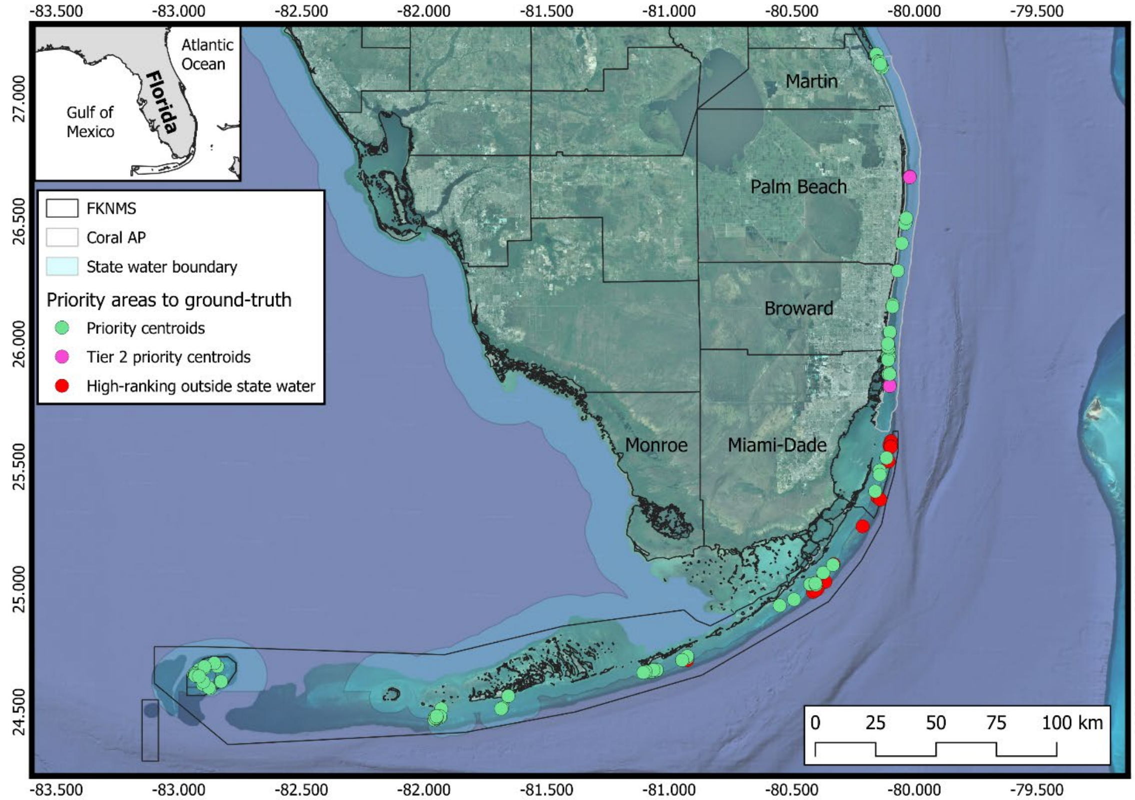
Ground-truthing and Selection of Florida's Coral Reef Restoration & Recovery (FCR3) Initiative's Restoration Sites



Ground-truthing and Selection of Florida's Coral Reef Restoration & Recovery (FCR3) Initiative's Restoration Sites

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Management Summary

Florida's Coral Reef (FCR) has seen significant coral population declines due to a combination of global, regional, and local factors. In conjunction with reducing stressors, restoration is required for the recovery of the coral populations. Governor DeSantis directed the establishment of Florida's Coral Reef Restoration and Recovery (FCR3) Initiative in 2023 with Executive Order 23-06 to support the long-term recovery of FCR by 2050. In FY 25-26, we used environmental and ecological data to select the best 25% of Tier 1 focal areas for in water ground-truthing. Here, we developed standard operating procedures to capture key ecological and topographic metrics predicted to enhance restoration success and conducted ground-truthing surveys at priority focal areas. We quantified key metrics from these surveys to calculate ranking scores for each priority focal areas and used these to guide recommendations for Tier 3 FCR3 Initiative sites. Ground-truthing surveys were conducted throughout FCR. Coral cover, density and diversity were highest in Monroe County with >20% coral cover at several sites. Comparatively, Martin County had no priority coral species, few adult corals and exceptionally low coral cover, despite having the highest juvenile coral density. *Montastraea cavernosa* was the most abundant priority species at most sites. *Acropora cervicornis* was found at most sites in Broward and Miami-Dade counties, at two sites in the Lower Keys and one in Palm Beach. Tier 3 FCR3 initiative sites were recommended for Martin, Palm Beach, Broward and Miami-Dade counties where the data and expert opinion suggest priority species restoration will be most successful. Martin County sites are furthest south of St. Lucie inlet on shallow shoreward ridges. Palm Beach sites are on the outer reef offshore Boynton Beach. Broward sites are on the inner reef offshore Dania Beach and Hollywood/Hallandale. Miami-Dade sites are on the inner reef offshore Sunny Isles and Surfside.

Executive Summary

Florida’s Coral Reef (FCR) has seen significant coral population declines due to a combination of global, regional, and local factors. In conjunction with reducing stressors, restoration is required for the recovery of the coral populations which underpin this ecologically and economically important resource. Governor DeSantis directed the establishment of Florida's Coral Reef Restoration and Recovery (FCR3) Initiative in 2023 with Executive Order 23-06 to support the long-term recovery of FCR by 2050. In FY 25-26, we used environmental and ecological data to evaluate Tier 1 focal areas and select the best 25% for in water ground-truthing. Here, we conducted ground-truthing surveys at these priority focal areas and at specific areas projected to provide extensive benefit to shoreline protection. We then ranked priority focal areas to recommend two sites per county as Tier 3 sites for FCR3 Initiative activities.

To evaluate priority focal areas, standard operating procedures (SOP) were developed to capture key ecological and topographic metrics predicted to enhance restoration success. This required capturing multiple data types. Hence, two types of ground-truthing surveys were conducted at each site: benthic transect surveys and a roving diver survey. Benthic transect surveys included a Line Point Intercept survey to quantify benthic cover, a belt transect survey to calculate coral demographic metrics, and relief height measurements. Each roving diver survey included a priority coral species survey and an overall site assessment. Nineteen key metrics were quantified from the surveys, normalized by county to ensure comparable scale and combined to calculate a ranking score per site. Site recommendations generally followed the ranking scores, although in some cases we suggest alternative focal areas and provide reasoning.

Ground-truthing surveys were conducted throughout FCR and evaluation was completed in Martin, Palm Beach, Broward and Miami-Dade counties. Benthic and stony coral community structure varied spatially as expected, with a latitudinal gradient in coral cover and diversity. Coral cover, density and diversity were highest in Monroe County with >20% coral cover at several mid-channel patch reefs in the Middle and Lower Keys. Comparatively, Martin County had no priority coral species, few adult corals and exceptionally low coral cover, despite having the highest juvenile coral density. *Montastraea cavernosa* was the most abundant priority species at most sites. *Colpophyllia natans*, *Diploria labyrinthiformis*, *Orbicella* spp. and *Pseudodiploria strigosa* were found in lower abundance at most sites, except at some Monroe County sites where *C. natans* and *Orbicella* spp. were relatively abundant. *Acropora cervicornis* was found at most sites in Broward and Miami-Dade counties, with one very highest density site in Miami-Dade, as well as at two sites in the Lower Keys and one in Palm Beach.

Tier 3 FCR3 initiative sites were recommended for Martin, Palm Beach, Broward and Miami-Dade counties where the data and expert opinion suggest restoration of priority species will be most successful. Martin County sites are furthest south of St. Lucie inlet on shallow shoreward ridges. Palm Beach sites are on the outer reef offshore Boynton Beach. Broward sites are on the inner reef offshore Dania Beach and Hollywood/Hallandale. Miami-Dade sites are on the inner reef offshore Sunny Isles and Surfside.

1. Introduction

Florida's Coral Reef (FCR) has seen significant coral population declines due to a combination of global, regional, and local factors. These include elevated ocean temperatures resulting in more frequent coral bleaching events, coral disease, poor water quality associated with land-based sources of pollution, and other natural and human impacts (Jones et al. 2022; Jones and Gilliam 2024; Eakin et al. 2026). Most recently, the ongoing coral disease outbreak stony coral tissue loss disease (SCTLD) has spread across the entire reef, affecting more than half of Florida's 45 species of reef-building corals (Papke et al. 2024).

To put this incredibly valuable natural resource on the road to recovery, we must address the stressors that are threatening it, while simultaneously developing and deploying intervention and restoration methods for critical reef species populations and reef conditions. One approach without the other is not enough to save FCR. However, with appropriate resourcing and targeted conservation actions, we will recover this ecosystem.

FCR's restoration community began outplanting branching corals in the early 2000's to address the significant loss of coral cover that has occurred over the past several decades. In 2019, "Mission: Iconic Reefs" was launched by the National Oceanic Atmosphere Administration (NOAA) to restore seven reefs in the Florida Keys. This comprehensive approach uses the best available restoration science to improve ecological function and restore diverse, reef-building corals within Florida Keys National Marine Sanctuary (FKNMS).

In recognition of the ecological and economic importance of FCR, Governor DeSantis directed the establishment of Florida's Coral Reef Restoration and Recovery (FCR3) Initiative in 2023 with Executive Order 23-06. The FCR3 Initiative aims to develop the infrastructure, technology, skilled workforce, and logistics necessary by 2050 to support the long-term recovery of no less than 25% of FCR. Through facilitating an unprecedented, evidence-based propagation and outplanting program conducted by the state and its partners, FCR will be restocked with hardy populations of native corals and other keystone species to re-establish and strengthen natural reproduction, dispersal, and recruitment patterns. Through strategic design and siting of restoration projects, FCR3 Initiative will also prioritize enhancing shoreline protection and strengthening Southeast Florida's coastal economy. Final site selection for FCR3 Initiative will identify 5-10 priority reefs (no less than one per county) and a detailed restoration plan, in the mold of "Mission: Iconic Reefs" project taking place within the FKNMS, will be created for each site.

Florida's Coral Reef Resilience Program (FCRRP) identified Tier 1 focal areas for coral restoration using coral larval connectivity, species persistence and colony size-frequency distribution scores (FCRRP, 2024). These efforts also excluded locations defined by reef managers that are at risk of human impact and hence not feasible for restoration. Following this in Fiscal Year 2024-2025, project #C50C5C utilized best available data, expert opinion and stakeholder feedback to narrow the Tier 1 focal areas to determine what geographic areas should be evaluated for the FCR3 Initiative. This geographic focus area determination project used biological and environmental datasets to calculate metrics predicted to enhance restoration success from in situ, modeled and satellite data. These metrics were used to evaluate focal areas from the Tier 1 four species model, consisting of *Acropora cervicornis*, *Montastraea cavernosa*, *Orbicella* spp, and *Pseudodiploria strigos*a, to choose 25% of the focal areas for ground-truthing (Jones and Gilliam 2025). One hundred and seven Tier 1 focal areas chosen for ground-truthing within state waters were called priority focal areas (Figure 1). A further 19 tier 1 focal areas outside state waters were recommended for ground-truthing due to ranking highly in the modeling process (Jones and Gilliam 2025). Concurrently, an FCRRP-led Tier 2 project assessed whether any additional Tier 1 focal areas should be ground-truthed based upon their projected benefit to shoreline protection (FCRRP, 2025). This identified an additional five focal areas (2 in Palm Beach, 1 in Broward and 2 in Miami-Dade) to ground-truth. Combined, geographic focus areas determination and the Tier 2 restoration plan identified 131 focal areas to ground-truth, spanning 751.68 hectares across FCR (Figure 1).

This project developed standard operating procedures (SOP) to capture key ecological and topographic metrics, trained researchers, and conducted ground-truthing surveys. The SOP was developed using the latest restoration science knowledge (Banister and van Woesik 2021; Shaver et al. 2022; Jones and Gilliam 2024; Silliman et al. 2024; Goergen et al. 2025; Humanes et al. 2025) to quantify metrics predicted to enhance restoration success. This required capturing multiple data types, including topography, benthic community composition, and coral demography. These metrics were combined with an overall site assessment to determine the highest-ranking 1-2 sites per county to conduct FCR3 Initiative activities.

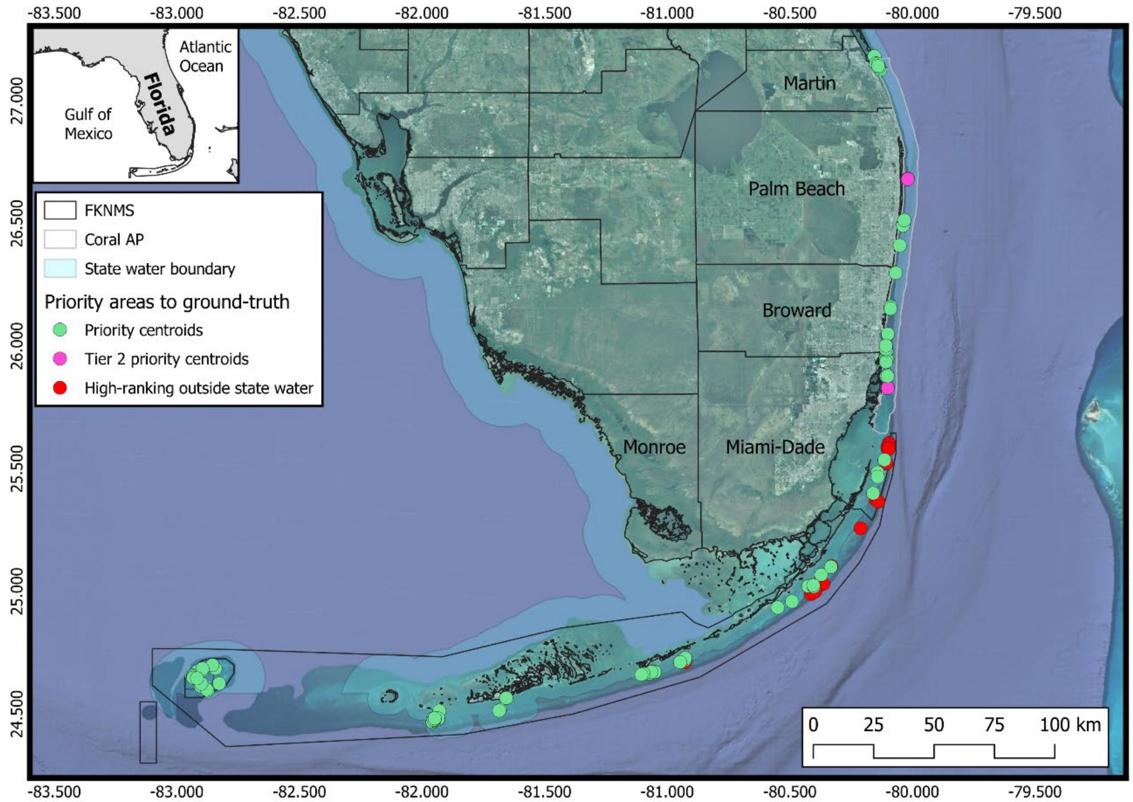

Figure 1. The 131 ground-truthing sites across Florida's Coral Reef. These include priority focal areas for ground-truthing within state waters (green points), Tier 2 priority centroids (pink points) and high-ranking focal areas outside state waters (red points). Inset: Florida peninsula.

2. Methods

2.1. Ground-truthing

All priority focal area sites were predetermined and included a centroid position with GPS coordinates and a polygon which defined the site. Prior to starting the ground-truthing survey, lidar and bathymetry data were used to assess potential habitat within the polygon, including any defining features, such as reef ledges, patch reefs, or raised areas. GPS positions were altered if needed to maximize the chance of diving on suitable reef. Divers then descended at the centroid position, or altered GPS position, briefly explored the area immediately around the centroid position and determined a representative area to survey. If suitable habitat was not found at the centroid position, surveyors attempted to locate coral habitat by searching in a 50 m radius around the GPS coordinate. If no suitable habitat was found within this area the surveyors expanded their search or attempted a different section of the polygon. If no suitable habitat was found this was recorded. Site names correspond to the site location initially established in Tier 1 and the habitat where the site is found. RGSH corresponds to sites located on the nearshore ridge shallow habitat. LIRI corresponds to sites located on the inner reef. LIRM corresponds to sites located on the middle reef. LIRO corresponds to sites located on the outer reef. SPGR corresponds to sites located on spur and groove habitat.

Two types of ground-truthing surveys were conducted: benthic transect surveys and a roving diver survey. Each benthic transect survey included a Line Point Intercept (LPI) survey, a belt transect survey, turf algal height measurements and relief height measurements. Each roving diver survey included a priority coral species survey, *Diadema antillarum* survey and an overall site assessment.

Focal areas in Broward County were surveyed first. For priority focal areas smaller than 5 hectares in size (approximately 250 m x 250 m), a minimum of 3 benthic transect surveys and 1 roving diver survey were conducted. For priority focal areas greater than 5 hectares in size, a minimum of 6 benthic transect surveys and 2 roving diver surveys were conducted in different sections of the polygon. After completing surveys in Broward County, this was refined such that the size threshold for doubling the survey effort was increased to 10 hectares in size. These changes were made after finding the most effective use of time for ground-truthing. This included studying the lidar data in GIS more extensively prior to the survey dive to determine the variability in topography within a focal area, using the onboard depth sounder to refine the initial GPS location for a survey dive, spending the first 5-15 minutes of a dive searching within the polygon to find a representative starting area for the surveys, positioning transects to capture any variability in topography and increasing the roving diver survey length from 30 minutes to 45 minutes to cover more of the polygon.

Due to the paucity of stony corals in Martin County, local knowledge of the area was used in conjunction with the onboard depth sounder to determine the initial search location in the large focal areas. Then a more extensive search of the focal area polygon was conducted before transects were positioned and surveys commenced.

2.1.1. Benthic Transect Surveys

Once suitable habitat was found as detailed above, 30 m benthic transects were laid out over reef substrate representative of the site, a minimum of 5 meters apart (see full SOP in supplementary materials for details). Four types of surveys were conducted along each transect: a relief survey which aimed to capture major sources of relief (e.g., reef ledges) and rugosity, an LPI survey which quantified benthic cover, a turf algal height survey, and a coral demographic survey (Figure 2). Relief measurements were taken within alternating 1m^2 subplots (50cm either side of the transect tape) along the entire 30 m x 1 m belt transect. In this the highest relief feature was measured (including live stony corals and *Xestospongia muta*) from the seafloor to the top of the feature.

For the LPI survey, the benthic taxa underneath the transect tape was identified at 25 cm intervals from the start position as detailed in the SOP. Benthic taxa were recorded at minimum to the following categories: Stony Coral (to species), *Millepora* spp., Bare substrate (uncolonized consolidated hardbottom or coral skeleton which is attached to the benthos), Rubble (loose substrate or coral skeleton with grain size > 2.5 cm and moveable), Sand (loose substrate ≤ 2.5 cm grain size and ≥2.5 cm depth), Turf algae: visible algal tufts or filaments, Macroalgae (fleshy algae e.g., *Dictyota* spp., *Halimeda* spp.), Crustose coralline algae (CCA), Seagrass, Branching Gorgonians (basal attachment only, not canopy cover), encrusting Gorgonians, Sponges, *Palythoa caribaeorum,* Other (e.g., hydroids, anemones, corallimorphs, zoanthids other than *P. caribaeorum*, bryozoans, tunicates). At the first 10 points which intercept turf algae, the turf algal height was measured with calipers to the nearest millimeter.

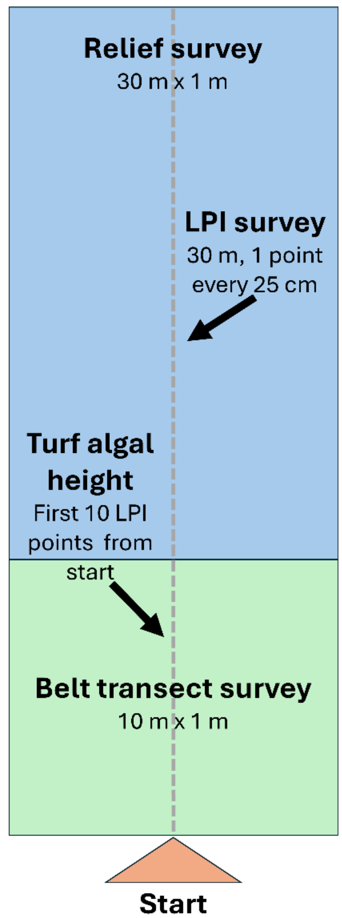

Figure 2. Benthic transect setup. The transect tape (grey dashed line) defines the center point. Belt transects were conducted in the first 10 m x 1 m (0.5 m either side of the transect tape). The line point intercept (LPI) survey was conducted over the full 30 m transect, with turf algal height measurements taken for the first 10 turf algae points. The relief height survey was conducted every other meter at the meter mark in a 1 m^2 box, 50 cm either side of the transect tape (e.g., 0 m to 1 m, then 2 m to 3m).

2.1.2. Belt transect survey

Between the start of the transect and the 10 m mark, a coral demographic belt transect survey was conducted (Figure 2). The belt transect center was defined by the transect tape and the belt transect encompassed 50 cm either side of the transect tape to total 10 m x 1

m. Within the belt transect, every live adult stony coral colony (≥ 4 cm maximum diameter) was recorded to species and measured. Every live stony coral colony juvenile (< 4cm maximum diameter) was tallied to species, or the lowest taxonomic unit.

