0.68%
Agaricia agaricites	1.73%	4.97%
Porites porites	1.28%	4.29%
Acropora cervicornis	1.22%	1.02%
Cladocora arbuscula	0.58%	0.00%
Colpophyllia natans	0.51%	0.11%
Diploria clivosa	0.32%	1.02%
Diploria strigosa	0.32%	0.90%
Mycetophyllia spp	0.19%	0.23%
Eusmilia fastigiata	0.13%	0.11%
Diploria labyrinthiformis	0.13%	0%
Scolymia cubensis	0.13%	0%
Oculina diffusa	0.06%	0%
Phyllangia americana	0.06%	0%
Agaricia lamarcki	0%	0.23%
Solenastrea hyades	0%	0.11%
Orbicella franksi	0%	0.11%
Helioseris cucullata	0%	0.11%

Although there has been considerable loss in colony density and richness at the highest coral sites and the population demographics have changed, there are still many corals that are seemingly yet unaffected by the disease or have exhibited resilience. It is important that actions are taken to curtail this disease quickly so that the remaining population can stabilize and recovery and restoration efforts can begin. There should be continued focus on the remaining corals because they are apparently resistant to the disease and perhaps better acclimated to the stressful conditions over the past several years. Below are a series of recommendations for future focus on coral disease in SE Florida.

5. RECOMMENDATIONS

Recommendation 1*: Continue ongoing efforts to determine the disease agent/etiology and investigate how to prevent its spread and/or treat corals to resist the disease.* FDEP CRCP and FWC are conducting workshops and phone calls to coordinate many coral and disease experts with managers. These efforts should continue.

Recommendation 2*: Analyze the coral disease data collected throughout the remaining FRT collected as part of the NOAA hurricane response effort to get a reef-wide understanding of the disease.* In the fall or 2017, NOAA conducted a cruise across the Florida Keys from Biscayne to Key West utilizing the same methodology as described in this report. These data contain valuable information on coral disease prevalence, location, coral density, richness, condition, and sizes. The data should be compiled and analyzed along with this report to provide an understanding of the present coral population condition throughout the FRT.

Recommendation 3*: Compile all available previously collected data at the survey sites across the FRT and analyze for community impacts.* This report utilized a previous dataset compilation by Fauth to analyze total density differences between 29 sites in SE FL. The analyses were informative, but limited. Density by species and coral size information could be more informative in understanding how the coral population demographics were affected by the disease and Hurricane Irma. This could be in tandem with Recommendation 2, where the data compilation and analyses include replicate sites across all 2017/2018 disease and Irma surveys.

Recommendation 4*: Conduct disease mitigation strategies to help save large and/or threatened species.* The largest corals have the highest reproductive capacity and therefore provide the most benefit to save. There are over 115 documented corals in SE Florida greater than 2 m in diameter and possibly many more that have yet-to-be visited. Most of these are the threatened species *Orbicella faveolata,* a mounding, reef-building species. These corals should be periodically visited to monitor their condition and if disease outbreaks occur, they should be targeted for disease intervention efforts.

Recommendation 5*: Conduct restoration efforts to aid in coral population recovery to previous levels.* Once the disease has passed and prevalence is very low, coral restoration efforts should be conducted to improve the probabilities of reproductive success and regain coral diversity and density in the system.

Recommendation 6*: Conduct yearly, randomized surveys throughout SE Florida to monitor the disease prevalence.* Two randomized yearly monitoring programs are conducted in SE Florida, NCRMP and FRRP DRM. Managers should coordinate with these efforts (and supplement where necessary) to ensure the appropriate disease information is being collected throughout the system and ensure someone is responsible for providing a relevant analysis that can be used for making management decisions. This includes expanding the survey protocols to include a rover diver survey for disease prevalence. The transect size may also need to be increased. Given the drastic drop in the coral population, the likelihood of getting enough corals in a transect to describe the condition of the population at a site has decreased.

6. REFERENCES

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Gilliam DS, Dodge RE, Spieler RE, Jordan LKB, Monty JA (2004) Marine biological monitoring in Broward County, Florida: Year 4 annual report. Broward County Board of County Commissioners, Fort Lauderdale, FL 92

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7. APPENDIX 1. SURVEY SITE VISITATION INFORMATION.

Site	Latitude	Longitude	County	Survey Date	Survey Team	Previous Study	Previous Survey Year
SEFL-01	27 7.9002	80 8.0418	Martin	November 9, 2017	FAU	FRRP	2014
SEFL-02	27 6.7128	80 7.5330	Martin	November 9, 2017	FAU	FRRP	2009
SEFL-03	27 6.3870	80 7.3398	Martin	November 9, 2017	FAU	FRRP	2009
SEFL-04	26 56.6225	80 1.3183	Palm Beach	December 8, 2017	FAU		-
SEFL-	26 55.6467	80 1.8060	Palm Beach	December 8, 2017	FAU		-
SEFL-06	26 53.8641	80 0.9830	Palm Beach	December 8, 2017	FAU		-
SEFL-07	26 43.3238	80 1.9301	Palm Beach	December 7, 2017	FAU	PB Mapping GT	2014
SEFL-08	26 42.6260	80 0.9490	Palm Beach	December 7, 2017	FAU	SECREMP	2013
SEFL-09	26 42.5580	80 1.7088	Palm Beach	December 7, 2017	FAU	Alternate Breakers	2005
SEFL-10	26 41.0370	80 1.8900	Palm Beach	December 7, 2017	FAU	FRRP	2007
SEFL-11	26 40.7100	80 1.0950	Palm Beach	December 7, 2017	FAU	SECREMP	2013
SEFL-12	26 39.1432	80 1.2409	Palm Beach	December 7, 2017	FAU		-
SEFL-13	26 36.6282	80 1.3818	Palm Beach	December 12, 2017	FAU	FRRP	2009
SEFL-14	26 34.8554	80 1.4645	Palm Beach	December 12, 2017	FAU		-
SEFL-	26 31.8678	80 1.7730	Palm Beach	December 12, 2017	FAU	FRRP	2008
SEFL-16	26 31.4131	80 1.9015	Palm Beach	January 10, 2018	FAU		-
SEFL-17	26 30.3258	80 1.9858	Palm Beach	December 12, 2017	FAU		-
SEFL-18	26 29.6155	80 2.2509	Palm Beach	January 10, 2018	FAU		-
SEFL-19	26 28.7652	80 2.5140	Palm Beach	January 10, 2018	FAU	FRRP	2008
SEFL-20	26 27.2298	80 2.7642	Palm Beach	January 10, 2018	FAU		-
SEFL-21	26 24.7112	80 3.0629	Palm Beach	January 10, 2018	FAU		-
SEFL-22	26 22.4700	80 3.2244	Palm Beach	January 10, 2018	FAU		-
SEFL-23	26 19.0985	80 3.5439	Broward	November 1, 2017	NSU/CEG		-
SEFL-24	26 18.6810	80 4.0368	Broward	November 1, 2017	NSU/CEG	FRRP	2008
SEFL-	26 16.5350	80 4.2620	Broward	November 1, 2017	NSU/CEG	BC Monitoring	2011
SEFL-26	26 16.4255	80 3.8189	Broward	November 1, 2017	NSU/CEG	BC Monitoring	2011
SEFL-27	26 14.4888	80 3.9828	Broward	November 9, 2017	NSU/NOAA		-
SEFL-28	26 13.2531	80 4.6325	Broward	November 9, 2017	NSU/NOAA		-
SEFL-29	26 13.2199	80 4.1414	Broward	November 9, 2017	NSU/NOAA		-
SEFL-30	26 12.6668	80 5.0748	Broward	November 9, 2017	NSU/NOAA		-
SEFL-31	26 10.8427	80 4.3509	Broward	November 9, 2017	NSU/NOAA		-
SEFL-32	26 10.7630	80 5.1984	Broward	November 9, 2017	NSU/NOAA		-
SEFL-33	26 9.2730	80 5.3130	Broward	November 19, 2017	NSU/FDEP	SECREMP	2013
SEFL-34	26 8.9130	80 5.7048	Broward	November 19, 2017	NSU/FDEP	FRRP	2014
SEFL-	26 8.5040	80 5.4360	Broward	November 19, 2017	NSU/FDEP	Nearshore Mapping	2013
SEFL-36	26 7.4232	80 5.6868	Broward	November 19, 2017	NSU/FDEP	FRRP	2009
SEFL-37	26 4.9120	80 6.2226	Broward	November 10, 2017	NSU/NOAA	BC Monitoring	2011
SEFL-38	26 3.8466	80 5.5938	Broward	November 2, 2017	NSU	FRRP	2013
SEFL-39	26 1.6856	80 5.9833	Broward	November 2, 2017	NSU		-
SEFL-40	25 59.5030	80 6.4990	Broward	November 10, 2017	NSU/NOAA	Nearshore Mapping	2013
SEFL-41	25 59.1366	80 6.3030	Broward	November 10, 2017	NSU/NOAA	FRRP	2005

Site	Latitude	Longitude	County	Survey Date	Survey Team	Previous Study	Previous Survey Year
SEFL-42	25 57.9707	80 5.8490	Miami-Dade	November 6, 2017	DERM		-
SEFL-43	25 57.7812	80 6.5028	Miami-Dade	November 6, 2017	DERM	FRRP	2008
SEFL-44	25 55.8005	80 5.3263	Miami-Dade	November 10, 2017	NSU/NOAA		-
SEFL-45	25 55.4250	80 5.9283	Miami-Dade	November 19, 2017	NSU/FDEP		-
SEFL-46	25 53.5866	80 6.4812	Miami-Dade	November 19, 2017	NSU/FDEP	FRRP	2014
SEFL-47	25 52.2269	80 5.6531	Miami-Dade	November 10, 2017	NSU/NOAA		-
SEFL-48	25 51.1860	80 6.2220	Miami-Dade	December 15, 2017	DERM	FRRP	2011
SEFL-49	25 51.1764	80 6.6312	Miami-Dade	December 15, 2017	DERM	FRRP	2011
SEFL-50	25 48.6390	80 5.8620	Miami-Dade	November 7, 2017	DERM/FDEP	Port Miami	2013
SEFL-51	25 47.1982	80 6.3868	Miami-Dade	November 7, 2017	DERM/FDEP		-
SEFL-52	25 44.4414	80 5.3810	Miami-Dade	November 20, 2017	DERM/FDEP		-
SEFL-53	25 42.477	80 6.025	Miami-Dade	November 20, 2017	DERM/FDEP		-
SEFL-54	25 43.8001	80 6.8066	Miami-Dade	November 7, 2017	DERM/FDEP		-
SEFL-55	25 43.6987	80 5.9878	Miami-Dade	November 7, 2017	DERM/FDEP		-
SEFL-56	25 43.3670	80 7.5295	Miami-Dade	November 2, 2017	DERM/FDEP		-
SEFL-57	25 42.1572	80 7.6615	Miami-Dade	November 2, 2017	DERM/FDEP		-
SEFL-58	25 41.3680	80 5.8250	Miami-Dade	November 2, 2017	DERM/FDEP	Nearshore Mapping	2013
SEFL-59	25 40.9140	80 5.2547	Miami-Dade	November 7, 2017	DERM/FDEP		-
SEFL-60	25 40.7770	80 7.3947	Miami-Dade	November 2, 2017	DERM/FDEP		-
SEFL-61	25 40.5078	80 5.9082	Miami-Dade	November 2, 2017	DERM/FDEP	FRRP	2008
SEFL-62	25 39.5120	80 7.9290	Miami-Dade	November 2, 2017	DERM/FDEP		-