A live colony was defined as any coral colony with any amount of living tissue within the belt transect. For each adult colony, the maximum diameter and height was measured to the nearest centimeter and colony health status assessed (see SOP for more detail). If isolates of a large colony were found, the maximum diameter of the entire colony was recorded as closely as possible and the percent partial colony mortality estimated. The health status assessment recorded the percentage of old colony mortality, percentage and cause of recent mortality (e.g., disease or predation) and any incidence of bleaching. Juvenile colonies which were not attached to the substrate were not recorded. Unattached adult coral colonies were recorded if they cannot be moved by gentle pressure.

2.1.3. Roving diver survey

One surveyor completed a 45-minute timed swim around the site, starting from the first area of suitable reef habitat and covering as much reef area as possible, where they searched for priority restoration species (*Acropora cervicornis*, *A. palmata*, *Colpophyllia natans*, *Diploria labyrinthiformis*, *Montastraea cavernosa*, *Orbicella* spp., and *Pseudodiploria strigosa*), recorded the abundance of *Diadema antillarum* and conducted an overall site assessment. During the survey, the surveyor tallied by size class all adult priority species colonies observed (≥ 4 cm maximum diameter) and quickly assessed health status. A maximum tally of 100 *Acropora cervicornis* colonies per size class and 50 colonies per species per size class for all other species was implemented due to extremely high colony abundance at some sites. Due to high abundance of certain priority species at some sites, bleaching, disease and predation were tallied by species independently of size class. While completing the roving diver survey, the surveyor conducted an overall site assessment where they assessed the sites suitability for restoration activity. This included noting habitat suitability, the condition of coral colonies and if there was any excessive damage, trash or discarded fishing gear etc. within the surveyed area. The surveyor also recorded in detail any defining features of the site, e.g., high reef complexity, large sand patches (>5 m diameter) etc. Upon completing the assessment, the surveyor, after discussion with the other divers, assigned the site an overall expert rank, on a 1 to 5 scale, where 1 = unsuitable for FCR3 Initiative restoration (e.g., excessive damage or limited available substrate), 3 = suitable for FCR3 Initiative restoration, with some reservations (e.g., multiple large sand patches), 5 = highly recommended for FCR3 Initiative restoration activity.

2.2. Data analysis

Ground-truth survey data was used to calculate quantitative metrics which represented the benthic community and topography at each focal area and could be used to determine the most suitable focal areas to conduct FCR3 Initiative restoration activities. Benthic community composition was averaged per site from the LPI surveys. Mean and range in relief height was calculated to quantify site complexity and rugosity which are predicted to enhance outplant survival (Jones & Gilliam 2024). Pearson's correlation analysis was used to assess whether these metrics were collinear and one needed to be omitted. Mean turf algal height was calculated as this has been shown to influence sediment retention (Tebbett and Bellwood 2020), which is suspected to create a demographic bottleneck, in particular affecting juvenile coral growth and survival (Bauman et al. 2025). Multiple coral demographic metrics were calculated from the belt transect surveys. This included adult coral density, diversity indices, old and recent colony mortality percentages, and disease and predation prevalence. The diversity indices Shannon diversity and Pielou's J for evenness were created independently within each county. Multiple size structure metrics, which reflect disturbance history and coral population health, were also quantified from demographic data. Mean colony diameter and mean colony height were calculated from untransformed data, coefficient of variation (CV =$\log_{10}$(standard deviation)/$\log_{10}$(mean)), skewness and kurtosis were calculated from size-frequency distributions of the $\log_{10}$-transformed maximum colony diameter. The CV reflects the range in colony sizes, skewness, how skewed the size-frequency distribution is and kurtosis, how tailed/peaked the size-frequency distribution is, with a kurtosis value of 3 reflecting a mesokurtic distribution where corals transition through size classes. Finally, the roving diver survey data was used to quantify priority species richness, total priority species abundance, the mean number of size classes occupied by a species and the mean diameter of priority species. Priority species were tallied by size class during surveys, hence mean diameter was calculated by assigning each colony in a size class the midpoint value of the size (e.g., colonies in the 10-20cm size class were all assigned a value of 15 cm). Colonies greater than 91 cm in diameter (the largest size class) were assigned a diameter of 100 cm.

After quantifying all metrics, those determined to have the strongest influence on coral restoration success were selected as ranking metrics (Table 1). Ranking metrics included direct measures of priority species health and survival (e.g., priority species abundance and size), factors previously shown to influence outplant growth and survival (e.g., mean relief height and colony density; Baker et al. 2024), factors which affect a site's suitability for large scale restoration (e.g., amount of available substrate) and those which preliminary data analysis showed represented major variability in the data and would impact restoration activity (e.g., *Palythoa caribaeorum* cover). The size structure metrics, kurtosis and skewness were transformed as appropriate to capture deviation from normality. Kurtosis was converted from a positive linear metric to the distance from the optimal mesokurtic distribution (i.e., the distance from 3). Skewness was converted from a real number with center zero to the distance from zero (i.e., no skew). Bleaching, disease and predation were quantified during both the roving diver survey and the belt transects, however these were not included as final ranking metrics as their prevalence was generally very low and, particularly in the case of predation and disease, only above background levels if *Acropora cervicornis* was present at a site. Further, as bleaching and disease are highly dependent upon the survey timing, percent old mortality was determined to be more representative of partial colony mortality and included as a ranking determinant.

Table 1. Metrics used to rank focal areas and determine Tier 3 focal areas. Metric = evaluation metrics; Data type = type of data used to calculate metric; Influence on restoration = the relationship the metric has with coral restoration (magnitude of effect in evaluation in parenthesis), Rationale = scientific justification for the response of the metric on restoration success. Where applicable, references to support the rationale are numbered and then listed.

Metric	**Survey type**	**Influence on restoration**	**Rationale**	**Reference**
Priority species abundance	Roving diver	Positive (2x)	Recruitment and survival of priority coral species	
Mean priority species colony diameter	Roving diver	Positive (2x)	Supports priority species colony growth	
Species richness	Roving diver	Positive (2x)	Supports coral diversity	
Mean number of size classes represented	Roving diver	Positive (2x)	Supports a range of colony sizes, including sexual recruits and colony growth to large sizes	
Shannon diversity	Belt transect	Positive	Supports coral diversity	
Pielous'J Index	Belt transect	Positive	Supports evenness of species distribution within the community	
All species density	Belt transect	Positive	Supports coral colony survival	Baker et al 2024
Mean colony diameter	Belt transect	Positive	Supports coral colony growth	
Mean colony height	Belt transect	Positive	Supports coral colony growth and influences wave attenuation	
Coefficient of variation	Belt transect	Positive	Supports a range of colony sizes, including sexual recruits and colony growth to large sizes	
Skewness	Belt transect	Negative	Limited recruitment, growth or survival of colonies	Humanes et al 2025
Kurtosis	Belt transect	Negative	Limited colony growth into larger size classes	
Colony mortality	Belt transect	Negative	Indicates high partial colony mortality at site	
Turf algal height	Line point intercept	Negative	Limits recruitment, growth and survival of colonies	Tebbett and Bellwood 2020
Mean relief height	Line point intercept	Positive	Influences water flow and sedimentation. Correlated	Baker et al 2024

			with increased colony survival	
Stony coral cover	Line point intercept	Positive	Supports coral colony growth and survival	
Macroalgal/ cyanobacterial cover	Line point intercept	Negative	Space competitor, constrains coral colony growth	Goergen et al 2025
Palythoa caribaeorum cover	Line point intercept	Negative	Space competitor	Goergen et al 2025
Rubble/ sand cover	Line point intercept	Negative	Related to amount of suitable substrate for restoration activity	Humanes et al 2025

2.3. Focal area evaluation and ranking

Once all focal area ranking metrics had been calculated, each metric was scaled within each county by min-max normalization. A custom function was created in R studio (R Core Team 2024) to scale the value of a metric in a focal area by subtracting the value from the minimum value for the metric and dividing by the range. This gave a linear representation of the data within each county between 0 and 1, which was more suitable for ranking focal areas. The direction and magnitude of influence of each metric on the focal area rank was determined by literature review and expert opinion (Table 1). Most metrics were included in the ranking of each county. *Palythoa caribaeorum* cover was only used to differentiate sites in Miami-Dade County due to high variability in cover there.

The total score a focal area could attain was 16 if it was the top-ranking focal area in a county for all positive metrics and the lowest scoring metric for all negative metrics, and the lowest, -6, if it scored highly on all negatively associated metrics. The overall expert rank on a 1-5 scale was added to the total score to determine the final ranking score for sites. Please note that the raw ranking scores of a site are only comparable to other sites within that county. Principal Component Analysis (PCA) was used to determine the metrics driving dissimilarity between focal areas and support Tier 3 focal area recommendations.

3. Results and site recommendations

3.1. Ground-truthing overview

3.1.1. Benthic community structure

Benthic community structure in most counties was dominated by turf algae (Figure 3), albeit with relatively high spatial variation. Turf algal cover was highest in Martin County (58.8% ±21.6 SD) and lowest in Palm Beach (27.6% ±13.7 SD) where it was only exceeded by macroalgal cover (41.3% ±12.0 SD), which was predominately composed of *Dictyota* spp.. Turf algal height varied widely within each county, but was generally long, ranging from 5.0 mm (±2.9 SD) in Broward to 8.2 mm (±4.6 SD) in Palm Beach. Stony coral cover ranged from 14.0% ±8.6 SD at Tier 2 sites in Monroe County to 1.1% ±1.4 SD at Tier 2 sites in Martin County. Tier 2 sites in Monroe County also had a higher proportion of unconsolidated substrate (sand = 11.8% ±8.6 SD; rubble = 4.0% ±3.2 SD), which exceeded 20% total cover at some sites despite positioning transects on the main patch reef within a polygon.

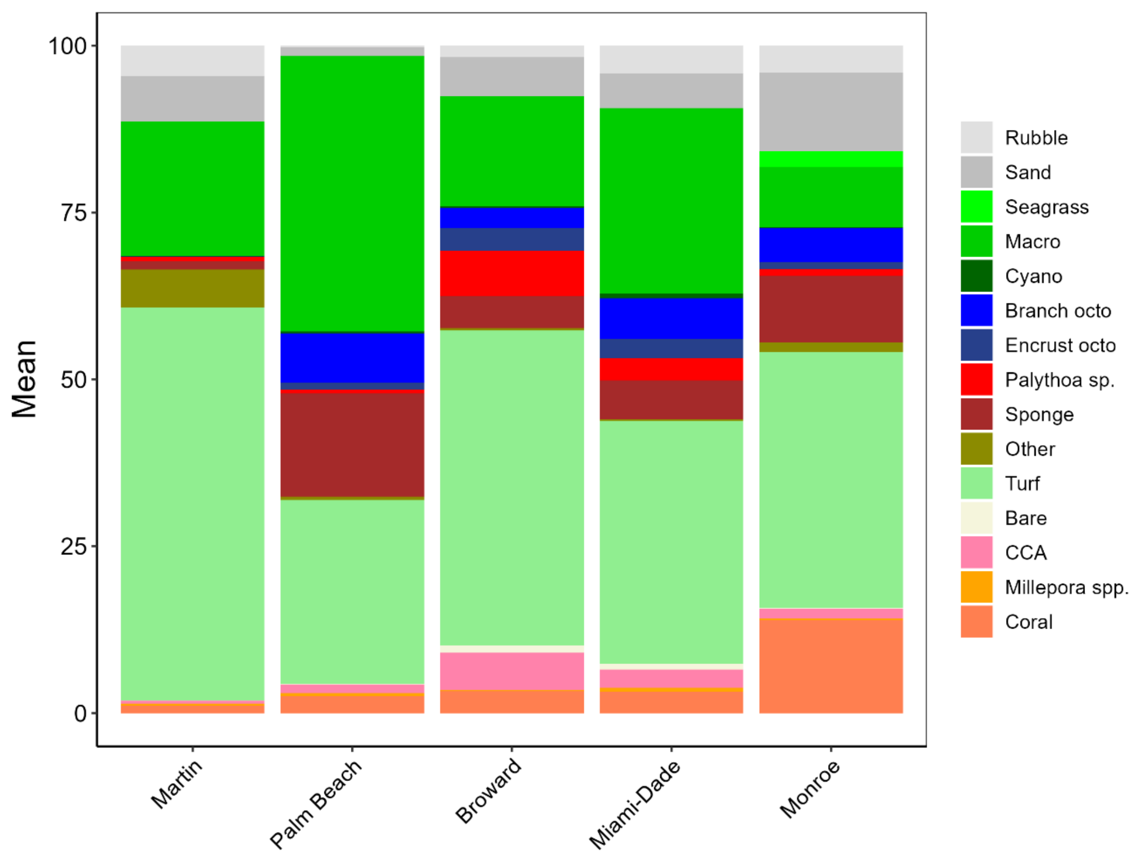

Figure 3. Mean benthic community cover in each county. Colors correspond to major benthic taxonomic group. Note: *Palythoa* sp. refers to *Palythoa caribaeorum*, Encrust octo = encrusting gorgonians, branch octo = branching gorgonians, bare = bare substrate.

3.1.2. Stony coral demography

Adult coral colony density ranged from 2.3 colonies m^{-2} in Martin County to 7.6 colonies m^{-2} in Monroe County. Species richness followed a clear latitudinal gradient. Of the 32 species captured during belt transect surveys, only 8 species were captured in transects in Martin County and two of these, *Isophyllia sinuosa* and the non-native species *Tubastraea coccinea*, were not seen elsewhere. Comparatively, 25 species were found in Monroe County, 21 in each of Broward and Miami-Dade and 15 in Palm Beach. Mean colony diameter also followed a latitudinal gradient, ranging from 6.9 cm in Martin County to 17.6 cm in Monroe County.

Siderastrea siderea was the most abundant adult coral (colonies ≥4 cm diameter) in Martin (1.2 colonies m^{-2} ±0.2 SE), Miami-Dade (0.8 colonies m^{-2} ±0.2 SE) and Monroe counties (3.7 colonies m^{-2} ±0.5 SE; Figure 4). *Porites astreoides* most abundant in Palm Beach (1.0 colonies m^{-2} ±0.2 SE) and Broward (1.5 colonies m^{-2} ±0.2 SE; Figure 4). For both species, mean colony diameter in each county within the Kristen Jacobs Coral Aquatic Preserve (KJCAP) was less than 10 cm, with very few large colonies, but many large *S. siderea* were found at Tier 2 sites in Monroe (colony diameter = 15.7 cm ±0.3 SE). *Pseudodiploria clivosa* was the only larger coral found in Martin County (0.01 colonies m^{-2}) with a mean colony diameter of 16cm.

Priority species were generally rare, and none were found in Martin County, but all except *Acropora palmata* were recorded in belt transects at multiple sites in Broward, Miami-Dade and Monroe counties. *Montastraea cavernosa* were the most abundant priority species found in belt transects, being particularly abundant in Palm Beach (0.5 colonies m^{-2} ±0.04 SE) and Monroe (0.7 colonies m^{-2} ±0.1 SE), although there was a stark difference in mean colony diameter (Palm Beach = 10.7 cm ±0.6 SE, Monroe = 34.9 cm ±1.8 SE). *Acropora cervicornis* was the most abundant priority species in Miami-Dade County (0.14 colonies m^{-2} ±0.1 SE), largely due to very high density at one site with many large colonies (47.7 cm ±3.6 SE). *Orbicella faveolata* (0.1 colonies m^{-2} ±0.04 SE), *O. annularis* (0.1 colonies m^{-2} ±0.07 SE) and *Colpophyllia natans* (0.07 colonies m^{-2} ±0.02 SE) were most abundant in Monroe County, with large colonies (> 50 cm) of each recorded at many of the sites.

Siderastrea siderea was the most abundant juvenile (<4 cm diameter) coral in each county and nearly an order of magnitude more abundant than the next species (Figure 5). Martin County had the highest *S. siderea* juvenile density (4.5 colonies m^{-2} ±1.2 SE), with Broward, Miami-Dade and Monroe counties all having *S. siderea* juvenile densities above 1 colony m^{-2}. Juvenile colonies of most other species were rare. Only 1 juvenile *A. cervicornis* was found, in Miami-Dade County, and *Orbicella* spp. juveniles were only found in Monroe County (0.005 colonies m^{-2} ±0.002 SE). *Colpophyllia natans* juvenile colonies in Monroe were the most common highly SCTLD susceptible species (0.01 colonies m^{-2} ±0.004 SE). In Martin County, the only species that were found as juveniles in belt transects were *S. siderea*, *P. astreoides* and *Phyllangia americana.*

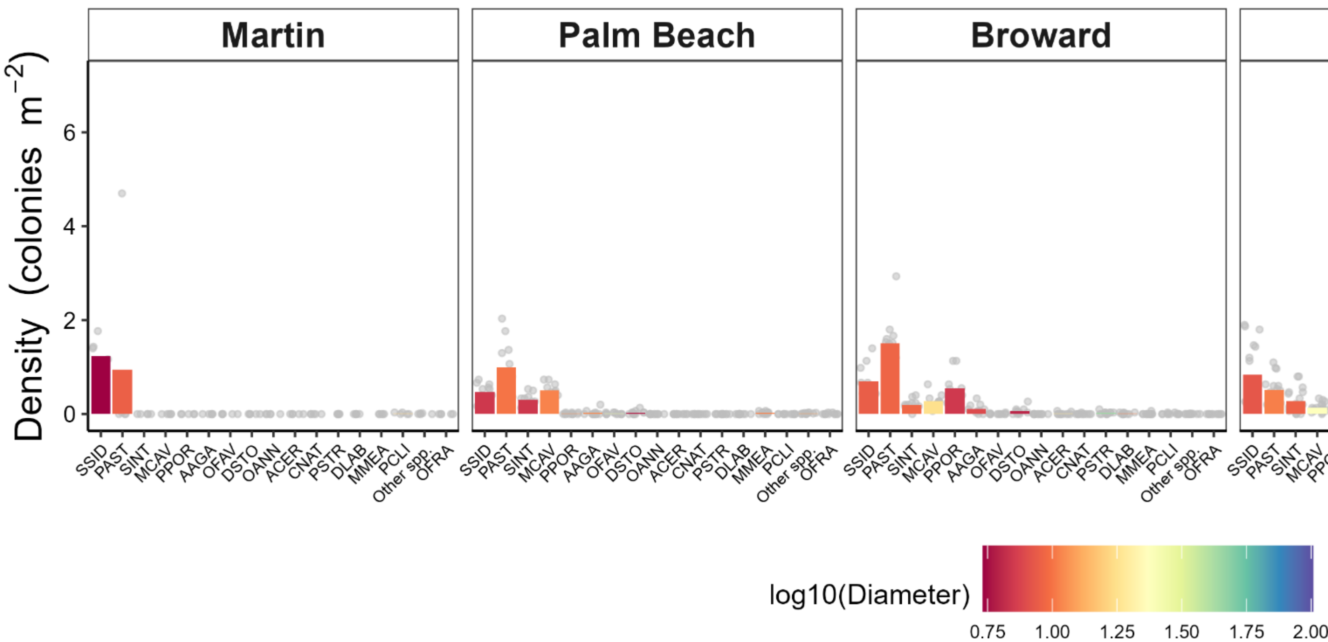

Figure 4. Adult coral species colony density and mean colony diameter (≥ 4cm diameter) captured in belt transects. Each bar represents the mean density of each species, color coded by the $\log_{10}$ transformed mean maximum colony diameter of the species. Bars towards the red spectrum consist primarily of small colonies, yellow bars have some medium sized colonies and blue spectrum bars have larger colonies. For reference, $\log_{10}$ diameter 2 = 100 cm actual mean diameter and $\log_{10}$ diameter 1 = 10 cm actual mean diameter. Grey points show the density of each species at individual sites within a county. Note: not all species were found in each county. See Table S1 for full species list and four-letter abbreviations.

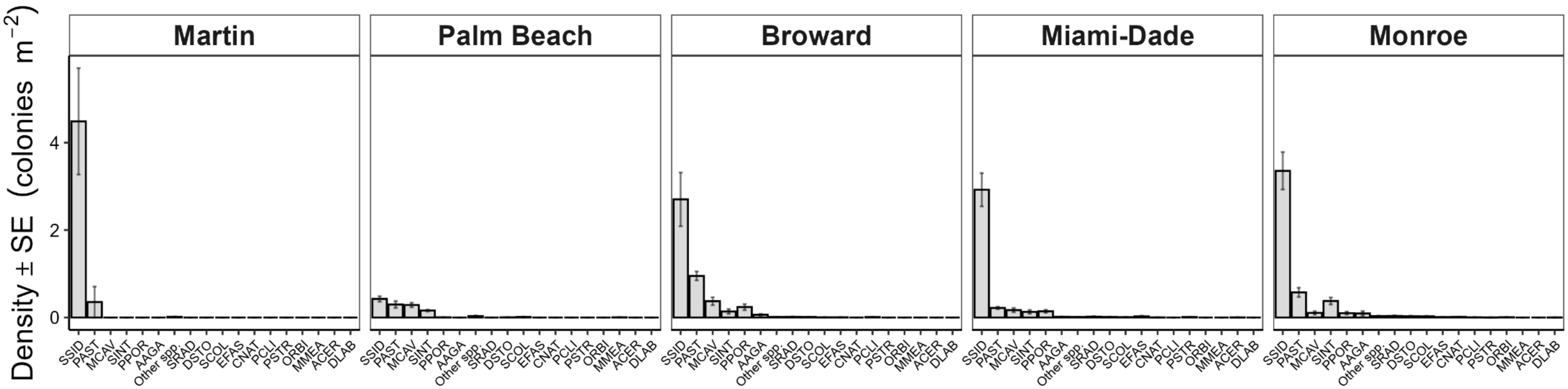

Figure 5. Juvenile coral species colony density (< 4cm diameter) captured in belt transects. Each bar represents the mean density of each species. Note, juveniles of most species were rare and many were not found in any transects within a county, particularly in Martin County. See Table S1 for full species list and four-letter abbreviations.