8. APPENDIX 2. A SERIES OF MAPS THAT SPATIALLY ILLUSTRATE THE DATA.

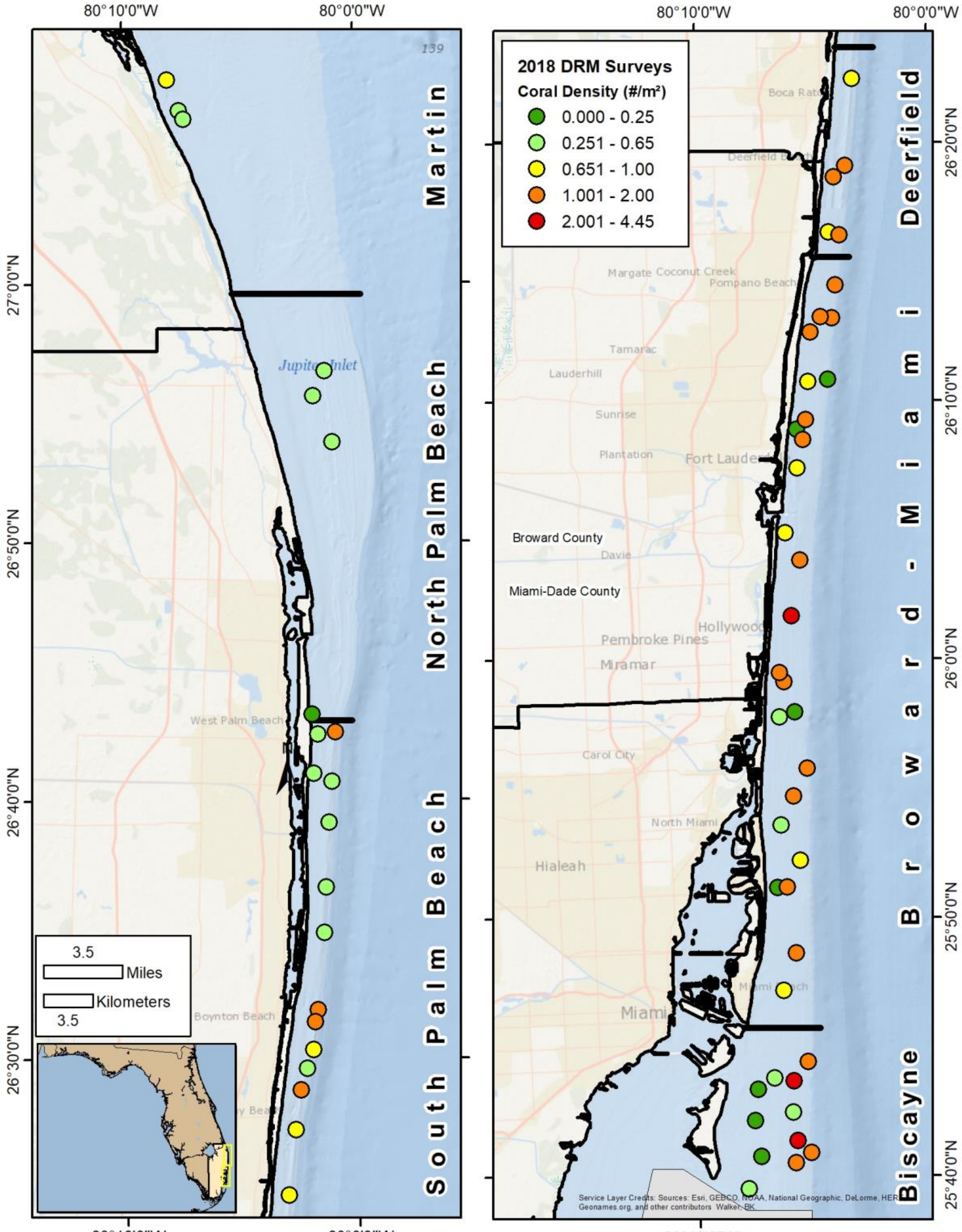

Figure A-1. Map illustrating the coral density at each site from the 2018 DRM surveys.