3.2. Martin County

3.2.1. Results

Six sites were evaluated within Martin County, one north of the St. Lucie Inlet and five to the South (Figure 6). No natural priority coral species were found during roving diver surveys, but healthy *M. cavernosa* and *O. faveolata* outplants were seen near the SECREMP site Martin County 1, indicating the species can survive and grow in that environment. No benthic transect surveys were conducted at site 38_RGSH due to consistently poor visibility, limited substrate and exceptionally few corals suggesting restoration activities would be exceptionally difficult to conduct and that reef-building corals are unlikely to thrive.

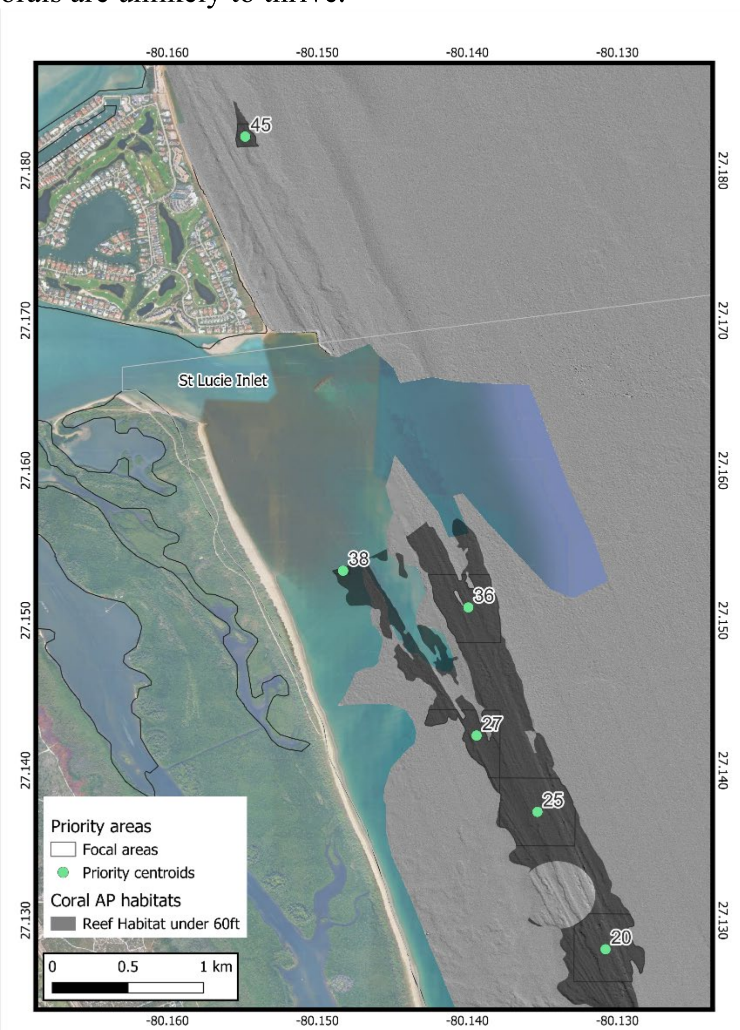

Figure 6. Tier 2 site locations in Martin County, with reef habitat outlined and overlaid on lidar data.

Benthic community structure was algal dominated (Figure 7). Turf algal cover was over 60% at four sites and turf algal and macroalgal cover combined 70% at the other site, 27_RGSH. Turf algal height was also high at every site, particularly 27_RGSH. Stony coral cover was 0% at 27_RGSH and 45_RGSH, but was 3 to 4% on each transect surveyed in 20_RGSH. Octocoral and sponge cover were also low, or 0% at all sites. Nearly 10% of the benthic substrate at site 45_RGSH also consisted of wormrock (recorded in the other category), which would be unsuitable to attach corals to.

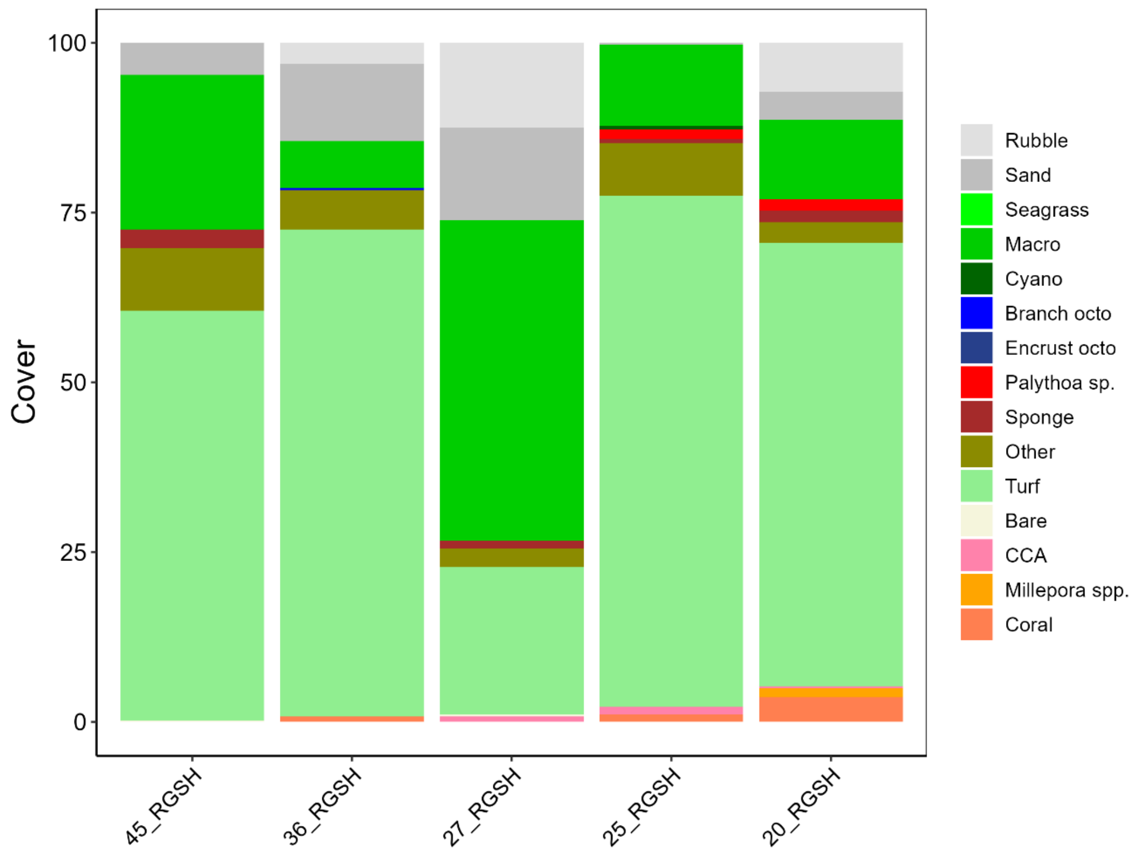

Figure 7. Spatial variation in benthic community composition (percent cover) at each Tier 2 site in Martin County. Sites arranged North to South. Note: *Palythoa* sp. refers to *Palythoa caribaeorum*, Encrust octo = encrusting gorgonians, branch octo = branching gorgonians, bare = bare substrate.

Where stony corals were found, the community was primarily composed of *S. siderea* or *P. astreoides*. Most colonies were small and size-frequency distributions were positively skewed at all sites (Figure 8; Table 2). Only at site 20_RGSH was the size-frequency distribution approaching lognormal and the mean colony diameter close to 10 cm, largely due to some larger *P. astreoides* colonies and a single moderately sized *P. clivosa*.

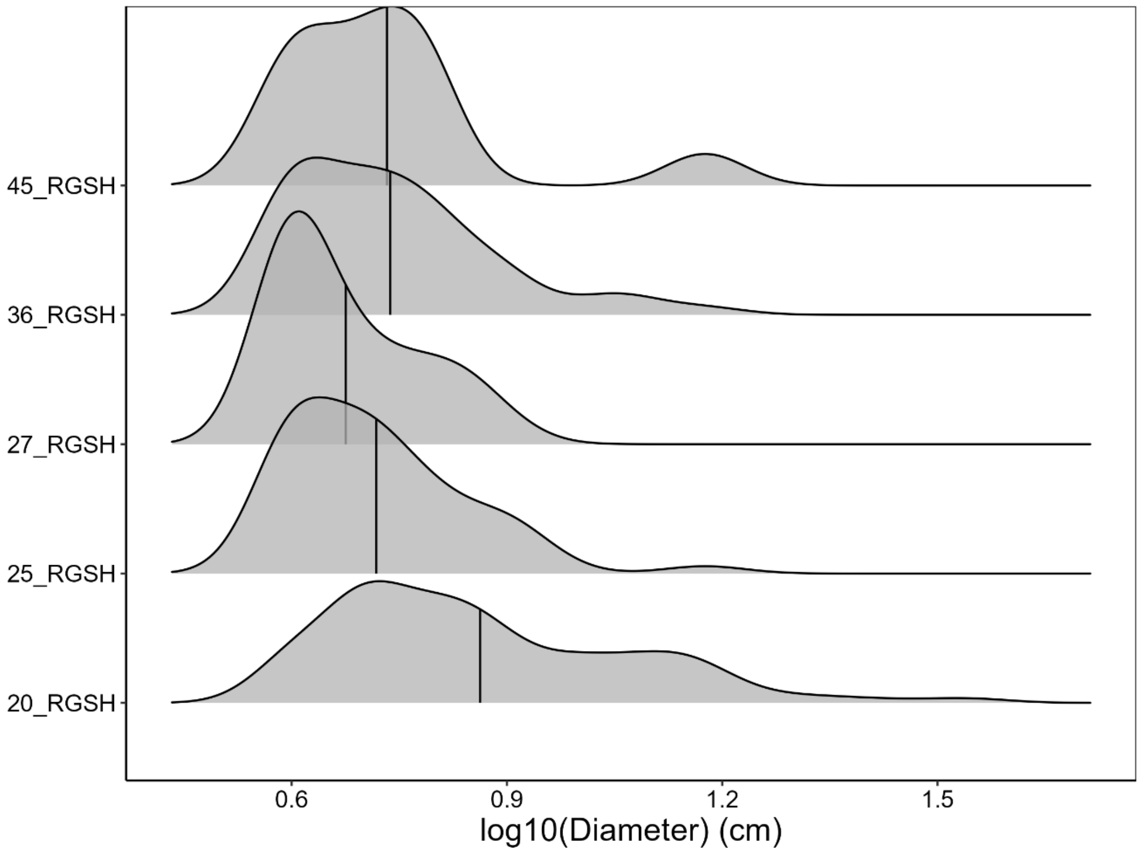

Figure 8. Spatial variation in size-frequency distribution of all coral species colonies using log10-transformed maximum colony diameter. Solid vertical line within histograms represents the mean colony diameter. Frequency estimated by kernel density estimate, which uses kernel smoothing (the weighted average of the observed data) for probability density estimation (using a smoothed histogram). Sites ordered North (top) to South (bottom).

PCA found that principal components (PC) 1 to 4 accounted for most variation between the remaining sites (Figure 9 to 10). PC1 was positively loaded with metrics related to a more developed coral community, stony coral cover, density, coefficient of variation in size-frequency distribution and coral colony maximum height and diameter (Figure 9). Each of these was highest at 20_RGSH (Table 2). Site 25_RGSH was also positively related to these metrics, although to a lesser extent. PC2 was positively loaded by the distance from optimum skewness and kurtosis of size-frequency distributions, and negatively by rubble/sand cover and by turf algal height (Figure 9), which were particularly abundant and tall at site 27_RGSH where only *S. siderea* colonies were found. Size-frequency distribution of maximum coral colonies at 45_RGSH, the only site north of the St. Lucie Inlet was highly positively skewed and platykurtic (Figure 8). PC3 indicated higher partial colony mortality at 25_RGSH (Figure 10), but this was largely related to species composition, with *Oculina robusta* and *P. americana* colonies found at the site. These species often have partial mortality of the coenochyme which connects branches and polyps, respectively.

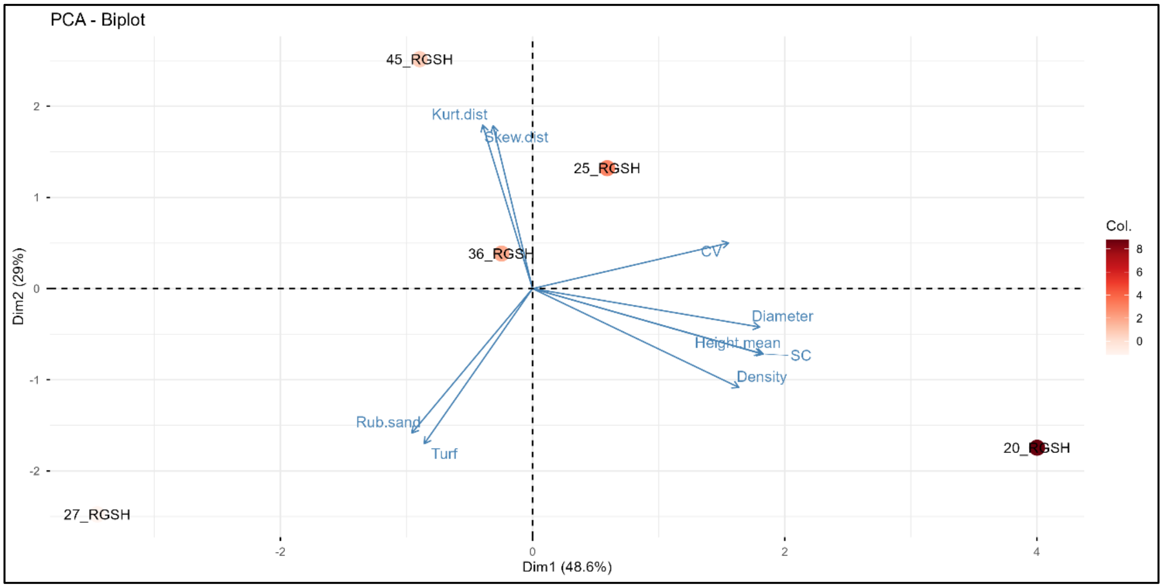

Figure 9. Principal component analysis (PCA) of Martin County Tier 2 sites. Vectors show metrics accounting for most variation in PC1 and PC2. Points are color coded by site rank. See Table S1 for PC vector abbreviation description.

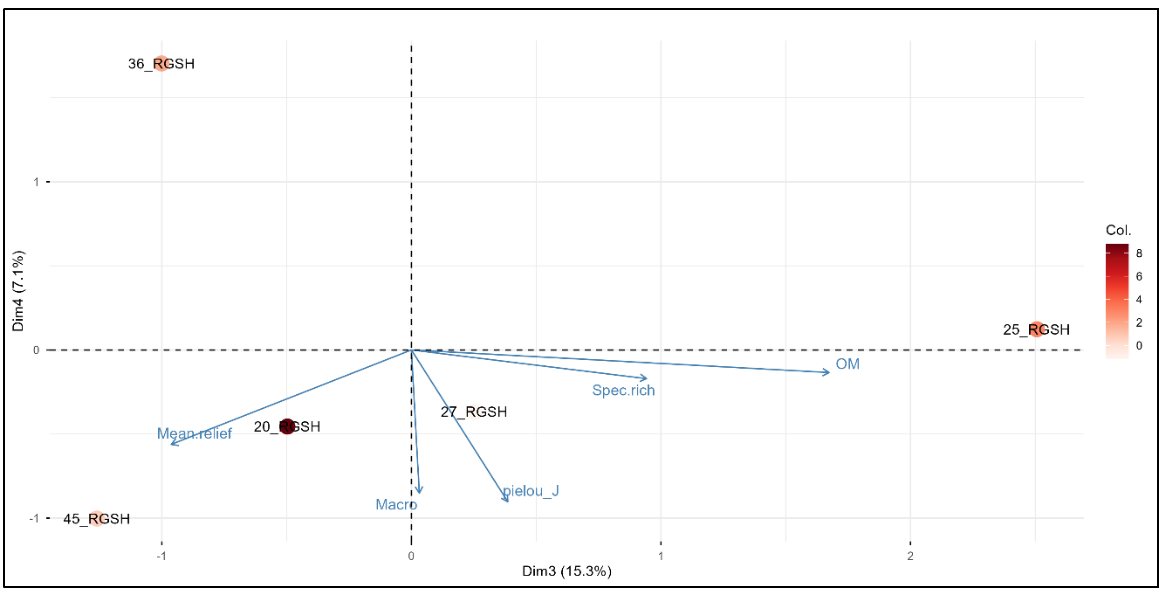

Figure 10. Principal component analysis (PCA) of Martin County Tier 2 sites. Vectors show metrics accounting for most variation in PC3 and PC4. Points are color coded by site rank.

Table 2a. Site ranking from highest to lowest ranked and associated data. Rank = final site ranking quantified using normalized scores from data. Density = mean adult colony density. Diameter = mean adult colony diameter. Height = mean adult colony height. OM = % old partial colony mortality. CV = coefficient of variation of size-frequency distribution (sfd). Skew = skewness of sfd calculated as the distance from 0, Kurt = kurtosis of sfd calculated as distance from optimal mesokurtic distribution. H' = Shannon diversity. J' = Pielou's J of evenness. Recommended Tier 3 sites in bold and shown in Figure 11. Sites with RGSH are located on nearshore ridge shallow habitat.

Site	Rank	Density	Diameter	Height	OM	CV	Skew	Kurt	S	H'	J'
20_RGSH	**8.8**	6.1	8.3	2.4	3.0	23.6	0.9	0.4	6	0.7	0.4
25_RGSH	**3.0**	1.7	5.5	1.7	6.1	17.2	1.3	2.0	6	0.7	0.4
36_RGSH	1.8	1.8	5.8	1.7	0.6	18.8	1.1	1.0	2	0.1	0.1
45_RGSH	0.7	0.4	5.8	1.4	0.3	21.6	1.9	3.2	2	0.3	0.4
27_RGSH	-1.1	1.4	4.9	1.4	2.2	14.3	0.9	0.7	1	0.0	1.0

Table 2b. Site rankings from highest to lowest ranked and associated data used to rank the site. Rank = final site ranking quantified using normalized scores from data. Turf height = mean turf algal height. Relief height = mean relief height. SC = stony coral cover. MA = macroalgal/cyanobacterial cover. Loose = sand/rubble cover. Expert rank = 1-5 suitability rank for FCR3 Initiative restoration activities. Recommended Tier 3 sites in bold.

Site	Rank	Turf height	Relief height	SC	MA	Loose	Expert rank
20_RGSH	**8.8**	7.7	76.7	3.6	11.7	11.4	3
25_RGSH	**3.0**	6.9	17.5	1.1	12.5	0.3	2.5
36_RGSH	1.8	7.0	32.6	0.8	6.9	14.4	1
45_RGSH	0.7	6.9	45.0	0.0	22.8	4.7	1
27_RGSH	-1.1	9.1	23.0	0.0	47.2	26.1	1

3.2.2. Tier 3 site recommendations

Ground-truthing surveys and data analysis suggested that sites 20_RGSH and 25_RGSH, the two furthest south and furthest from the St. Lucie Inlet (Figure 11) would be best for FCR3 Initiative Tier 3 restoration activities in Martin County (Table 2). Several natural *P. clivosa* were present at both recommended sites and several *M. cavernosa* and *O. faveolata* colonies outplanted close to the nearby SECREMP site, Martin County 1, were healthy. Within the tier 2 polygons, extended roving diver swims and benthic transects found that stony coral colonies were most abundant on the shoreward ridges in the western side of the polygons (indicated by arrows in Figure 11), where Martin County 1 is located. These ridges have historically had higher coral cover and large coral colonies including *P. clivosa* and *M. cavernosa*. We recommend focusing FCR3 Initiative restoration activities on these shoreward reef terraces within the existing polygons.

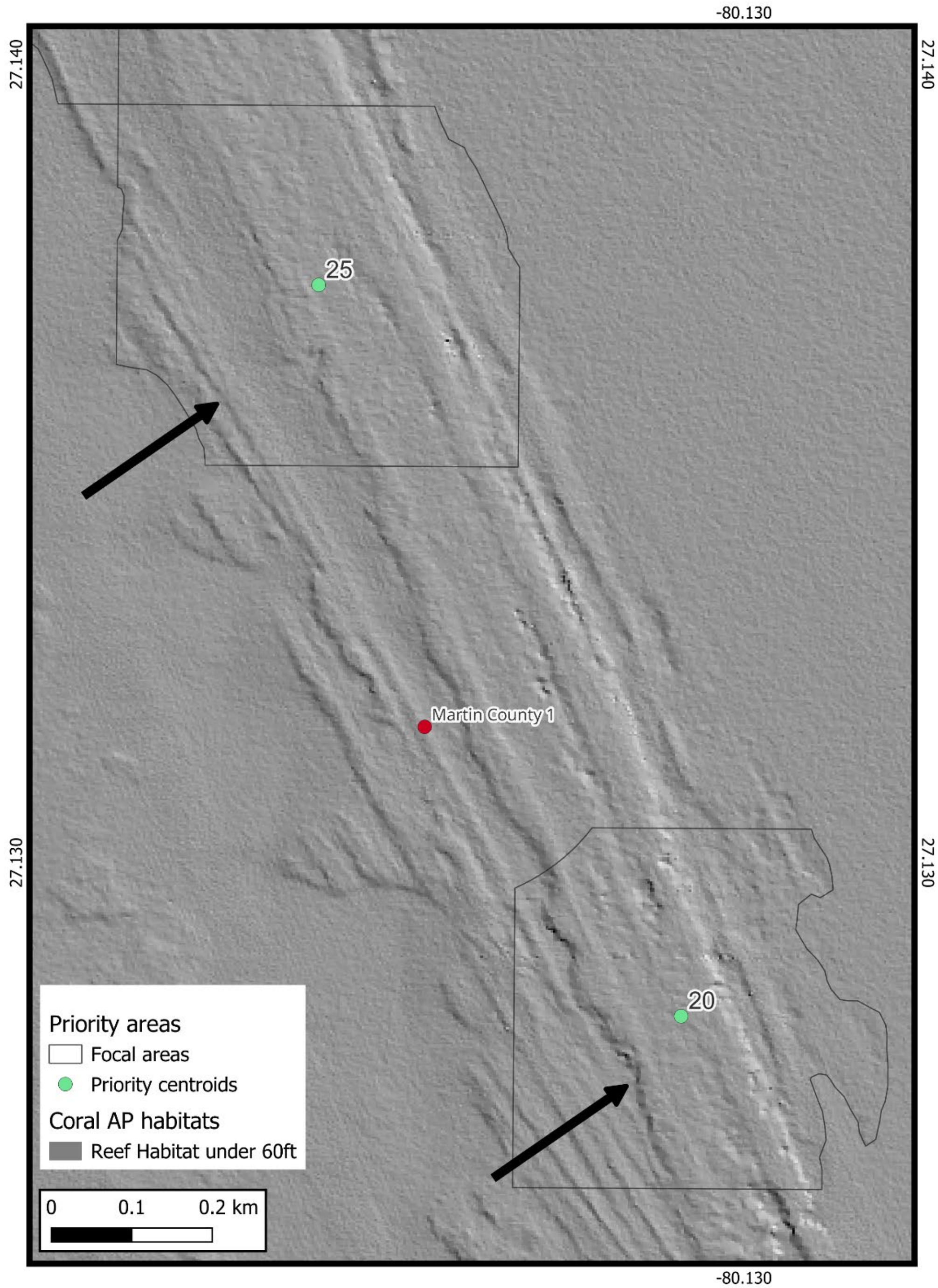

Figure 11. Recommended Tier 3 sites for Martin County. Arrows identify the reef terraces where coral colonies are most abundant and where restoration is recommended. Both reef terraces extend between polygons and pass the SECREMP site Martin County 1 (MC1) where coral cover has historically been highest in Martin County.

3.3. Palm Beach County

3.3.1. Results

Eleven sites were ground-truthed in Palm Beach County, two near the town of Palm Beach, eight offshore Boynton Beach and one near Highland Beach in the south of the county (Figure 12). All sites surveyed were on the outer reef, most near a large shoreward facing reef ledge, and one on spur and groove habitat (abbreviated as SPGR). The sites offshore the town of Palm Beach were identified in FCRRP's Tier 2 analysis as benefitting shoreline protection and were located around 2 km northwest of Mar-a-Largo, near the SECREMP site PB2.

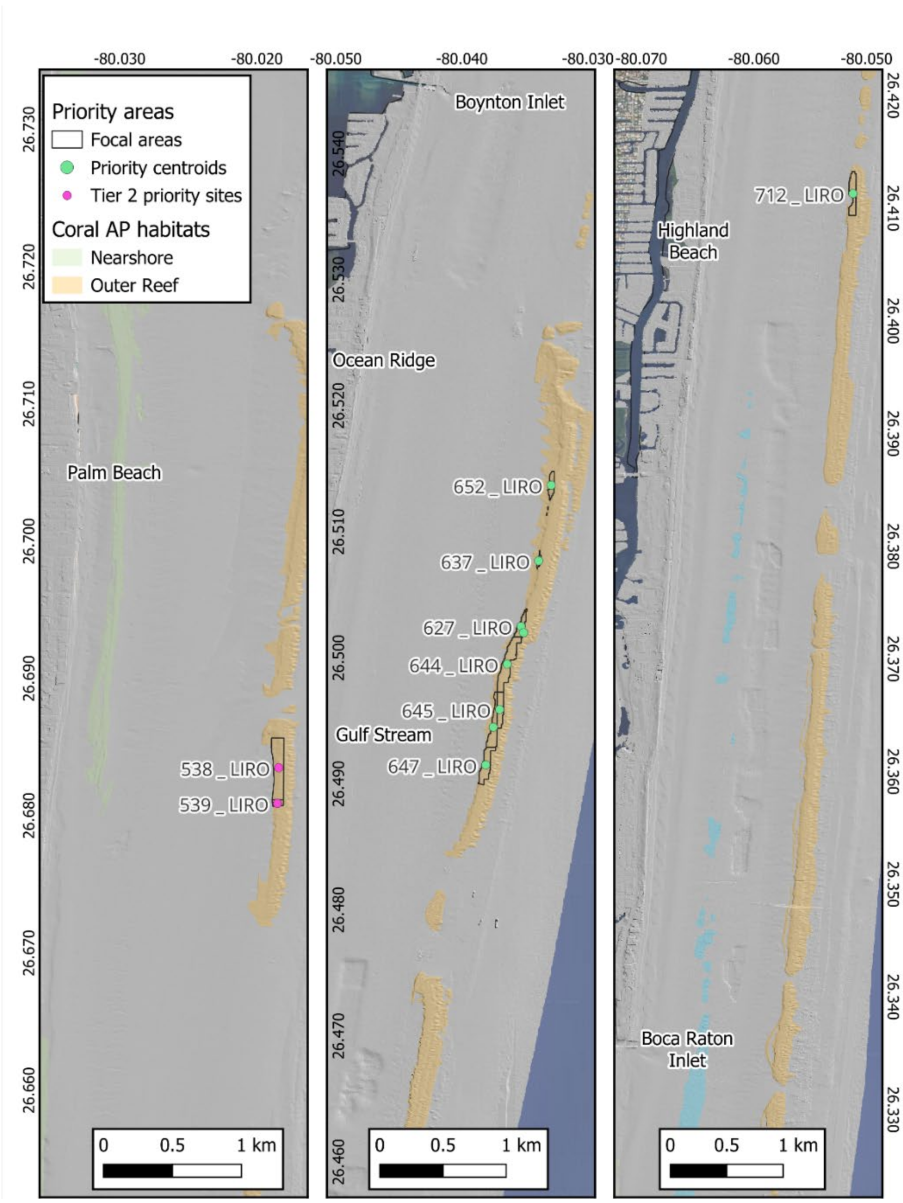

Figure 12. Tier 2 site locations in Palm Beach County, with reef habitat outlined and overlaid on lidar data.

Benthic community structure was dominated by macroalgal cover, which ranged from 58.1% to 23.9% (Figure 13). Sponges were the dominant fauna contributing to cover, followed by octocorals, which were particularly high on flatter reef portions on the central and eastern portions of the tier 2 polygons. Stony coral cover was, however, also relatively high at some sites, particularly at 652_LIRO (5.8%), where mean colony diameter was largest (Figure 14), and 645_LIRO (4.1%). Coral density was also high at both sites, particularly around the two reef ledges to the west of the 652_LIRO polygon and along the main reef ledge which intersects sites 649_LIRO, 645_LIRO and 644_LIRO (Figure 12). Size-frequency distributions at all sites were slightly to strongly positively skewed and platykurtic, highlighting the dominance of smaller colonies and generally slow transition in size classes (Figure 14). Although overall, neither skewness or kurtosis was as extreme as in Martin County.

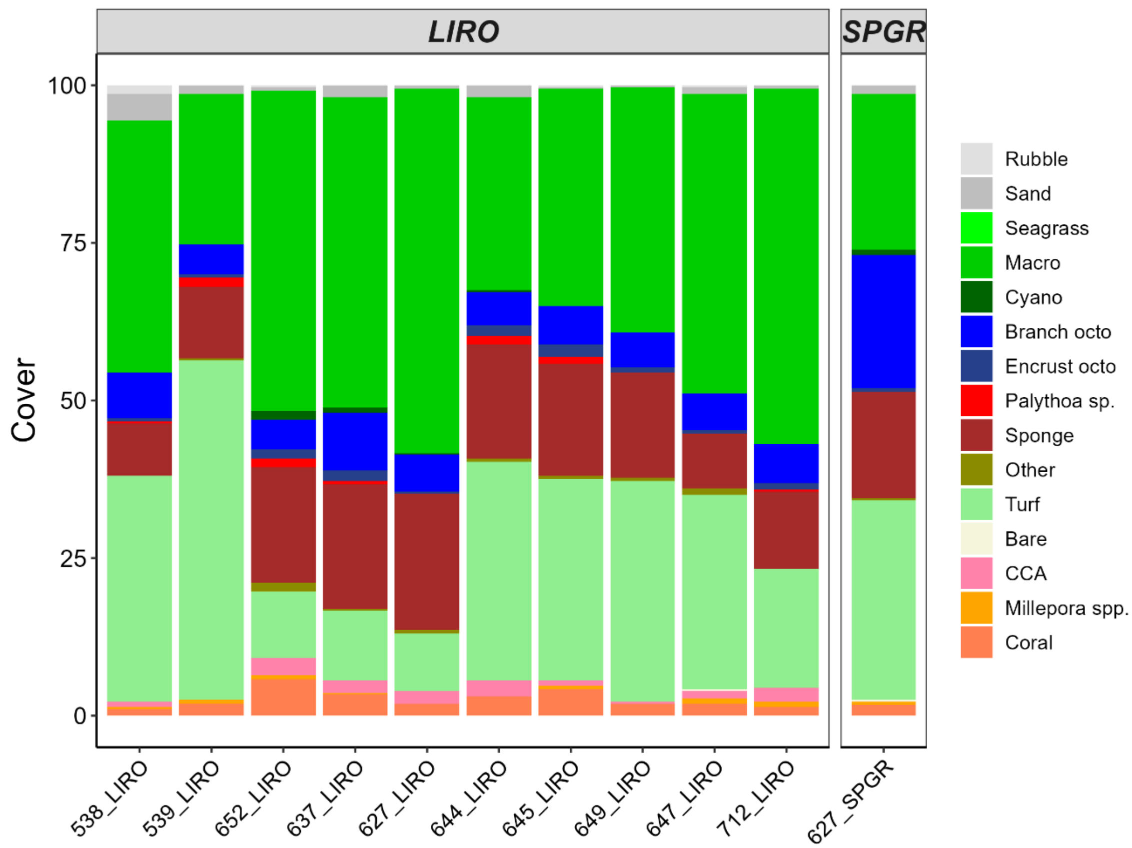

Figure 13. Spatial variation in benthic community composition (% cover) at each Tier 2 site in Palm Beach County. Panels are divided by habitat and sites arranged North to South within habitat. Note: *Palythoa* sp. refers to *Palythoa caribaeorum*, Encrust octo = encrusting gorgonians, branch octo = branching gorgonians, bare = bare substrate.

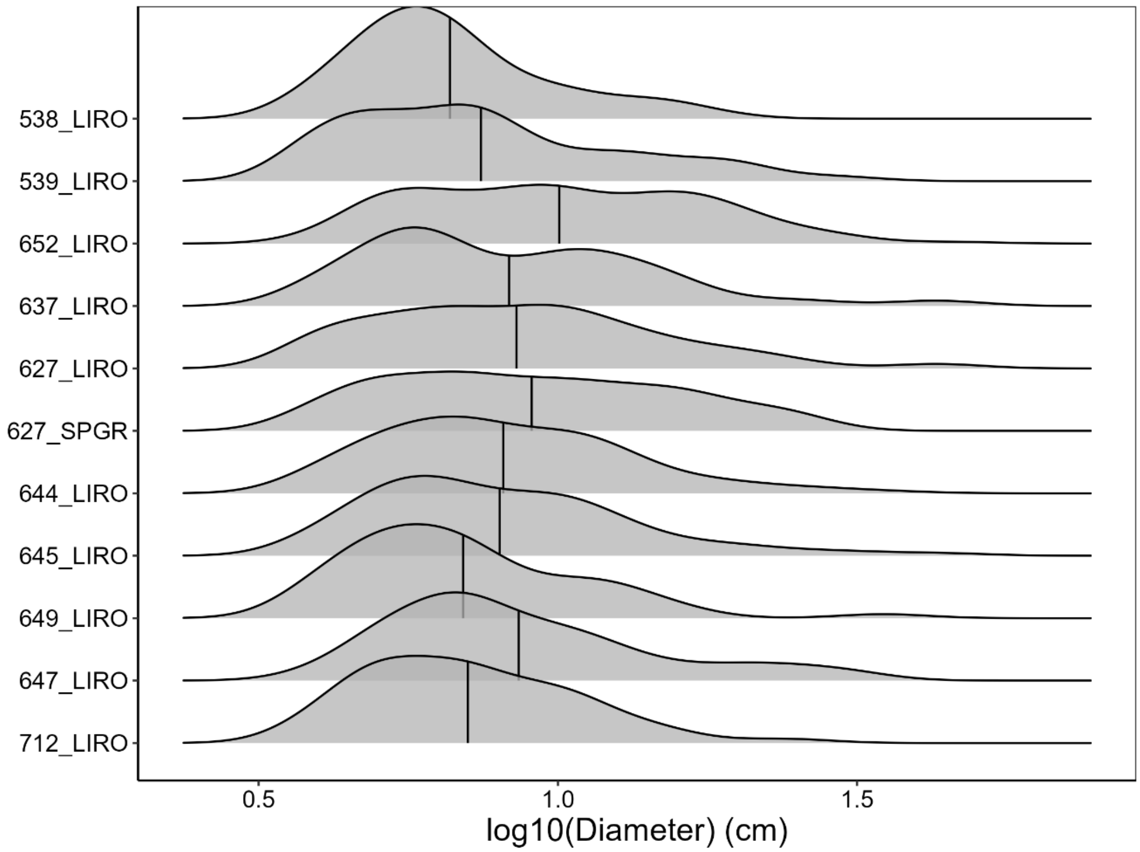

Figure 14. Spatial variation in size-frequency distribution of all coral species colonies using log10-transformed maximum colony diameter. Solid vertical line within histograms represents the mean colony diameter. Frequency estimated by kernel density estimate, which uses kernel smoothing (the weighted average of the observed data) for probability density estimation (using a smoothed histogram). Sites ordered North (top) to South (bottom).

Montastraea cavernosa was the most abundant priority coral species in Palm Beach County, with all but the two northern sites having at least 100 colonies (Figure 15). Priority species colony abundance was generally higher at sites towards the southern end of the county, than at sites surveyed in central Palm Beach County. Other priority species colonies were rare, but scattered colonies of at least two other priority species were also found at all sites, including *O. faveolata* colonies at most sites and two *A. cervicornis* colonies at 637_LIRO. However, only 1% of priority species colonies were larger than 50 cm and only 1 colony larger than 100 cm diameter was recorded, an *O. faveolata* at site 645_LIRO.

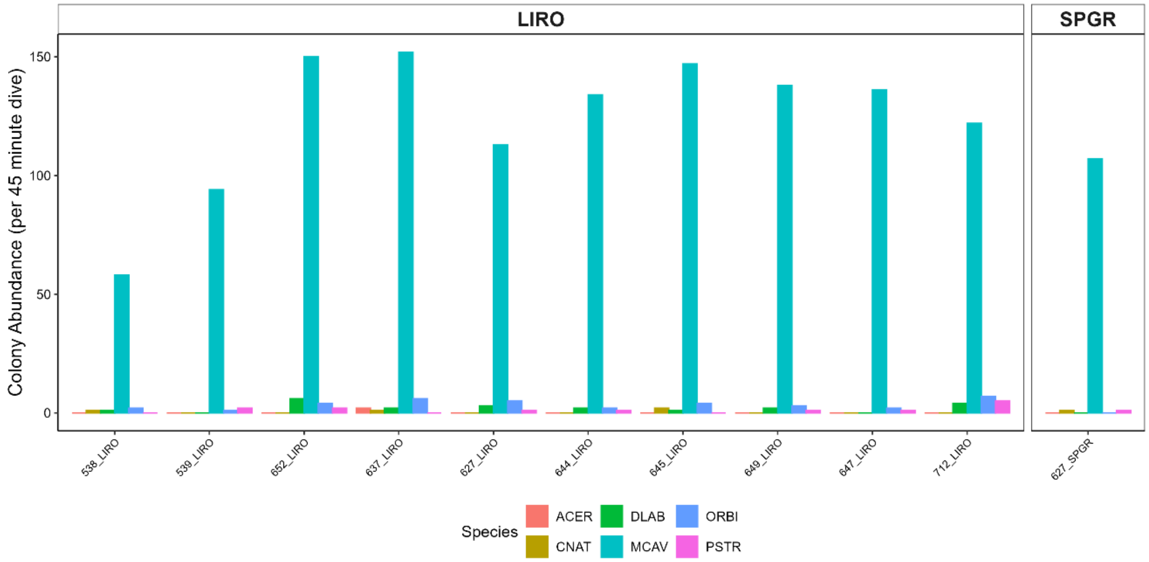

Figure 15. Spatial variation in priority species abundance recorded during 45-minute roving diver survey at Palm Beach County Tier 2 sites. Sites separated by habitat, where LIRO = outer reef, SPGR = spur and groove.

PCA found that 49% of variation between sites was explained by the first 2 principal components and 89% by the first 6 principal components (Figures 16 to 18). PC1 was positively weighed equally by multiple coral metrics, including priority species abundance, colony size and stony coral cover, all of which were particularly high ranking at 652_LIRO. PC1 was negatively weighted most by evenness in coral species composition (Figure 16). PC2 was most heavily weighted by priority species mean diameter and Shannon diversity which were both relatively high at the only spur and groove site, 627_SPGR. PC3 was heavily weighted positively by mean relief, which was highest at the second highest ranking site, 645_LIRO (Figure 17). It was also strongly negatively related to macroalgal cover, which was primarily composed of *Dictyota* sp. PC4 was positively weighted by partial colony mortality and negatively by Shannon diversity. Sites 652_LIRO and 645_LIRO, the two highest-ranking sites (Table 3), were both negatively associated with PC4 (Figure 17). Finally, PC5 split sites between those where size-frequency distribution of coral diameter had positive skew and high kurtosis, like 645_LIRO, and those with an even size spread in priority species colonies, like 652_LIRO (Figure 18).

Table 3a. Site rankings from highest to lowest ranked and associated data. Rank = final site ranking quantified using normalized scores from data. Abundance = priority species colony abundance. Species richness = priority species richness. Diameter = mean diameter of priority species colonies, Size classes = mean number of size classes occupied by priority species. Turf height = mean turf algal height. Relief height = mean relief height. SC = stony coral cover. MA = macroalgal/cyanobacterial cover. Loose = sand/rubble cover. Expert rank = 1-5 suitability rank for FCR3 Initiative restoration activities. Recommended Tier 3 sites in bold.

Site	Rank	Abundance	Species richness	Diameter	Size classes	Turf height	Relief height	SC	MA	Loose	Expert rank
652_LIRO	**12.7**	162	4	18.3	3.5	5.8	22.9	5.8	52.2	0.8	4
645_LIRO	**10.0**	154	4	17.5	3.0	6.6	34.5	4.2	34.4	0.6	3
637_LIRO	8.8	163	5	18.0	2.8	11.7	16.1	3.3	50.0	1.9	3
627_SPGR	8.3	109	3	23.5	2.7	8.8	29.2	1.7	25.6	1.4	2
644_LIRO	8.0	139	4	15.7	2.3	7.2	29.8	3.1	30.8	1.9	3
712_LIRO	7.6	138	4	14.9	3.5	5.0	27.6	1.4	56.4	0.6	3
627_LIRO	7.3	122	4	16.3	2.8	7.4	22.3	1.9	58.1	0.6	2.5
647_LIRO	7.1	139	3	19.9	2.7	9.6	30.2	1.9	47.5	1.4	3
649_LIRO	5.5	144	4	16.8	2.5	7.0	28.2	1.9	38.9	0.3	3
539_LIRO	4.9	97	3	16.4	3.0	9.8	31.3	1.9	23.9	1.4	2
538_LIRO	3.9	62	4	19.0	2.3	11.2	22.3	1.1	40.0	5.6	3

Table 3b. Site ranking from highest to lowest ranked and associated data. Rank = final site ranking quantified using normalized scores from data. Density = mean adult colony density. Diameter = mean adult colony diameter. Height = mean adult colony height. OM = % old partial colony mortality. CV = coefficient of variation of size-frequency distribution (sfd). Skew = skewness of sfd calculated as the distance from 0, Kurt = kurtosis of sfd calculated as distance from optimal mesokurtic distribution. H' = Shannon diversity. J' = Pielou's J of evenness. Recommended Tier 3 sites in bold. Sites with LIRO = linear outer reef habitat. Sites with SPGR = spur and groove habitat.