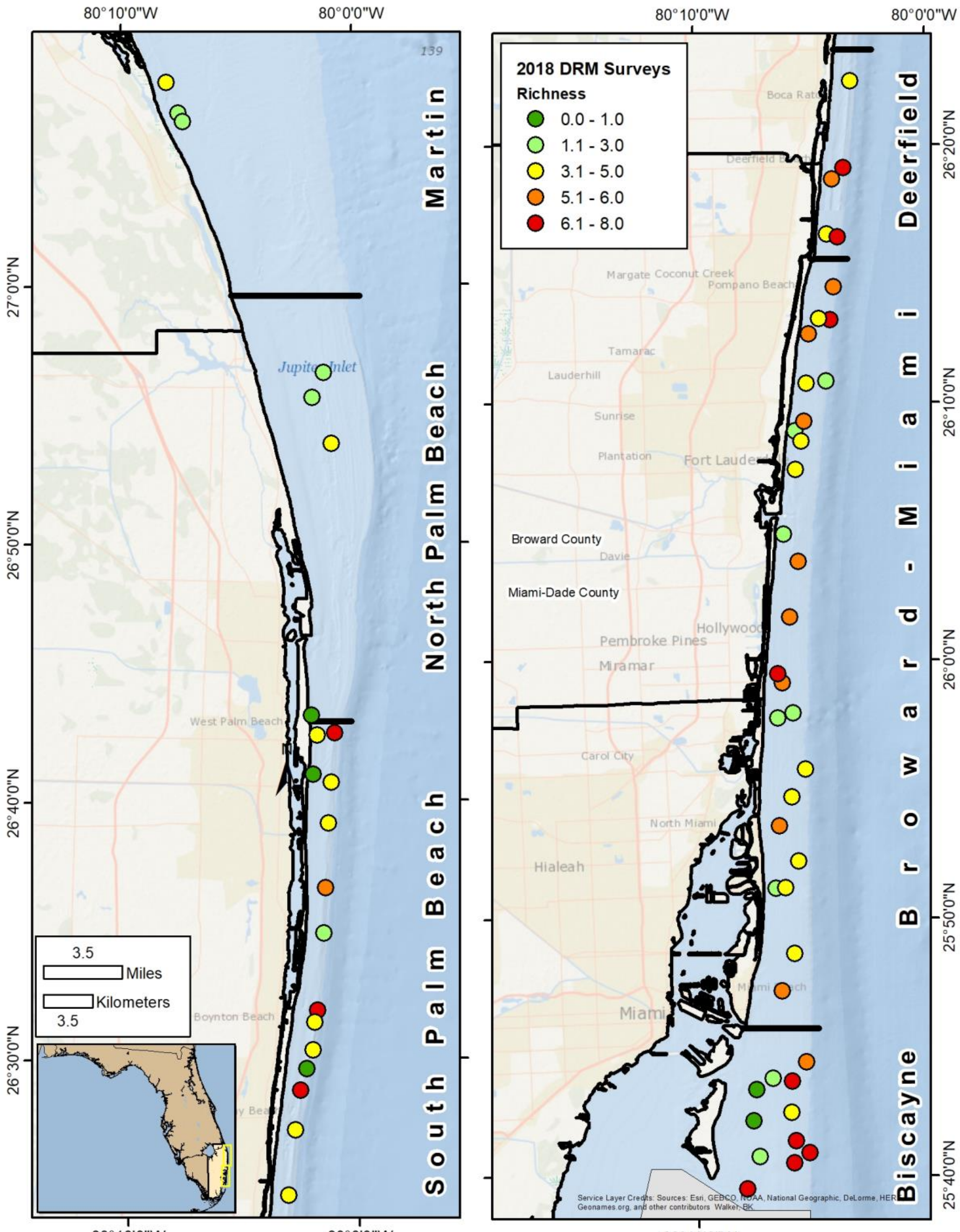

Figure A-2. Map illustrating the coral richness at each site from the 2018 DRM surveys.