Site	Rank	Density	Diameter	Height	OM	CV	Skew	Kurt	H'	J'
652_LIRO	**12.7**	4.4	11.6	5.1	10.9	23.0	0.3	0.7	1.6	0.7
645_LIRO	**10.0**	3.4	9.2	3.7	6.0	23.6	1.0	1.0	1.6	0.8
637_LIRO	8.8	2.7	9.8	4.5	8.2	25.1	0.9	0.7	1.7	0.8
627_SPGR	8.3	1.6	10.4	3.8	4.7	24.3	0.2	1.0	1.9	0.8
644_LIRO	8.0	4.2	9.1	3.7	6.2	22.2	0.6	0.2	1.7	0.7
712_LIRO	7.6	1.8	7.7	2.9	6.7	20.3	0.7	0.2	1.6	0.8
627_LIRO	7.3	3.2	10.0	4.8	8.8	25.2	0.6	0.2	1.5	0.8
647_LIRO	7.1	2.1	9.9	4.6	8.5	23.2	0.9	0.1	1.5	0.8
649_LIRO	5.5	1.8	7.8	2.9	7.4	22.5	1.1	1.8	1.4	0.9
539_LIRO	4.9	1.6	8.6	3.0	9.5	25.5	0.7	0.2	1.4	0.8
538_LIRO	3.9	1.9	7.1	3.3	5.1	19.5	0.9	0.3	1.7	0.9

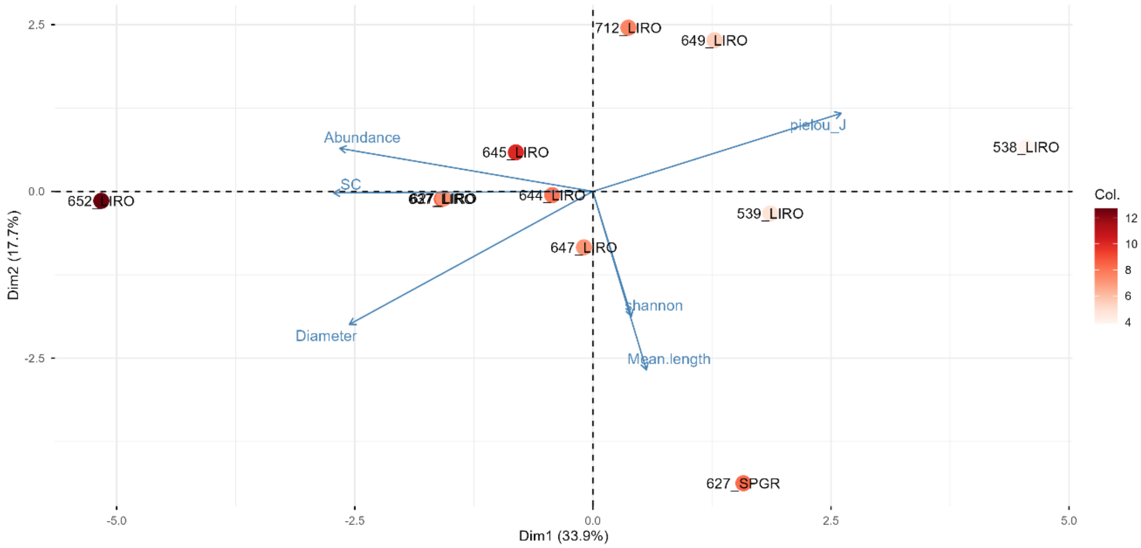

Figure 16. Principal component analysis (PCA) of Palm Beach County Tier 2 sites. Vectors show metrics accounting for most variation in PC1 and PC2. Points are color coded by site rank.

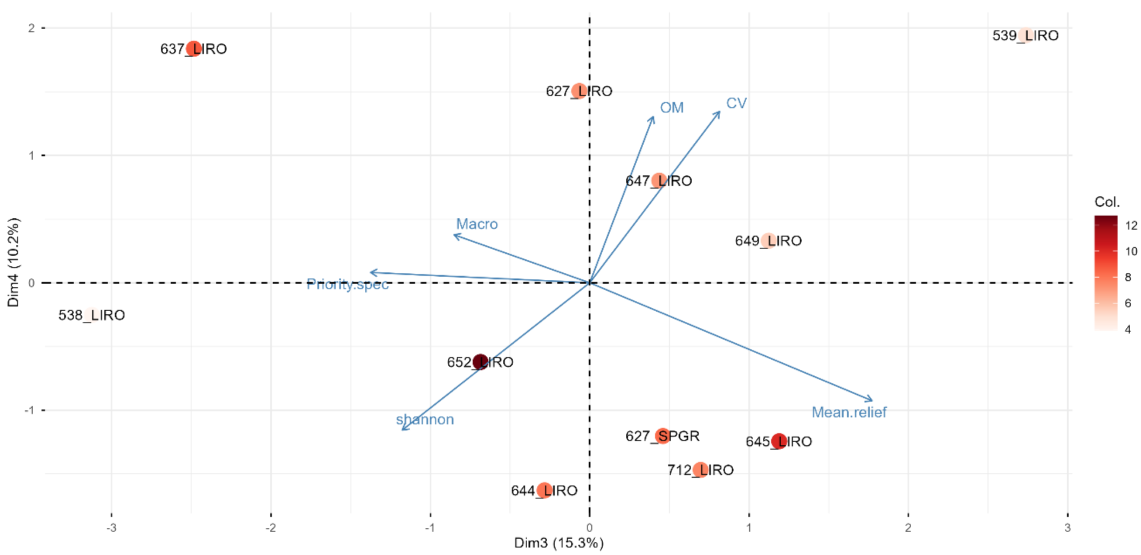

Figure 17. Principal component analysis (PCA) of Palm Beach County Tier 2 sites. Vectors show metrics accounting for most variation in PC3 and PC4. Points are color coded by site rank.

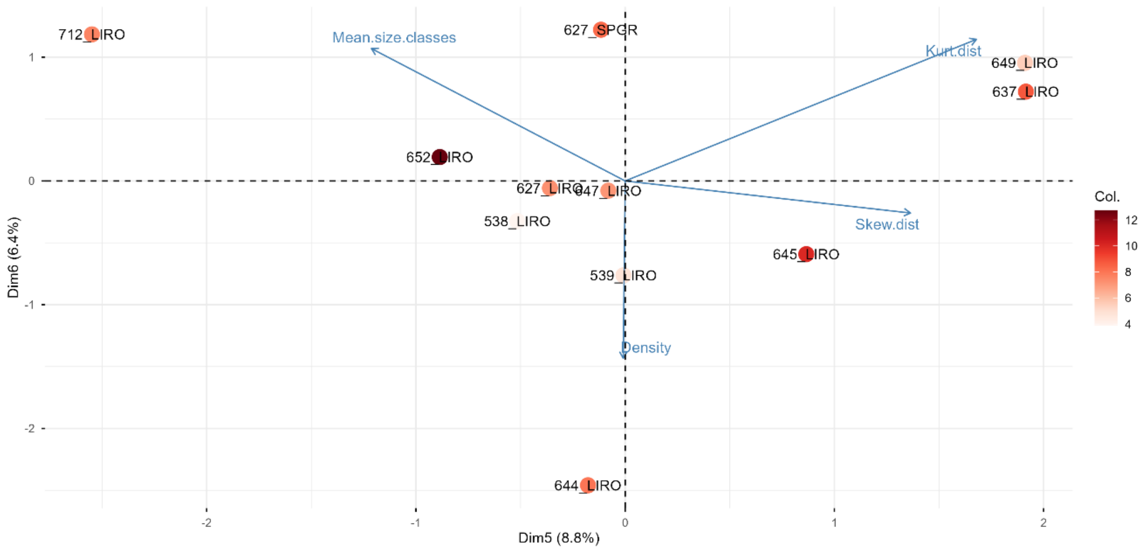

Figure 18. Principal component analysis (PCA) of Palm Beach County Tier 2 sites. Vectors show metrics accounting for most variation in PC5 and PC6. Points are color coded by site rank.

3.3.2. Tier 3 site recommendations

Analysis found that 652_LIRO and 645_LIRO were the highest-ranking Tier 2 sites and are recommended as Tier 3 sites for FCR3 restoration activities in Palm Beach County (Table 3; Figure 19). Both sites are found along the same reef which begins ~2km south of Boynton Inlet and extends ~5km. Each site had large areas of suitable habitat for restoration activities, higher abundance of priority species and a range in priority species colony sizes. It should be noted that two of the benthic transect surveys for 645_LIRO were conducted on the western polygon boundary where more coral colonies were located. We recommend that the Tier 3 site for 645_LIRO is therefore moved slightly west to incorporate the shoreward facing reef ledge (highlighted in figure 19).

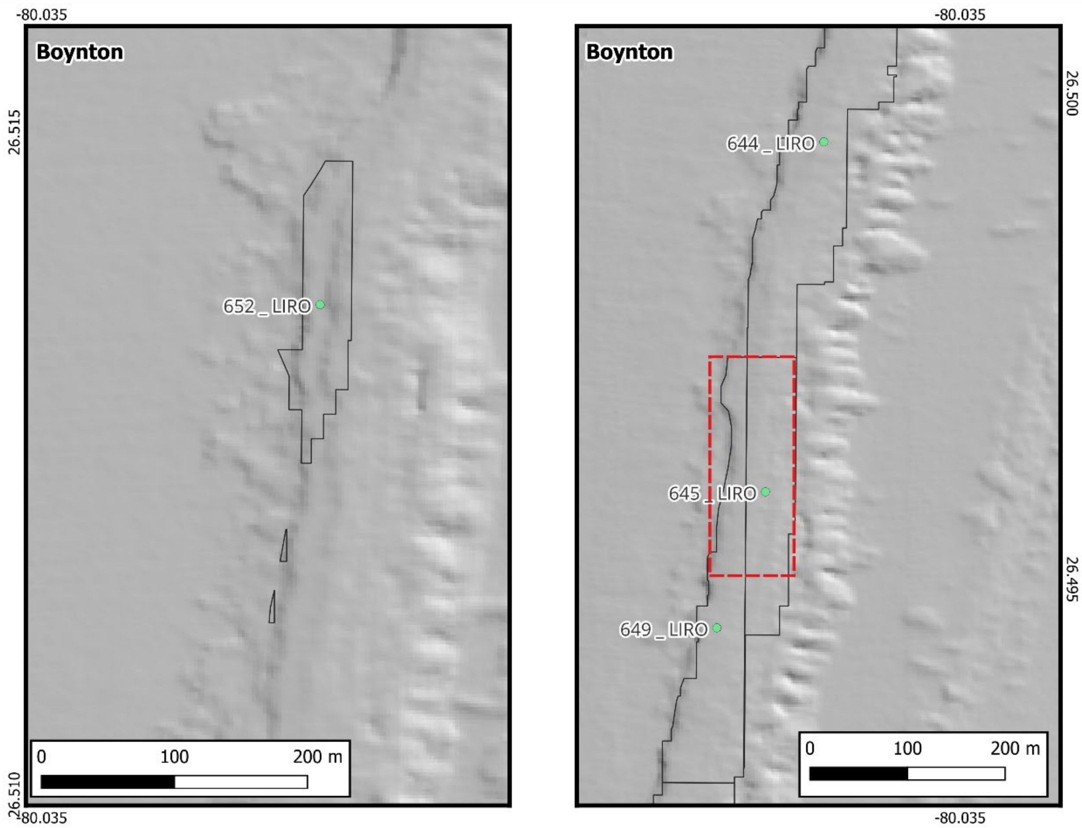

Figure 19. Recommended Tier 3 sites for Palm Beach County. 652_LIRO and 645_LIRO with lidar data showing underlying reef structure. The centroid position and polygon for 645_LIRO is recommended to be moved West to incorporate the northern ledge portion of site 649_LIRO. Expansion North and South along the western ledge should also be considered.

One consideration for final Tier 3 selection is that the two highest-ranking tier 2 sites are both on the same reef offshore Boynton Beach. The sites surveyed in other areas of Palm Beach County did not rank as highly, with substantially lower coral density and mean diameter (Figure 14 and 16) in particular. Site 712_LIRO, offshore Highland Beach (Figure 20), was the higher ranking of the two alternative areas surveyed, had plenty of suitable substrate for restoration activities, including an extensive shoreward facing ledge. It also had relatively high abundance of priority coral species and even spread in priority species size classes, indicating *M. cavernosa* at least, can grow to moderate sizes. Site 538_LIRO and 539_LIRO were the lowest ranking sites, but do have good substrate for restoration, several priority coral species and are more easily accessible from Lake Worth Inlet. There is, however, no extensive reef ledge where coral density was highest at other sites and while there were scattered moderate sized colonies, most coral colonies were small.

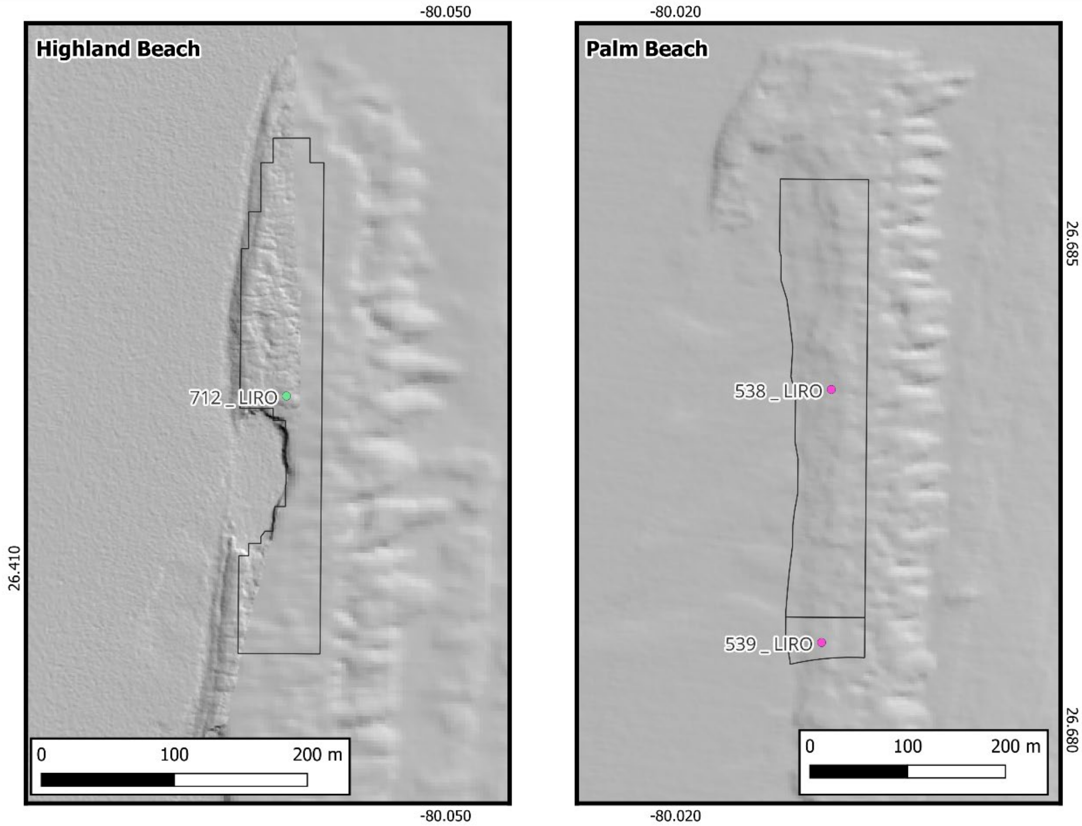

Figure 20. Alternative FCR3 Tier 3 sites in Palm Beach County. Left: Tier 2 site in southern Palm Beach County off Highland Beach, which was the highest-ranking site outside of the Boynton Beach cluster of sites. Right: Sites 538_LIRO and 539_LIRO off the town of Palm Beach where are sites are more easily accessible from Lake Worth Inlet.

3.4. Broward County

3.4.1. Results

Eleven sites were surveyed in Broward County (Figure 21). One site was surveyed on the middle reef in the Deerfield subregion between Hillsboro and Boca Inlets. Three sites were surveyed on the inner reef offshore Fort Lauderdale, north of Port Everglades. Seven sites were surveyed in the south of the county, two sites on the inner reef off Dania Beach, four sites on the nearshore ridge shallow off Hollywood and one site on the inner reef off Hollywood/Hallandale Beach boundary.

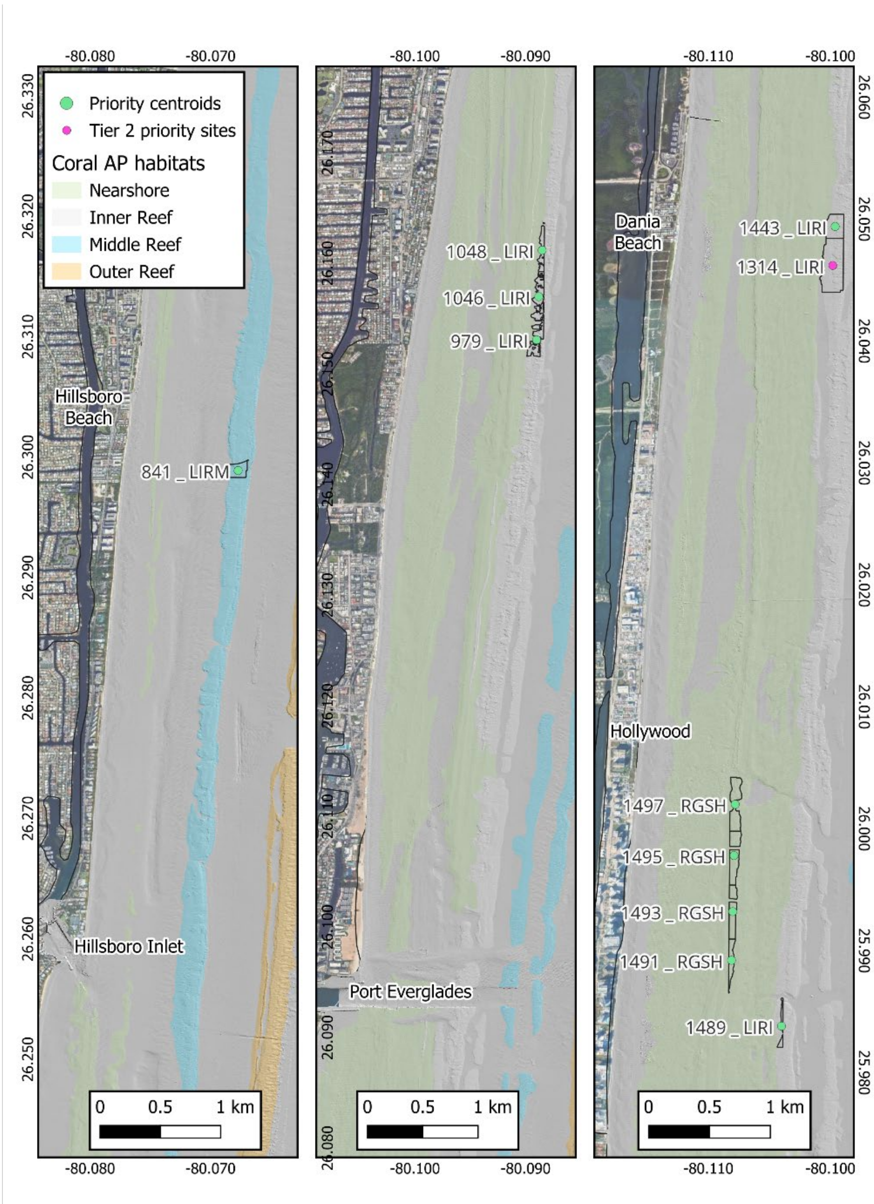

Figure 21. Tier 2 site locations in Broward County, with reef habitat outlined and overlaid on lidar data.

Turf algae was the most abundant taxa at all sites, accounting for 31% to 58% to benthic cover (Figure 22). Macroalgal cover was almost as high at 1314_LIRI and 1443_LIRI where it accounted for 24% and 23% respectively. Stony coral cover ranged from 1% at 1497_RGSH to 5% at 1046_LIRI. It also measured around 4% at 1046_LIRI, 979_LIRI, 1443_LIRI and 1493_LIRI. Sponge cover was nearly twice as high at 841_LIRM, the only middle reef site surveyed, as at any other site. Sand also accounted for over 10% of benthic cover at 841_LIRM, as it also did at 1497_RGSH, where a large sand patch split two reefs.

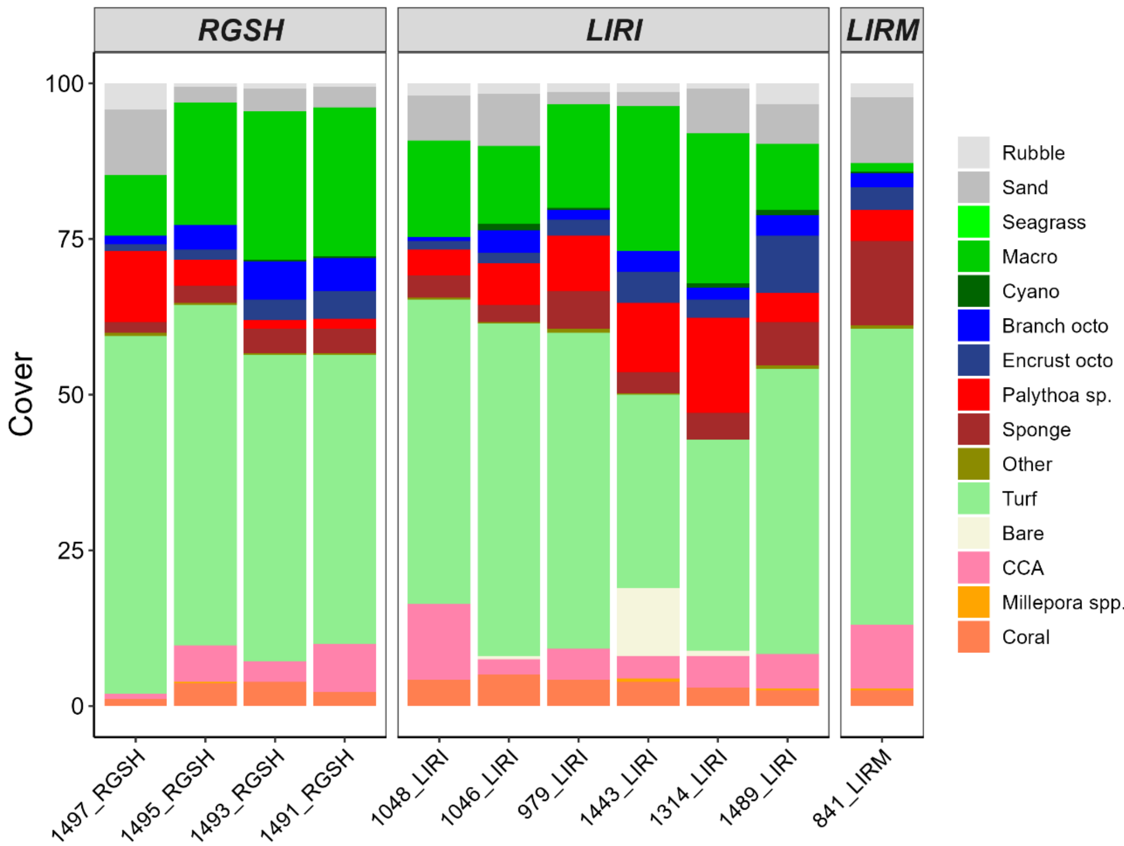

Figure 22. Spatial variation in benthic community composition (% cover) at each Tier 2 site in Broward County. Panels are divided by habitat and sites arranged North to South within habitat. Note: *Palythoa* sp. refers to *Palythoa caribaeorum*, Encrust octo = encrusting gorgonians, branch octo = branching gorgonians, bare = bare substrate.