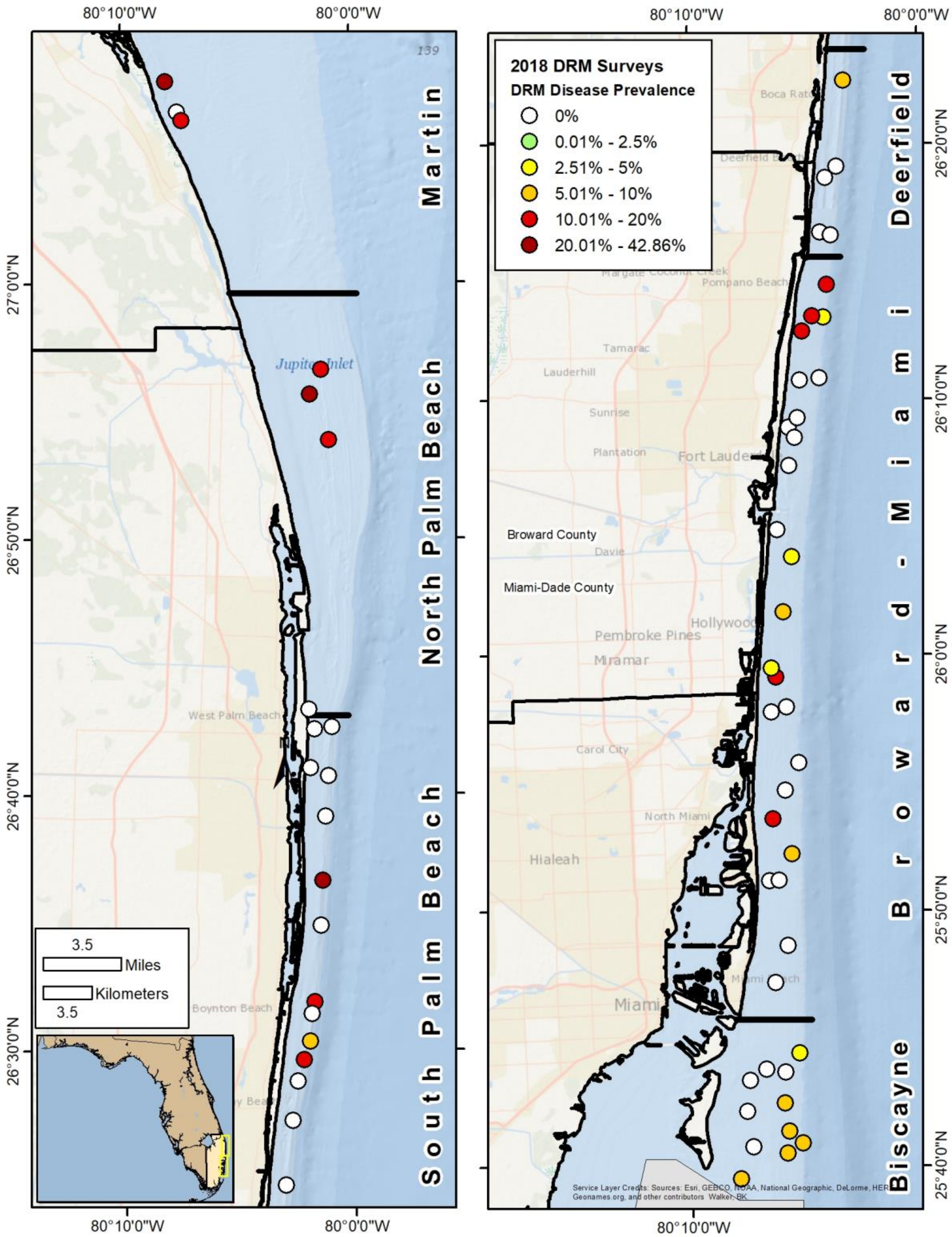

Figure A-3. Map illustrating the coral disease prevalence at each site from the 2018 DRM surveys.

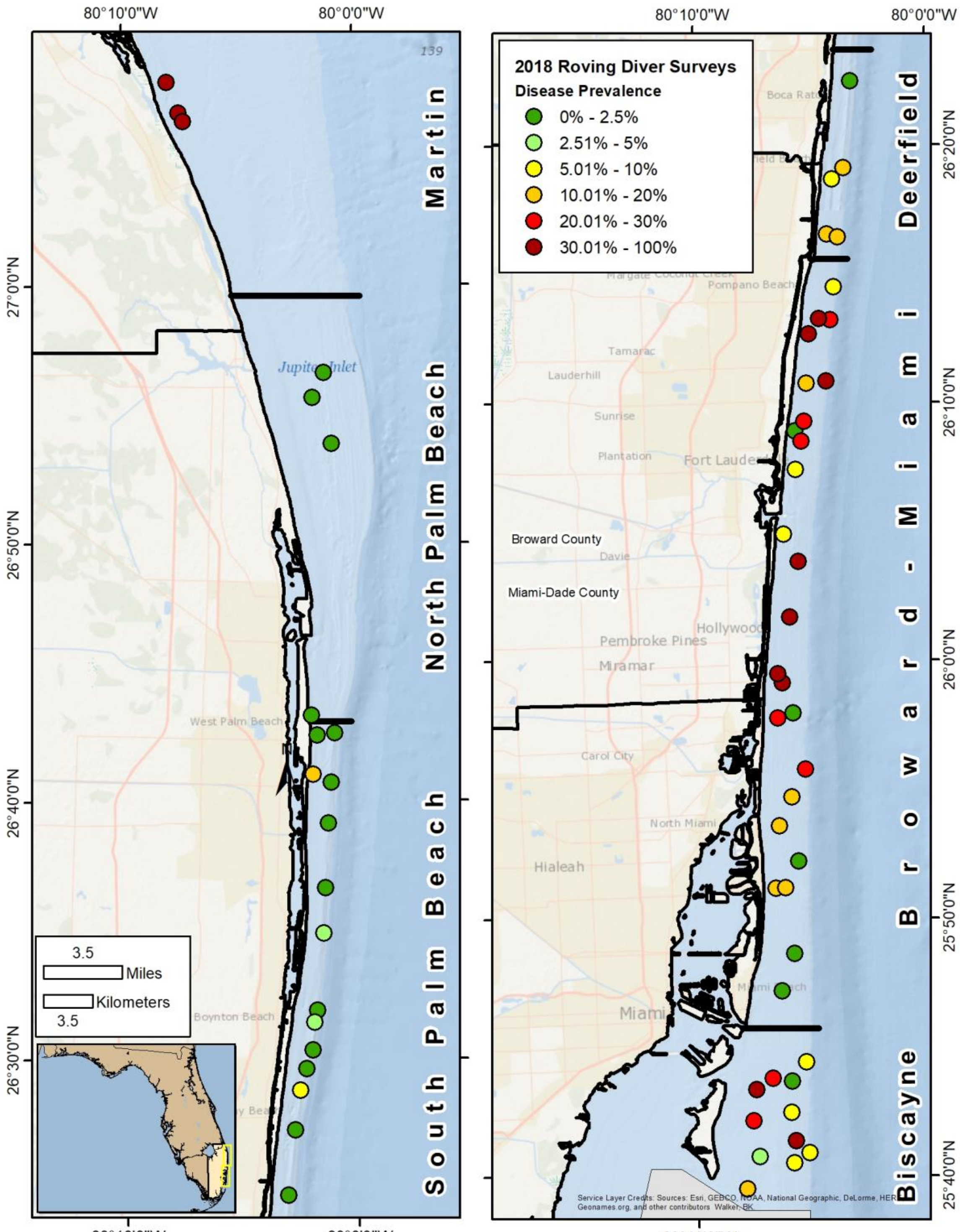

Figure A-4. Map illustrating the coral disease prevalence at each site from the 2018 roving diver surveys.