Montastraea cavernosa was the most abundant priority species overall and the most abundant at 9 of the 11 sites (Figure 23). *Pseudodiploria strigosa* colonies were found at all sites but were much less abundant. All four Tier 2 sites on the nearshore ridge shallow and three inner reef sites had *A. cervicornis* colonies. Few *A. cervicornis* colonies under 10 cm were found, with 60% of colonies between 10 and 50 cm diameter. No *Acropora palmata* colonies were found. All inner reef sites had *Orbicella* spp. colonies, 58% of which were greater than 50 cm diameter. However, only 2 *Orbicella* spp. colonies recorded were smaller than 10 cm diameter. In comparison to Palm Beach County, where most priority colonies were small, 17% of priority species colonies were larger than 50 cm diameter.

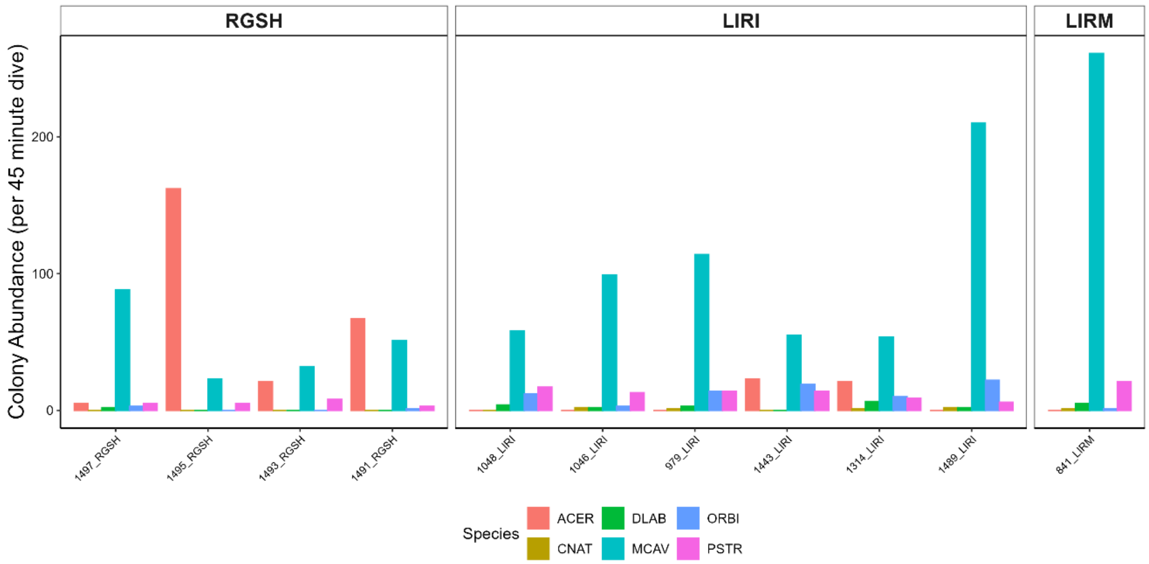

Figure 23. Spatial variation in priority species abundance recorded during 45-minute roving diver survey at Broward County Tier 2 sites. Sites separated by habitat, where RGSH = nearshore ridge shallow, LIRI = inner reef and LIRM = middle reef.

Mean coral colony diameter, colony height and coefficient of variation were highest at site 1489_LIRI (Figure 24). Multiple larger (>50 cm) *M. cavernosa* colonies were recorded at 1489_LIRI, which also had one *O. faveolata* colony over 300 cm recorded during the roving diver survey. Despite this, the size-frequency distribution at the site was still positively skewed and platykurtic, with many small colonies. Kurtosis was exceptionally high in the size-frequency distributions at sites 979_LIRI, 1497_RGSH and 1495_RGSH suggesting limited, or very slow, transition between size classes. Size-frequency distributions at those sites also had strong positive skew with most colonies smaller than 10 cm diameter. Skewness was lowest at site 841_LIRM on the middle reef in the Deerfield subregion.

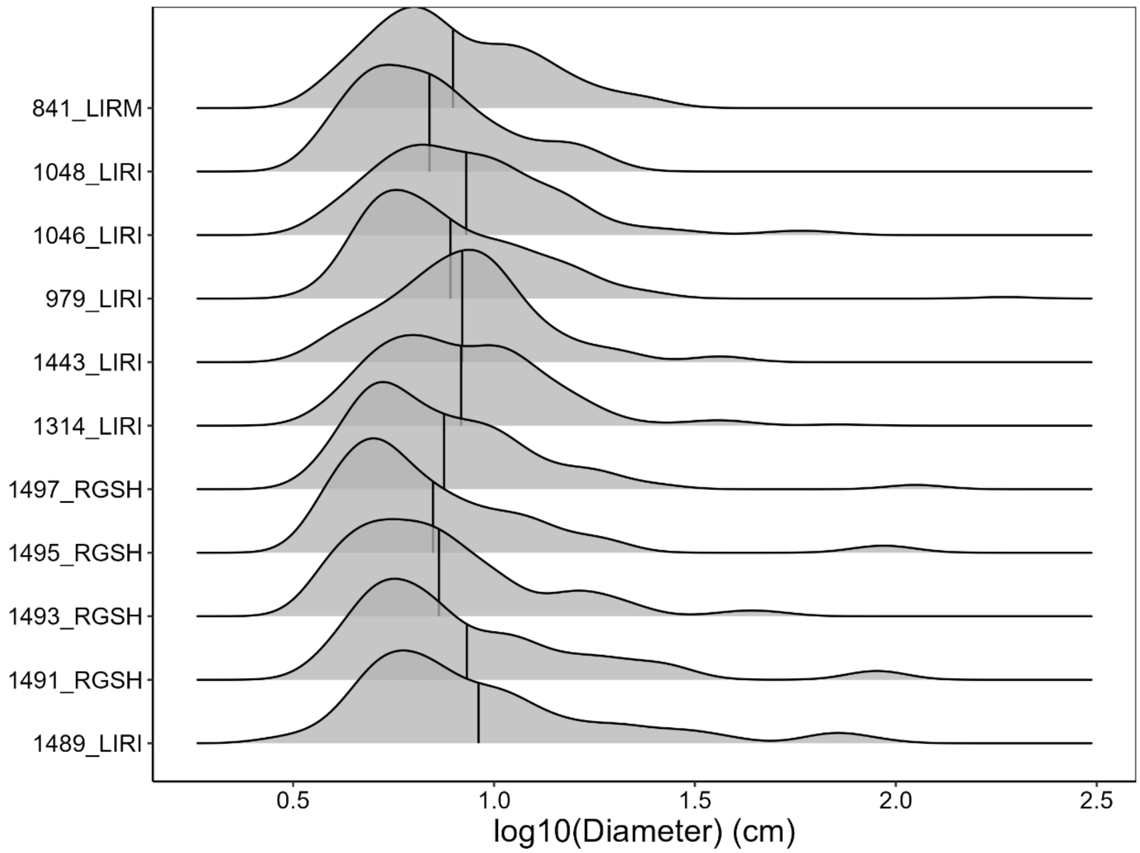

Figure 24. Spatial variation in size-frequency distribution of all coral species using log10-transformed maximum colony diameter. Solid vertical line within histograms represents the mean colony diameter. Frequency estimated by kernel density estimate, which uses kernel smoothing (the weighted average of the observed data) for probability density estimation (using a smoothed histogram). Sites ordered North (top) to South (bottom).

Metrics from each survey technique accounted for important variation between tier 2 sites in Broward County (Figures 25 to 27). PCA revealed that principal components 1 to 6 significantly affected spatial variation. Sites were primarily divided by coefficient of variation in size-frequency distribution (Figure 25) and mean relief height, both of which varied substantially between sites (Table 4). PC2 was strongly influenced by benthic cover (stony coral, macroalgal, sand/rubble cover), stony coral diversity (Pielou’s J) and priority species size structure (Figure 25). PC3 was influenced by size frequency distribution skewness and kurtosis (Figure 26), and mean colony height, where sites with shorter colonies, such as 979_LIRI and 1497_RGSH, had very skewed, platykurtic size-frequency distributions. PC4 was influenced by Shannon diversity and stony coral cover. PC5 was influenced by priority species abundance (Figure 27), which was particularly high at 1489_LIRI and 841_LIRI, and turf algal height (Table 4). Finally, PC6 was influenced by stony coral density and priority species richness (Table 4; Figure 27).

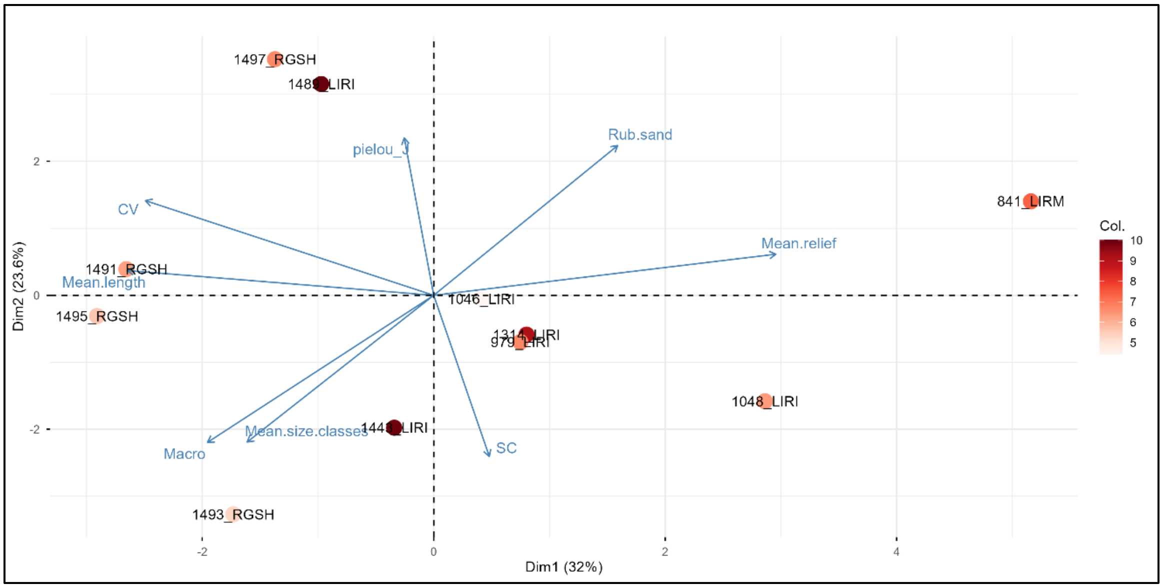

Figure 25. Principal component analysis (PCA) of Broward Tier 2 sites. Vectors show metrics accounting for most variation in PC1 and PC2. Points are color coded by site rank.

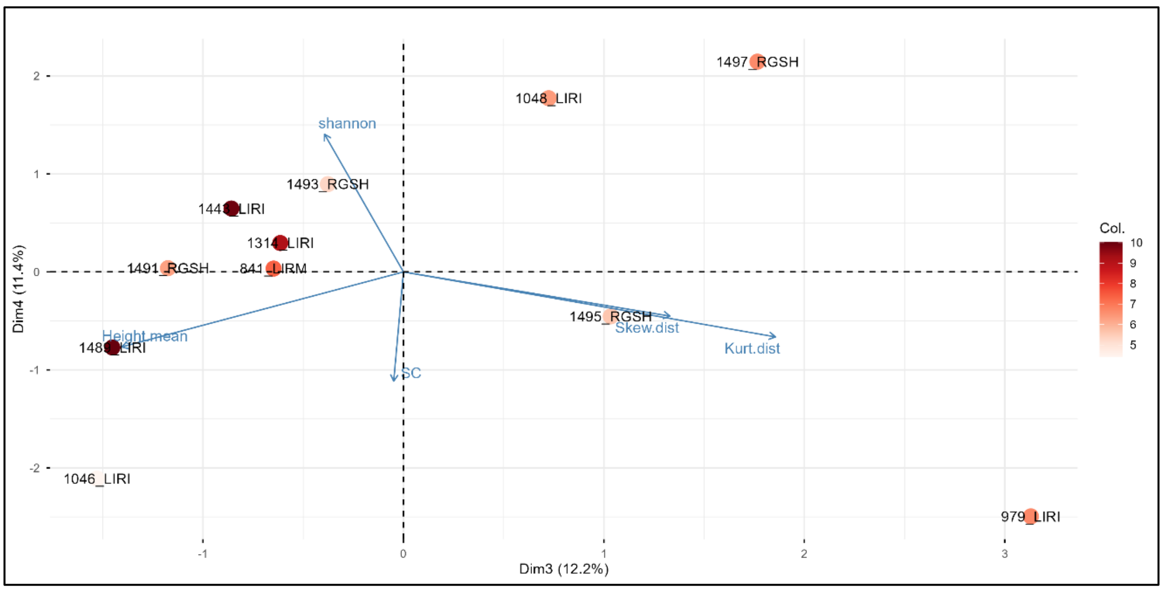

Figure 26. Principal component analysis (PCA) of Broward Tier 2 sites. Vectors show metrics accounting for most variation in PC3 and PC4. Points are color coded by site rank.

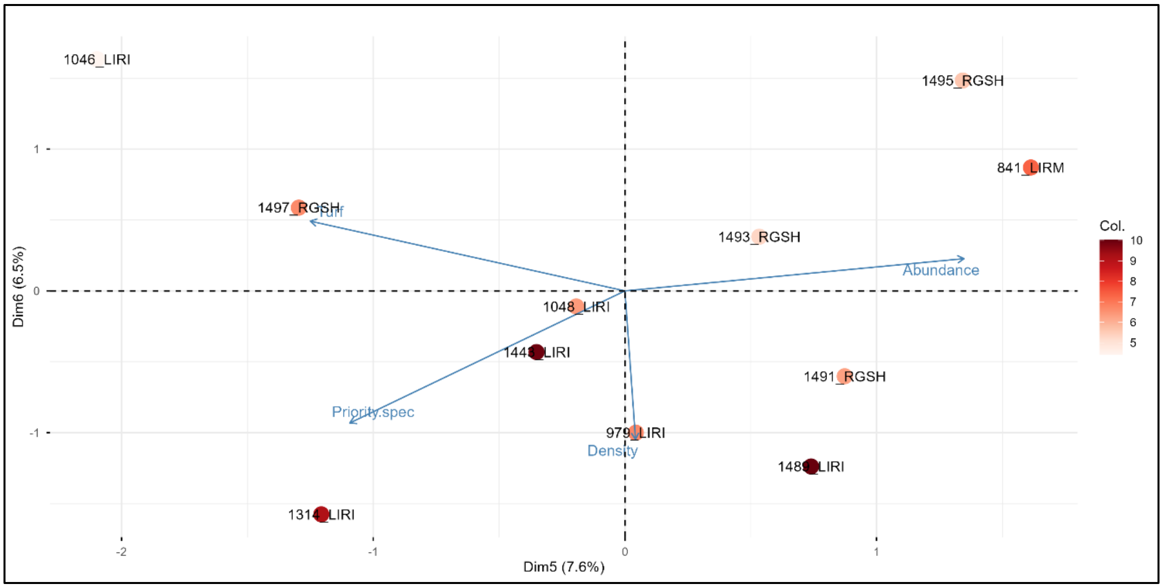

Figure 27. Principal component analysis (PCA) of Broward Tier 2 sites. Vectors show metrics accounting for most variation in PC5 and PC6. Points are color coded by site rank.

Table 4a. Site rankings from highest to lowest ranked and associated data. Rank = final site ranking quantified using normalized scores from data. Abundance = priority species colony abundance. Species richness = priority species richness. Diameter = mean diameter of priority species colonies, Size classes = mean number of size classes occupied by priority species. Turf height = mean turf algal height. Relief height = mean relief height. SC = stony coral cover. MA = macroalgal/cyanobacterial cover. Loose = sand/rubble cover. Expert rank = 1-5 suitability rank for FCR3 Initiative restoration activities. Recommended Tier 3 sites in bold.

Site	Rank	Abundance	Species richness	Diameter	Size classes	Turf height	Relief height	SC	MA	Loose	Expert rank
1489_LIRI	**10.0**	242	5	40.1	3.8	5.3	23.6	2.5	11.4	9.7	3
1443_LIRI	**10.0**	111	4	34.8	6	5.2	20.7	3.9	23.3	3.6	5
1314_LIRI	9.1	101	6	30.1	5	5.0	28.0	2.9	24.7	8.1	4
841_LIRM	7.4	289	5	13.3	2.4	3.5	50.0	2.5	1.7	12.8	1
979_LIRI	6.7	146	5	20.5	4.4	4.3	37.8	4.2	16.9	3.3	3
1497_RGSH	6.7	103	5	45.6	4	5.8	21.7	1.1	9.7	14.7	4
1048_LIRI	6.4	91	4	20.5	5	3.9	32.3	4.2	15.6	9.2	2
1491_RGSH	6.3	122	4	49.4	4.5	5.4	17.3	2.2	24.2	3.9	1
1495_RGSH	5.6	190	3	37.4	5.3	5.3	16.7	3.6	19.7	3.1	2
1493_RGSH	5.3	61	3	45.5	6.3	4.8	14.0	3.9	24.2	4.4	2
1046_LIRI	4.4	119	5	10.8	2.6	6.4	19.8	5.0	13.6	10.0	2

Table 4b. Site ranking from highest to lowest ranked and associated data. Rank = final site ranking quantified using normalized scores from data. Density = mean adult colony density. Diameter = mean adult colony diameter. Height = mean adult colony height. OM = % old partial colony mortality. CV = coefficient of variation of size-frequency distribution (sfd). Skew = skewness of sfd calculated as the distance from 0, Kurt = kurtosis of sfd calculated as distance from optimal mesokurtic distribution. H' = Shannon diversity. J' = Pielou's J of evenness. Recommended Tier 3 sites in bold. Sites with RGSH are located on nearshore ridge shallow habitat. Sites with LIRI are located on the inner reef. Site with LIRM is located on the middle reef.

Site	Rank	Density	Diameter	Height	OM	CV	Skew	Kurt	H'	J'
1489_LIRI	**10.0**	3.6	12.8	4.9	11.3	32.2	1.3	1.5	1.6	0.7
1443_LIRI	**10.0**	3.2	9.3	4.1	7.2	20.6	0.8	1.5	1.6	0.7
1314_LIRI	9.1	3.9	9.5	3.9	7.6	22.6	1.0	2.0	1.7	0.7
841_LIRM	7.4	4.0	8.8	3.4	5.0	21.7	0.5	0.4	1.8	0.7
979_LIRI	6.7	5.9	9.5	3.3	10.0	23.9	1.9	8.6	1.4	0.7
1497_RGSH	6.7	2.1	9.6	3.7	11.6	27.6	2.1	7.0	1.7	0.8
1048_LIRI	6.4	4.2	7.6	2.9	8.2	21.4	0.7	0.3	1.9	0.7
1491_RGSH	6.3	3.0	11.9	4.4	6.9	31.6	1.6	2.8	1.5	0.7
1495_RGSH	5.6	2.4	9.7	3.9	7.7	31.5	2.2	6.6	1.3	0.8
1493_RGSH	5.3	2.7	8.7	3.3	6.8	26.8	1.3	1.7	1.4	0.6
1046_LIRI	4.4	3.4	10.1	4.3	6.4	24.1	1.2	2.3	1.4	0.7

3.4.2. Tier 3 site recommendations

Analysis suggested that sites 1489_LIRI, on the inner reef off Hollywood, and 1443_LIRI, on the inner reef off Dania Beach, would be best for FCR3 Initiative restoration activities and are recommended as the Tier 3 sites for Broward County (Figure 28; Table 4). Site 1489_LIRI had a high abundance of medium and large priority species colonies, particularly *M. cavernosa* and *O. faveolata* (Figure 23). It also had high coefficient of variation in size-frequency distribution and the greatest mean colony diameter (Figure 24), both indicators of growth and survival of coral colonies. Site 1443_LIRI had a high spread in size structure of priority species, a lognormal size-frequency distribution and lots of suitable habitat for restoration activity. This included patches of bare substrate (Figure 22), a high relief patch reef around 30 m North of the centroid and slightly deeper areas of consolidated hardbottom (see lidar image in Figure 28), that could enable incorporating boulder corals and branching *Acropora* spp. The next highest-ranking site, 1314_LIRI, adjoined 1443_LIRI to the south and also contains several raised reef patches that could be incorporated if the polygon was to be expanded. Site 841_LIRM had the highest abundance of priority species colonies (Figure 23), but the patch reef nature of the site meant that much of the polygon was composed of unsuitable habitat for outplanting and sand cover was higher on the patch reefs.