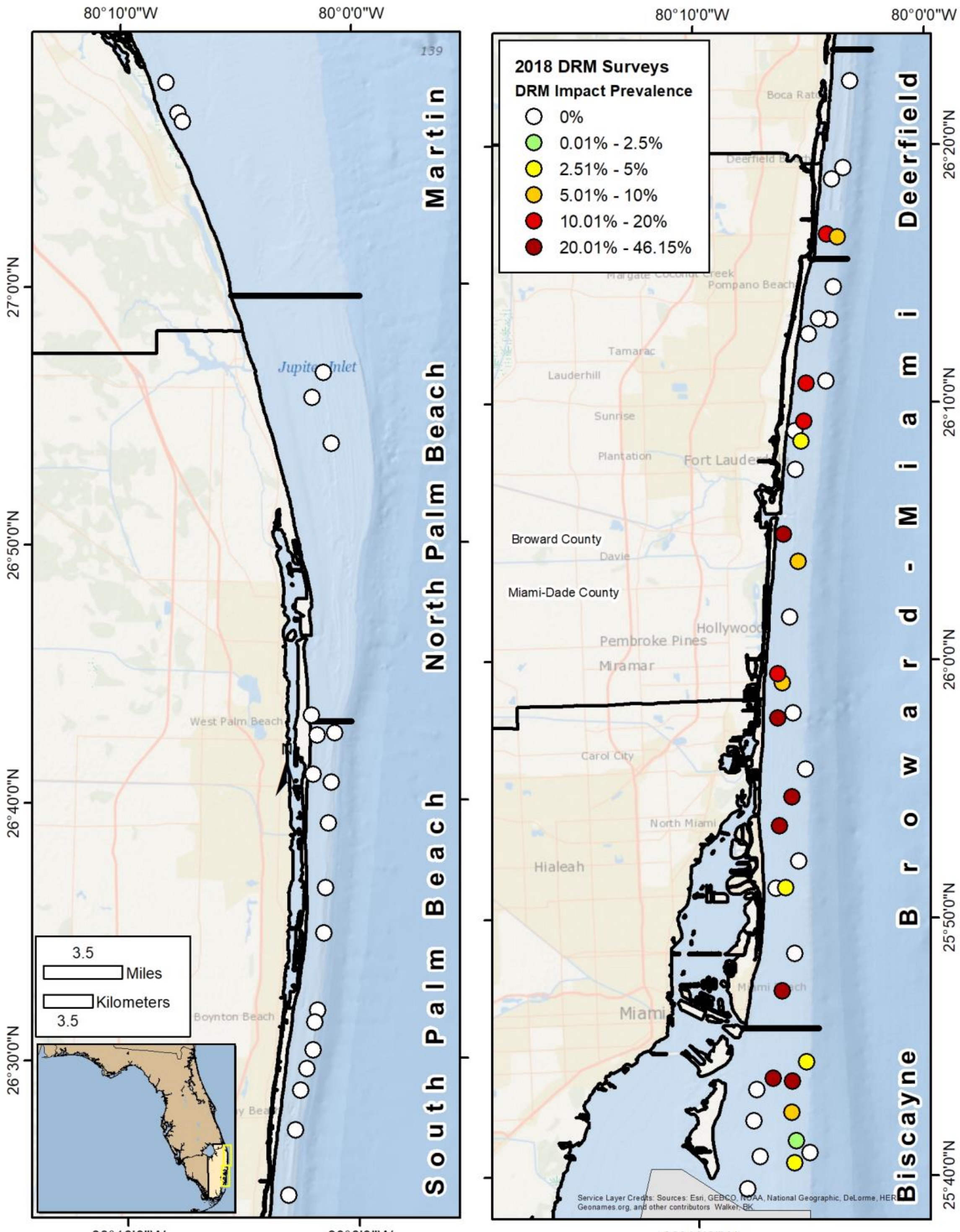

Figure A-5. Map illustrating the coral impact prevalence at each site from the 2018 DRM surveys.