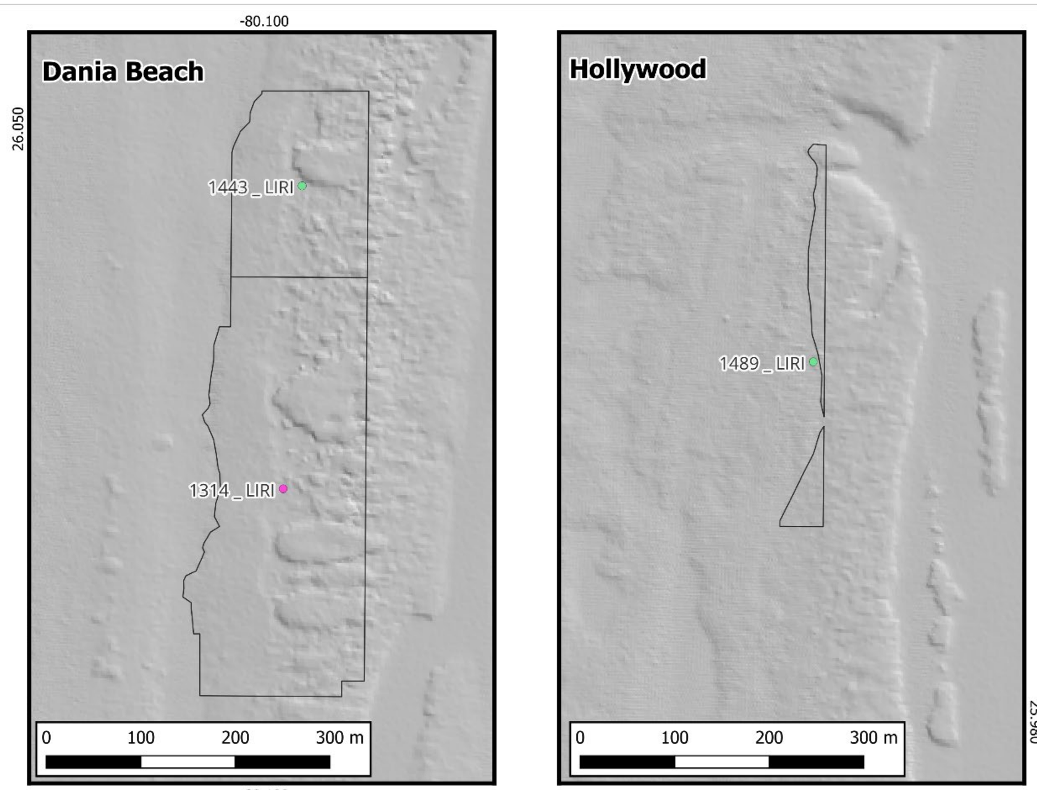

Figure 28. Recommended Tier 3 sites for Broward County. 1443_LIRI and 1489_LIRI with lidar data showing underlying reef structure. Site 1314_LIRI also ranked highly and should be considered if expansion of the Tier 3 sites is required.

3.5. Miami-Dade County

3.5.1. Results

Prior to undertaking ground-truthing it was decided that focus would be placed on surveying and evaluating Tier 2 sites outside Biscayne National Park. This meant that 18 sites were surveyed in Miami-Dade County (Figure 29). Sites were split into three clusters, one off Sunny Isles, one off Surfside and one off North Miami Beach, the latter of which scored highly for potential shoreline protection benefit in the Tier 2 process. Sites were split between the nearshore ridge shallow habitat and the inner reef.

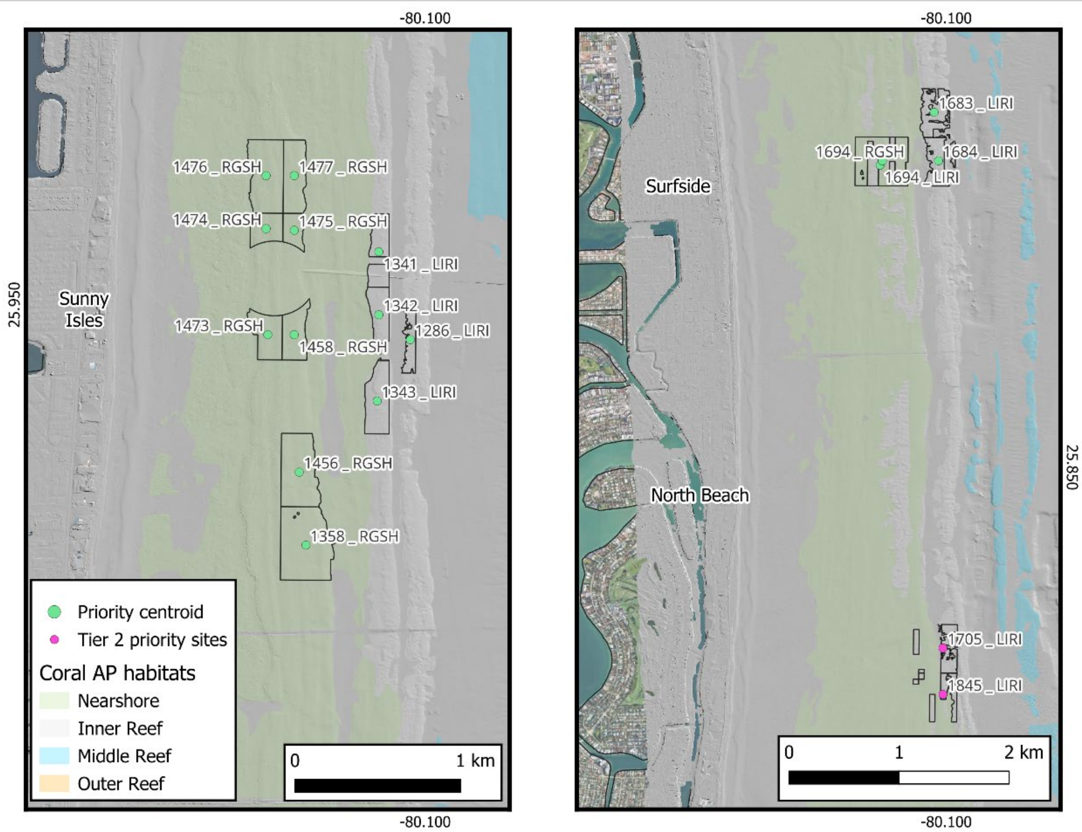

Figure 29. Tier 2 site locations in Miami-Dade County, with reef habitat outlined and overlaid on lidar data.

Stony coral cover ranged from 12% at 1476_RGSH, most of which was *A. cervicornis*, to 1.4% at several inner reef and one nearshore ridge site (Figure 30). Benthic community structure was generally dominated by either turf algae or macroalgal cover, as seen in all other counties. Only at site 1343_LIRI did turf algae and macroalgae cover combined not exceed 50%, and this was largely because rubble cover was 11% and *P. caribaeorum* cover 20%.

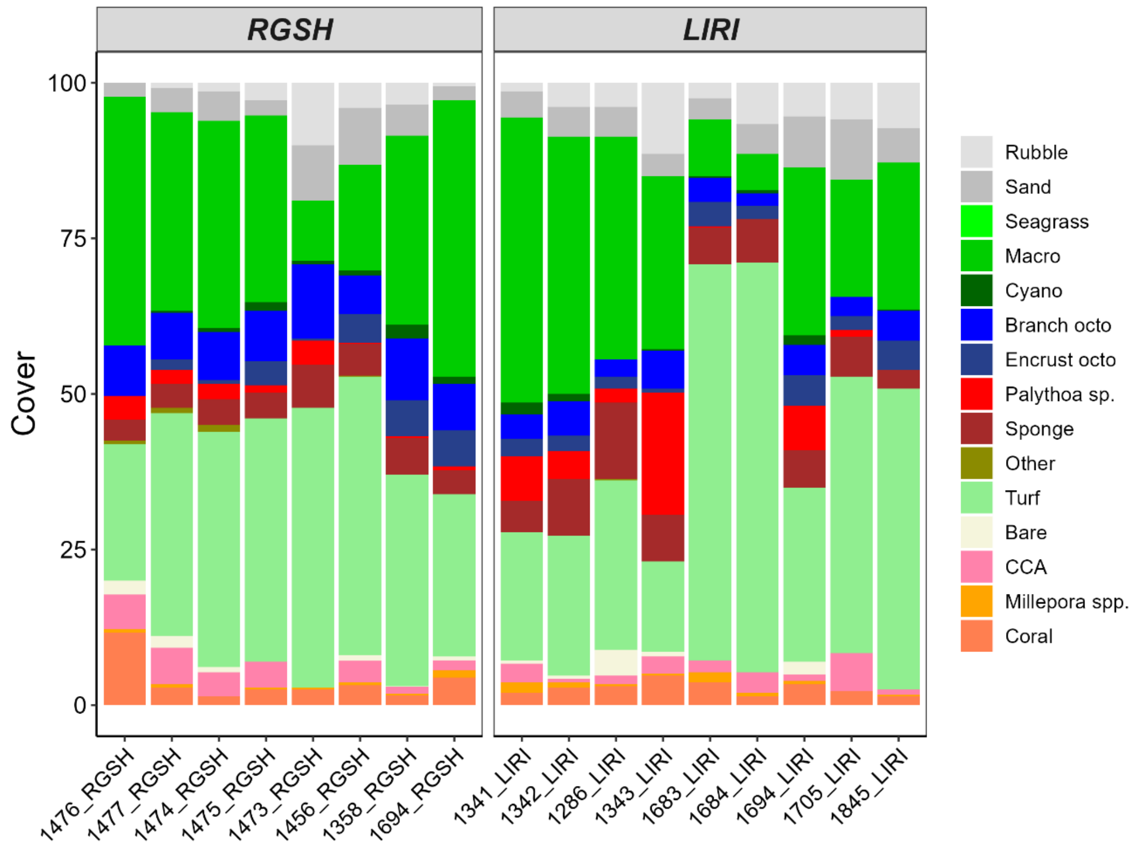

Figure 30. Spatial variation in benthic community composition (% cover) at each Tier 2 site in Miami-Dade County. Panels are divided by habitat and sites arranged North to South within habitat. Note: *Palythoa* sp. refers to *Palythoa caribaeorum*, Encrust octo = encrusting gorgonians, branch octo = branching gorgonians, bare = bare substrate.

Acropora cervicornis abundance at 1476_RGSH and the adjacent 1477_RGSH was an order of magnitude greater than the abundance of other priority species (Figure 31; Table 5). Most of these colonies were healthy, with the densest area of *A. cervicornis* near to the 1476_RGSH centroid, with colonies present in each of the adjoining Tier 2 sites. *Montastraea cavernosa* abundance was highest at 1694_LIRI and 1341_LIRI, with an even spread in colony sizes. *Colpophyllia natans*, *D. labyrinthiformis*, *Orbicella* spp. and *P. strigosa* colonies were less common, but were all comparatively abundant at 1286_LIRI and 1684_LIRI.

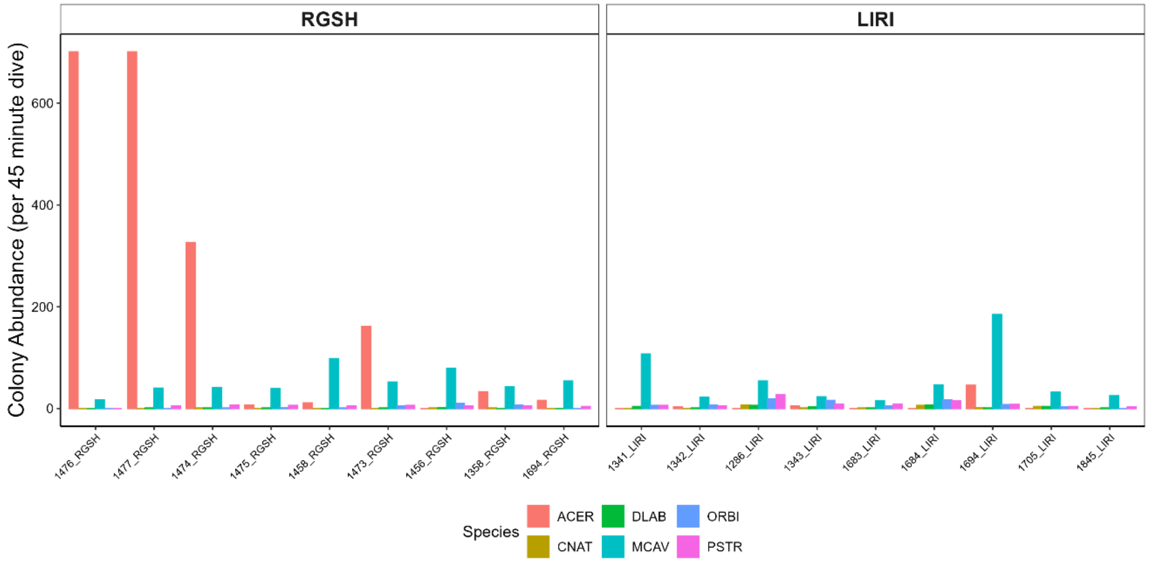

Figure 31. Spatial variation in priority species abundance recorded during 45-minute roving diver survey at Miami-Dade County Tier 2 sites. Sites separated by habitat, where RGSH = nearshore ridge shallow and LIRI = inner reef.

Except at 1476_RGSH, all log10 transformed size-frequency distributions were positively skewed (Figure 32; Table 5). Site 1476_RGSH had the largest overall mean colony diameter and several *A. cervicornis* colonies greater than 100 cm diameter. Site 1473_RGSH also had several colonies with diameters above 50cm, which led to a high coefficient of variation in size-frequency distribution. In addition to an even spread of *M. cavernosa*, 1694_LIRI had high coefficient of variation and relatively high mean colony diameter overall.

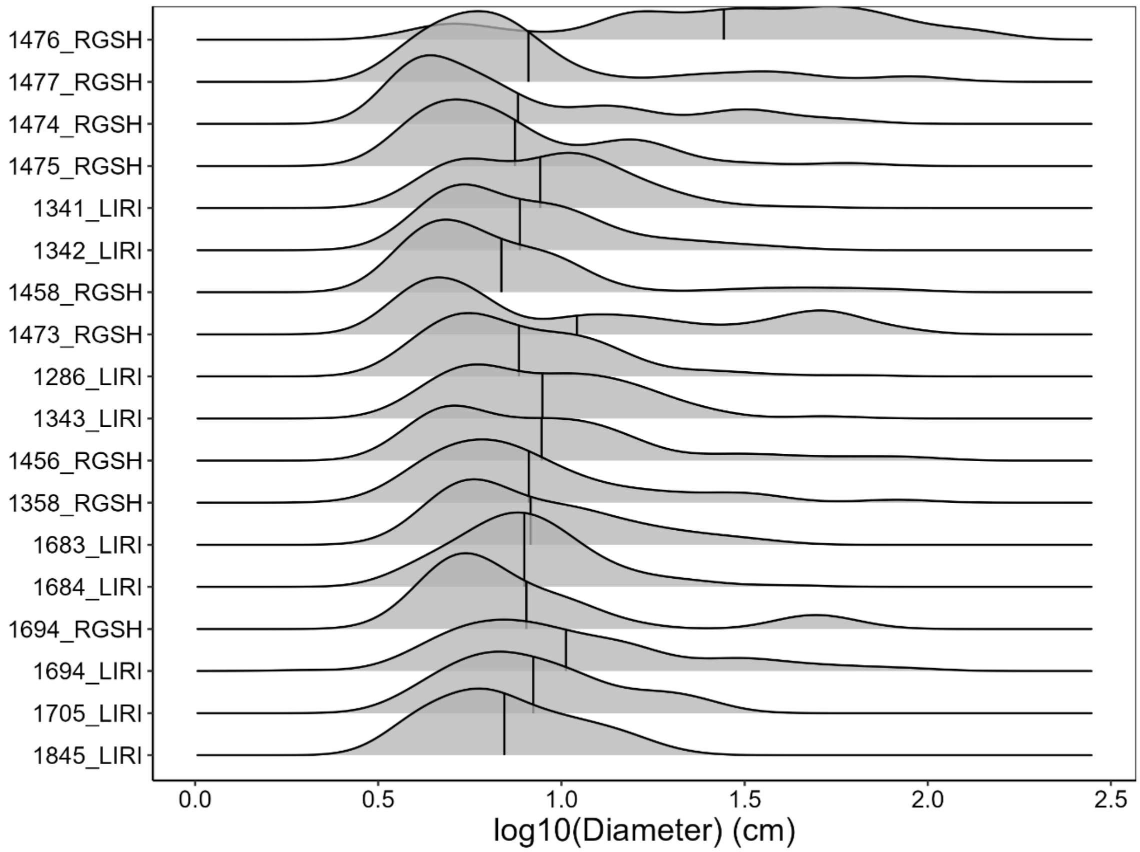

Figure 32. Spatial variation in size-frequency distribution of all coral species colonies using log10-transformed maximum colony diameter. Solid vertical line within histograms represents the mean colony diameter. Frequency estimated by kernel density estimate, which uses kernel smoothing (the weighted average of the observed data) for probability density estimation (using a smoothed histogram). Sites ordered North (top) to South (bottom).

Table 5a. Site rankings from highest to lowest ranked and associated data. Rank = final site ranking quantified using normalized scores from data. Abundance = priority species colony abundance. Species richness = priority species richness. Diameter = mean diameter of priority species colonies, Size classes = mean number of size classes occupied by priority species. Turf height = mean turf algal height. Relief height = mean relief height. SC = stony coral cover. MA = macroalgal/cyanobacterial cover. Loose = sand/rubble cover. PL = *Palythoa caribaeorum* cover Expert rank = 1-5 suitability rank for FCR3 Initiative restoration activities. Recommended Tier 3 sites in bold.

Site	Rank	Abundance	Species richness	Diameter	Size classes	Turf height	Relief height	SC	MA	Loose	PL	Expert rank
1476_RGSH	8.3	718	2	51.5	7.5	7.8	28.7	11.7	40.0	2.2	3.9	1
1694_LIRI	**8.0**	248	6	40.8	5.7	10.6	26.6	3.3	28.5	13.6	7.1	3
1341_LIRI	**7.3**	123	4	35.9	5.0	6.3	37.6	1.9	47.8	5.6	7.2	3
1474_RGSH	7.2	377	6	46.5	4.0	10.2	15.4	1.4	33.9	6.1	2.5	2
1683_LIRI	7.2	31	5	32.1	2.4	6.4	34.8	3.6	9.4	5.8	0.3	3
1358_RGSH	6.8	88	5	52.3	5.2	7.3	18.6	1.5	32.6	8.5	0.3	3
1477_RGSH	6.7	747	4	51.8	5.0	6.6	20.0	2.8	32.2	4.7	2.2	1
1343_LIRI	6.7	57	6	40.0	3.8	7.3	39.0	4.7	28.1	15.0	19.7	3
1473_RGSH	6.3	225	5	39.3	4.4	9.1	13.9	2.5	10.3	18.9	3.9	2
1286_LIRI	6.2	113	5	23.5	4.6	5.0	24.7	3.1	35.8	8.6	2.2	3
1342_LIRI	5.9	38	5	29.0	3.2	7.1	27.4	2.8	42.5	8.6	4.4	3
1694_RGSH	5.9	74	3	53.2	6.0	11.8	20.6	4.4	45.6	2.8	0.6	3
1684_LIRI	5.7	91	5	21.6	4.6	4.2	23.1	1.4	6.4	11.4	0.0	3
1456_RGSH	5.3	97	5	48.1	4.0	10.7	22.6	3.2	17.8	13.2	0.1	2
1475_RGSH	5.0	55	5	47.8	3.4	7.2	15.0	2.5	31.4	5.3	1.1	2
1705_LIRI	4.8	47	5	27.6	3.4	6.8	24.4	2.2	18.9	15.6	1.1	2
1845_LIRI	2.2	29	3	27.4	3.3	5.5	16.9	1.4	23.9	12.8	0.0	1

Table 5b. Site ranking from highest to lowest ranked and associated data. Rank = final site ranking quantified using normalized scores from data. Density = mean adult colony density. Diameter = mean adult colony diameter. Height = mean adult colony height. OM = % old partial colony mortality. CV = coefficient of variation of size-frequency distribution (sfd). Skew = skewness of sfd calculated as the distance from 0, Kurt = kurtosis of sfd calculated as distance from optimal mesokurtic distribution. H' = Shannon diversity. J' = Pielou's J of evenness. Recommended Tier 3 sites in bold. Sites with RGSH are located on nearshore ridge shallow habitat. Sites with LIRI are located on the inner reef.