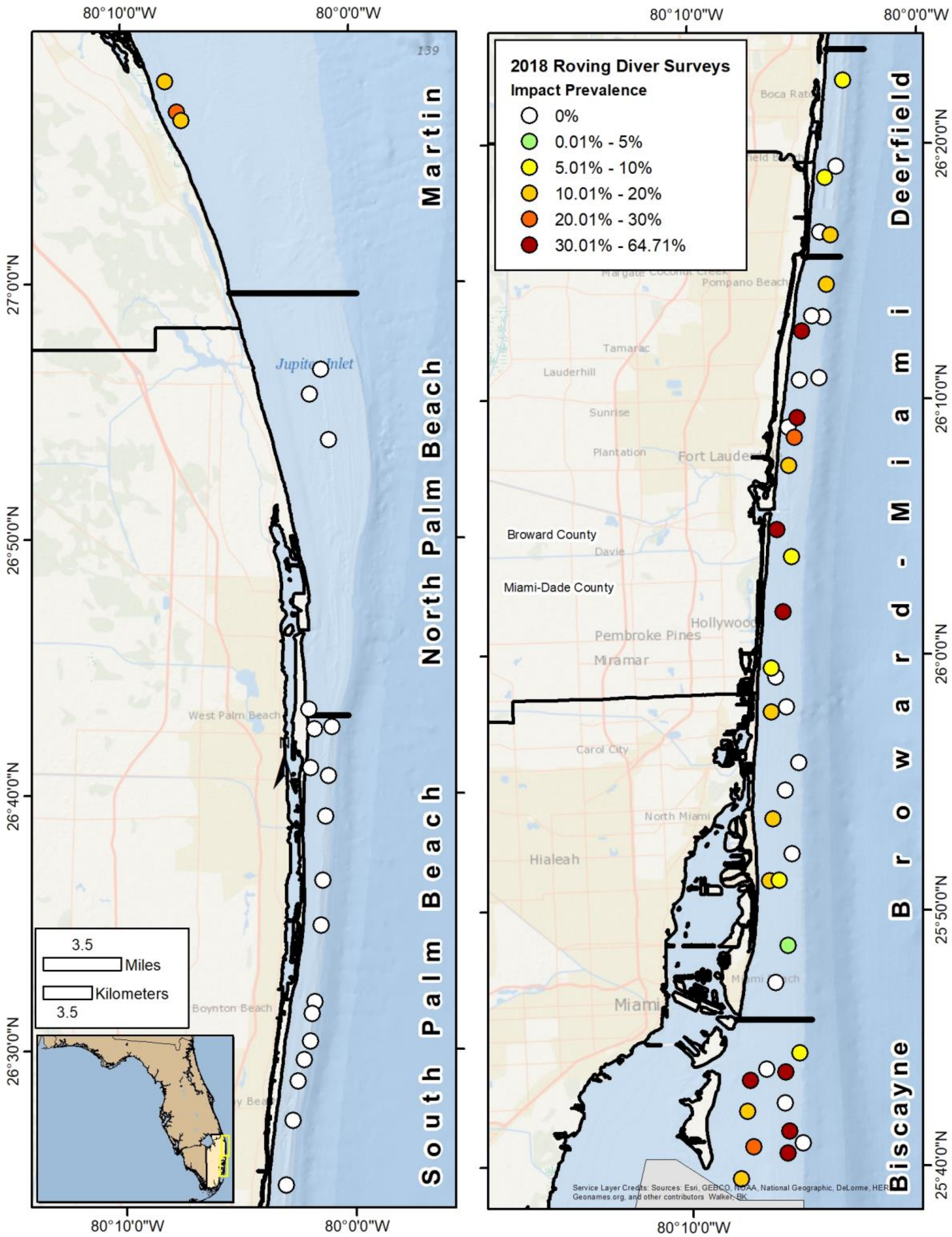

Figure A-6. Map illustrating the coral impact prevalence at each site from the 2018 roving diver surveys.

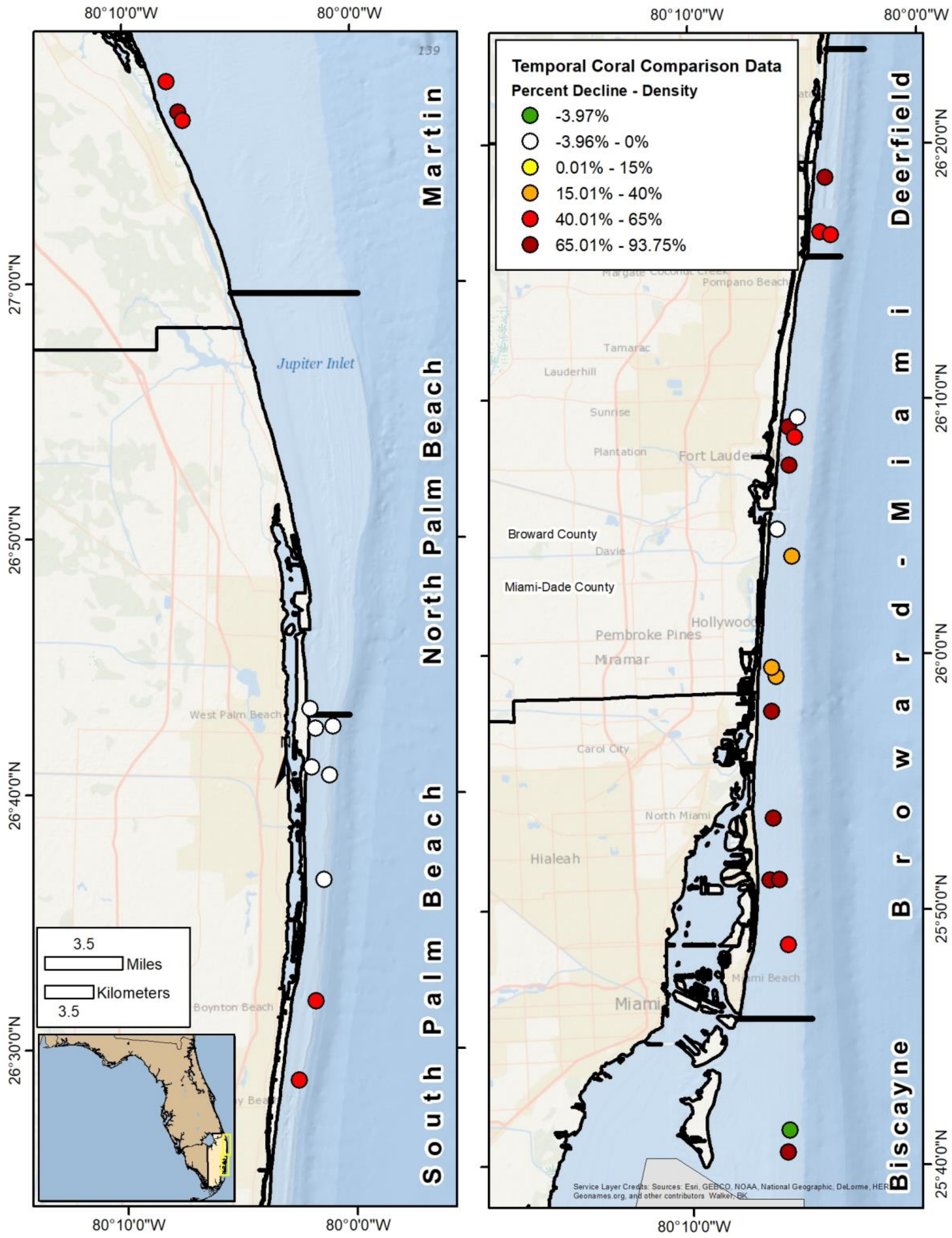

Figure A-7. Map illustrating the percentage of decline of coral density at the high-coral sites between historical surveys and the 2018 DRM surveys.

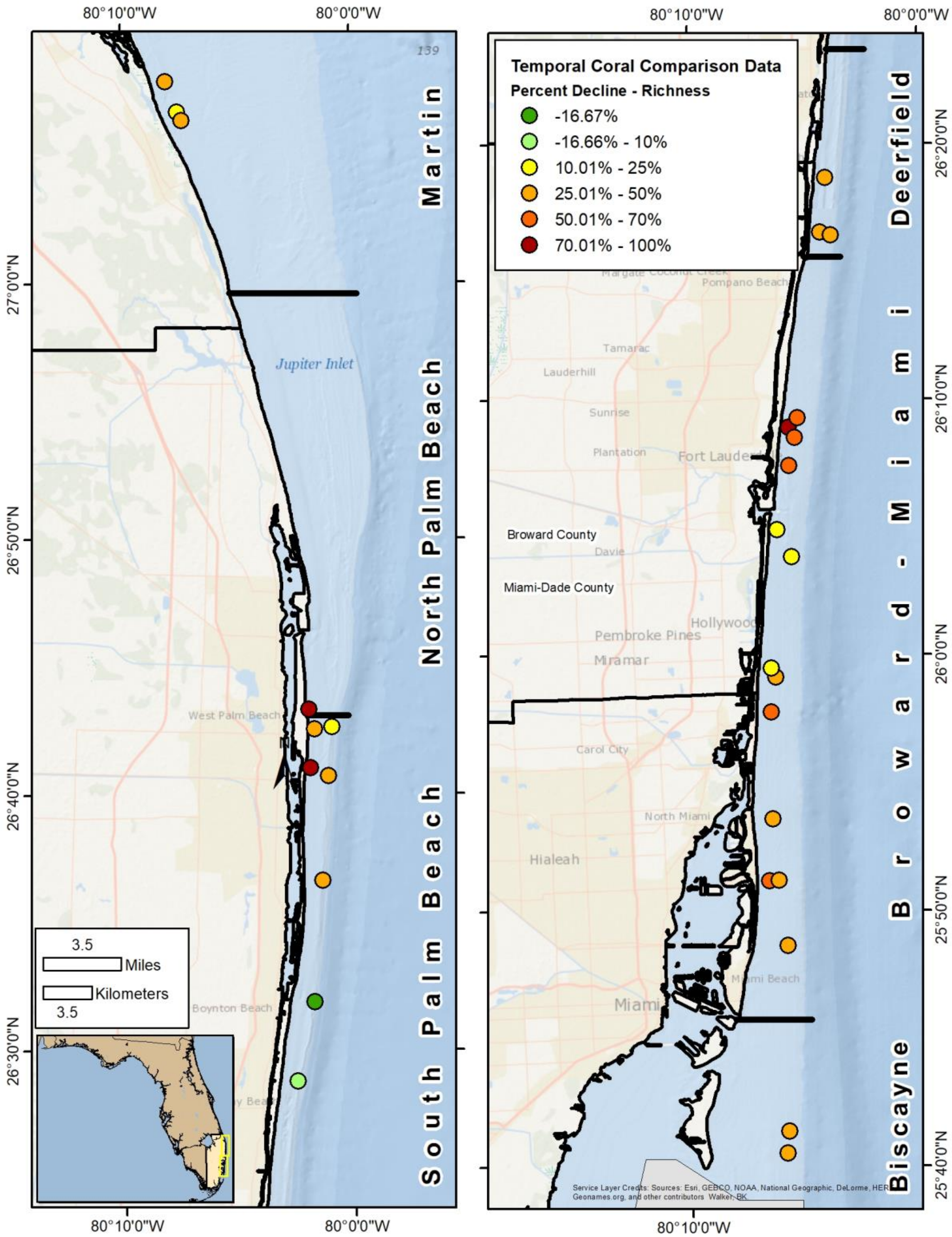

Figure A-8. Map illustrating the percentage of decline of coral richness at the high-coral sites between historical surveys and the 2018 DRM surveys.