Site	Rank	Density	Diameter	Height	OM	CV	Skew	Kurt	H'	J'
1476_RGSH	8.3	2.4	40.5	18.0	20.5	28.4	0.4	0.6	0.9	0.5
1694_LIRI	**8.0**	2.5	14.3	6.6	14.8	31.5	0.9	0.5	1.8	0.7
1341_LIRI	**7.3**	4.0	10.0	4.0	7.1	23.0	0.4	0.2	1.4	0.8
1474_RGSH	7.2	1.2	11.1	5.5	9.4	38.6	1.1	0.1	1.7	0.9
1683_LIRI	7.2	3.2	9.7	5.4	10.2	25.2	0.8	0.0	1.7	0.7
1358_RGSH	6.8	1.6	11.0	5.2	8.7	31.6	1.4	1.9	1.8	0.7
1477_RGSH	6.7	1.6	12.9	5.3	9.3	38.4	1.7	1.9	1.7	0.8
1343_LIRI	6.7	2.1	10.5	3.9	7.8	25.0	0.6	0.2	1.5	0.7
1473_RGSH	6.3	1.0	18.9	7.5	14.4	42.6	0.6	1.1	1.8	0.9
1286_LIRI	6.2	4.3	9.1	3.0	5.4	25.8	1.1	1.7	1.8	0.7
1342_LIRI	5.9	4.3	9.1	3.8	4.2	25.8	1.0	0.7	1.7	0.7
1694_RGSH	5.9	1.2	11.6	6.5	6.5	35.0	1.7	1.9	1.5	0.8
1684_LIRI	5.7	3.0	8.8	2.7	6.7	21.2	0.9	1.6	1.5	0.7
1456_RGSH	5.3	1.4	12.5	5.2	12.8	33.1	1.3	1.6	1.9	0.8
1475_RGSH	5.0	1.7	9.5	3.6	9.6	30.6	1.2	1.2	1.6	0.8
1705_LIRI	4.8	2.9	9.5	3.4	7.2	23.3	0.5	0.6	1.7	0.7
1845_LIRI	2.2	1.8	7.7	3.2	8.1	22.1	0.4	0.7	1.8	0.7

PCA found that site 1476_RGSH was substantially different to all others, with higher coral cover, colony size and spread in priority species size (Figure 33). The secondary division of sites found in PCA was along the PC2 axis (Figure 33), which accounted for 24% of variation between sites. PC2 was positively weighted with coral density and mean relief and negatively weighted with coefficient of variation in size-frequency distribution and Pielou's J of evenness. Site 1341_LIRI was strongly positively related to PC2, with high mean relief and high colony density. 1694_LIRI was moderately related to PC1 and PC2 with an even spread in priority species colony sizes and the highest number of priority species (Figure 31). PC3 was negatively related to loose substrate cover (rubble and sand), and to a lesser extent partial colony mortality, as well as size-frequency distribution skewness and kurtosis (Figure 34). Finally, PC4 was negatively weighted by macroalgal cover and *Palythoa caribaeorum* cover.

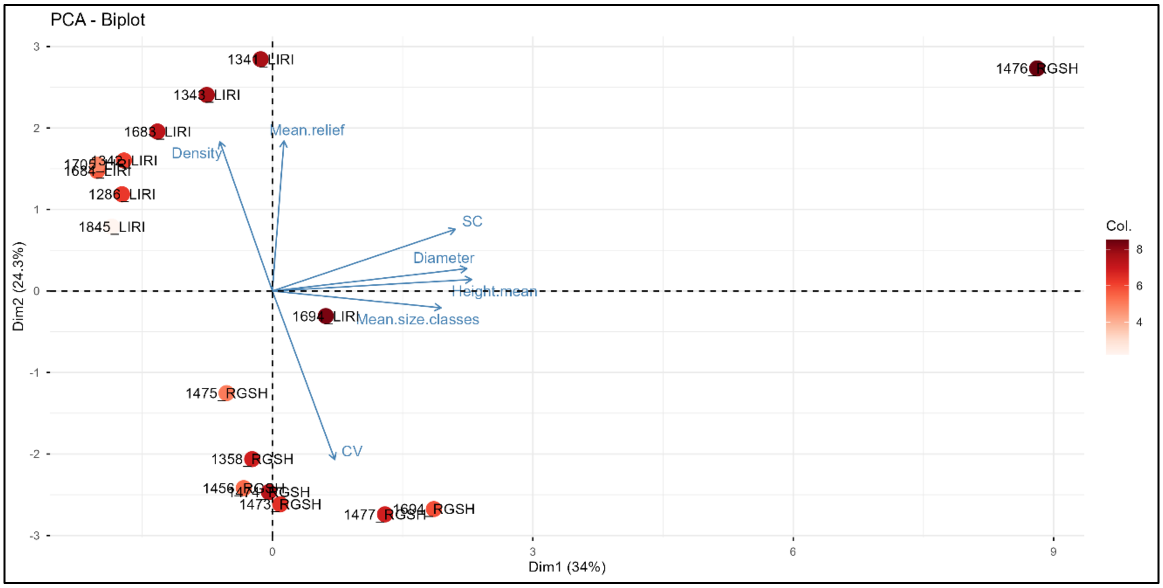

Figure 33. Principal component analysis (PCA) of Miami-Dade County Tier 2 sites. Vectors show metrics accounting for most variation in PC1 and PC2. Points are color coded by site rank.

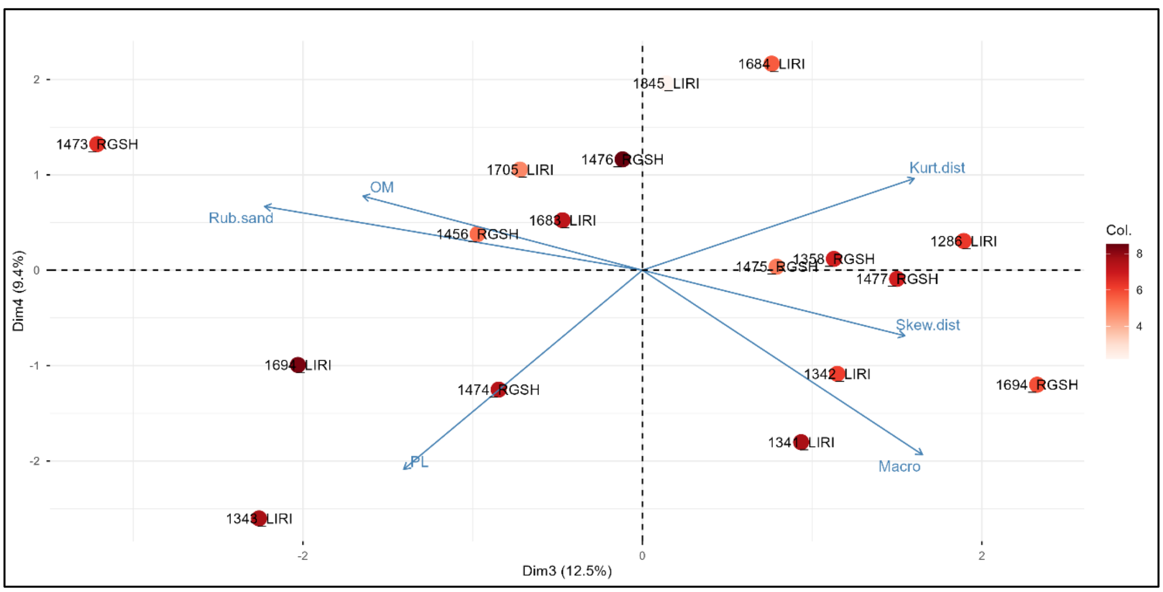

Figure 34. Principal component analysis (PCA) of Miami-Dade County Tier 2 sites. Vectors show metrics accounting for most variation in PC3 and PC4. Points are color coded by site rank.

3.5.2. Tier 3 site recommendations

The highest-ranking site in Miami-Dade County, 1476_RGSH, located off Sunny Isles, had very high *A. cervicornis* density (Table 5), with many large colonies/masses throughout the site. This contributed heavily towards separating it substantially from all other sites in PC1 of the PCA (Figure 30). Despite the high abundance of healthy *A. cervicornis* colonies which meant that priority species abundance, coral cover, and overall, and priority, colony diameter and height was largest, we do not recommend it as an initial Tier 3 site for FCR3 Initiative restoration activities. This is primarily due to amount of free substrate away from *A. cervicornis* colonies, but also the rarity of other priority species colonies and low mean relief which suggests non-Acroporids may not thrive.

Instead, we recommend the second and third highest-ranking sites, 1694_LIRI, which scored nearly as highly as 1476_RGSH and is composed of old spur and groove reefs, and 1341_LIRI as Tier 3 sites (Figure 35). Surveys and results suggest these will be better for the massive species initially being prioritized for FCR3 Initiative restoration activities. Site 1694_LIRI is intertwined with 1694_RGSH. It was evident during roving diver surveys that combining the sites into a single Tier 3 FCR3 Initiative site would make future FCR3 Initiative restoration activities easier and maximize the potential of finding suitable habitat for all priority species to grow. 1694_RGSH was a lower ranking site, but has good substrate for restoration activities and several *M. cavernosa* colonies > 90 cm diameter, indicating potential for survival and substantial growth (Figure 34).

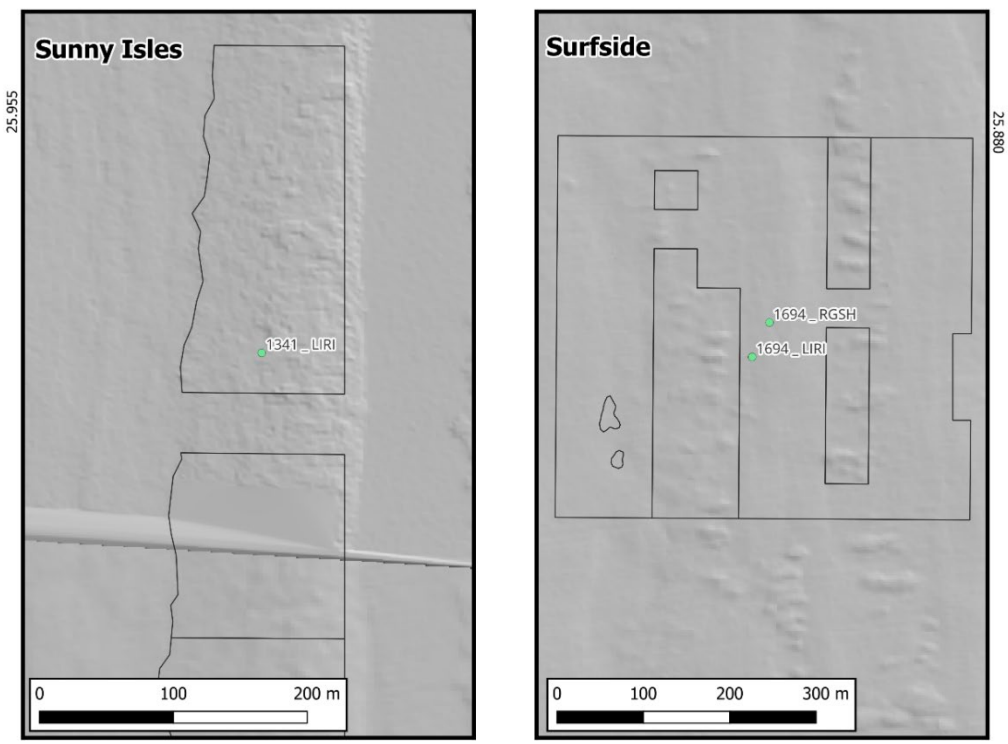

Figure 35. Recommended Tier 3 sites for Miami-Dade County. 1341_LIRI is on the inner reef off Sunny Isles. 1694_LIRI is on the inner reef off Surfside. The polygon for 1694_LIRI is surrounded by 1694_RGSH. It is recommended to group both areas together as a single Tier 3 site.

As the highest-ranking overall site, we suggest monitoring and management of the *A. cervicornis* population at 1476_RGSH (Figure 36) to assess and maintain species persistence in the area, with the potential of expanding FCR3 restoration activities to the site in the future. We also note that prior to adding *P. caribaeorum* cover to differentiate sites in Miami-Dade County, 1343_LIRI was the third highest-ranking site. There are areas within that polygon with lower *P. caribaeorum* cover that will likely be conducive to priority species survival and growth and some reef areas in 1342_LIRI and 1343_LIRI should be considered if expansion outside the recommended site, 1341_LIRI is undertaken in the future.

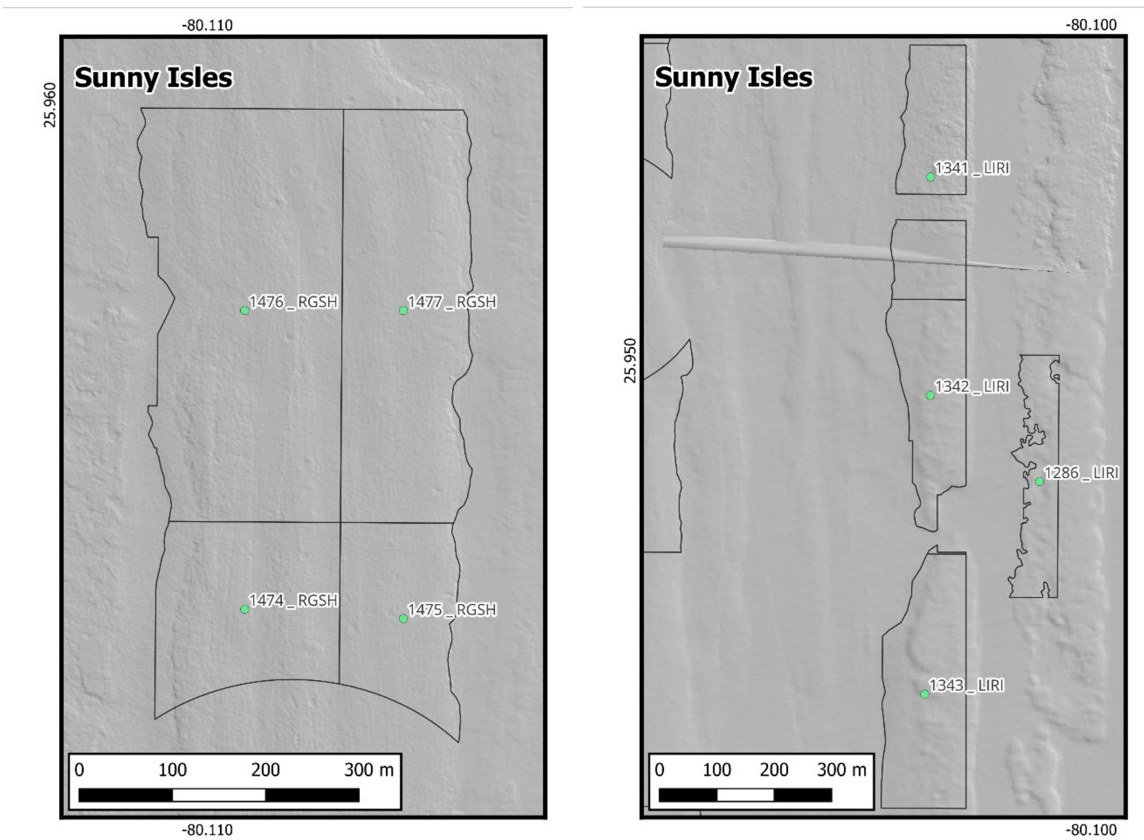

Figure 36. Alternative FCR3 Initiative Tier 3 sites in Miami-Dade County. Left: The highest ranked site in Miami-Dade County, 1476_RGSH and surrounding sites. Right: Site 1343_LIRI ranked highly when *Palythoa caribaeorum* cover was not included. Ground-truthing surveys suggested some reef areas in both 1343_LIRI and 1342_LIRI should be considered for restoration if expansion of the Tier 3 sites is required.

4. References

Baker AC, Lirman D, Akins L, Ditzler H, Ehrenclou L, Fix L, Gilliam DS, Jones NP, Jones S, Miller M, O'Neil K, Paul V, Reckenbeil B, Sneed J, Walker B, Lepiz Conejo F (2024) FY24 Activities of the Southeast Florida Coral Reef Restoration Hub. In: Report FDoEP (ed)

Banister RB, van Woesik R (2021) Ranking 67 Florida reefs for survival of Acropora cervicornis outplants. Frontiers in Marine Science 8:672574

Bauman AG, Chase TJ, Jones NP, Renegar DA, Januchowski-Hartley FA (2025) Putting algal turf sediments in perspective along Florida's Coral Reef. In: Protection FDoE (ed)

Eakin CM, Heron SF, Connolly SR, Devotta DA, Liu G, Geiger EF, De La Cour JL, Gomez AM, Skirving WJ, Baird AH (2026) Severe and widespread coral reef damage during the 2014-2017 Global Coral Bleaching Event. Nature Communications 17:1318

Goergen E, Lustic C, Levy J, Johnson M, Griffin S, Moulding A, Ross A (2025) Guide to coral reef restoration: optimizing efficiency and scale for in situ nurseries and outplanting. NOAA Coral Reef Conservation Program DOI 10

Humanes A, Fabricius KE, Ferrari R, Ortiz JC (2025) Ecological quantitative criteria for reef site prioritisation to maximise survivorship and growth of outplanted corals. Journal of Environmental Management 392:126585

Jones NP, Gilliam DS (2024) Temperature and local anthropogenic pressures limit stony coral assemblage viability in southeast Florida. Mar Pollut Bull 200:116098

Jones NP, Gilliam DS (2025) Geographic Focus Area Determination for Florida's Coral Reef Restoration & Recovery (FCR3) Initiative's Restoration Sites. Award no. C50C5C. . In: Protection. FDoE (ed), Miami, Fl, 1–22

Jones NP, Ruzicka RR, Colella MA, Pratchett MS, Gilliam DS (2022) Frequent disturbances and chronic pressures constrain stony coral recovery on Florida's Coral Reef. Coral Reefs 41:1665–1679

Papke E, Carreiro A, Dennison C, Deutsch JM, Isma LM, Meiling SS, Rossin AM, Baker AC, Brandt ME, Garg N (2024) Stony coral tissue loss disease: a review of emergence, impacts, etiology, diagnostics, and intervention. Frontiers in Marine Science 10:1321271

Florida's Coral Reef Resilience Program (FCRRP) (2024) Ecological Restoration of Florida's Coral Reef: Tier 1 Strategy.

Florida's Coral Reef Resilience Program (FCRRP) (2025) Restoration of the Kristin Jacobs Coral Aquatic Preserve: Tier 2 Plan

Shaver EC, McLeod E, Hein MY, Palumbi SR, Quigley K, Vardi T, Mumby PJ, Smith D, Montoya-Maya P, Muller EM (2022) A roadmap to integrating resilience into the practice of coral reef restoration. Global Change Biology 28:4751–4764

Silliman BR, Hensel MJ, Gibert JP, Daleo P, Smith CS, Wieczynski DJ, Angelini C, Paxton AB, Adler AM, Zhang YS (2024) Harnessing ecological theory to enhance ecosystem restoration. Current Biology 34:R418–R434

R Core Team (2024) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria

Tebbett SB, Bellwood DR (2020) Sediments ratchet-down coral reef algal turf productivity. Science of the Total Environment 713:136709

Supplementary materials

Table S1. Stony coral species with four letter code and predominant growth form.

Four letter code	Species	Growth form
AAGA	*Agaricia agaricites*	Encrusting
ACER	*Acropora cervicornis*	Arborescent
AFRA	*Agaricia fragilis*	Laminar
ALAM	*Agaricia lamarcki*	Laminar
CNAT	*Colpophyllia natans*	Massive
DLAB	*Diploria labyrinthiformis*	Massive
DSTO	*Dichocoenia stokesii*	Submassive
EFAS	*Eusmilia fastigiata*	Corymbose
ISIN	*Isophyllia sinuosa*	Submassive
MALI	*Mycetophyllia aliciae*	Laminar
MANG	*Mussa angulosa*	Submassive
MAUR	*Madracis auretenra*	Digitate
MCAV	*Montastraea cavernosa*	Massive
MDEC	*Madracis decactis*	Digitate
MLAM	*Mycetophyllia lamarckiana*	Encrusting
MMEA	*Meandrina meandrites*	Submassive
OANN	*Orbicella annularis*	Massive
ODIF	*Oculina diffusa*	Digitate
OFAV	*Orbicella faveolata*	Massive
OFRA	*Orbicella franksi*	Massive
ORBI	*Orbicella sp.*	Massive
OROB	*Oculina robusta*	Digitate
PAME	*Phyllangia americana*	Encrusting
PAST	*Porites astreoides*	Encrusting
PCLI	*Pseudodiploria clivosa*	Massive
PDIV	*Porites divaricata*	Digitate
PPOR	*Porites porites*	Digitate
PSTR	*Pseudodiploria strigosa*	Massive
SBOU	*Solenastrea bournoni*	Massive
SCOL	*Scolymia sp.*	Solitary
SCUB	*Scolymia cubensis*	Solitary
SINT	*Stephanocoenia intersepta*	Submassive
SRAD	*Siderastrea radians*	Submassive
SSID	*Siderastrea siderea*	Massive
TCOC	*Tubastraea coccinea*	Submassive

Table S2. Metrics used in Principal Components Analysis and abbreviation in figures 9:10, 16:18, 25:27, 33:34.

Metric and description	**PC vector name**
Priority species abundance	Abundance
Mean priority species colony diameter	Mean.length
Species richness	Priority.spec
Mean number of size classes represented	Mean.size.classes
Shannon diversity	Shannon
Pielous'J Index	Pielou_J
All species density	Density
Mean colony diameter	Diameter
Mean colony height	Height.mean
Coefficient of variation	CV
Distance from Skewness value of 0	Skew.dist
Distance from Kurtosis value of 3	Kurt.dist
Mean percent partial colony mortality	OM
Turf algal height	Turf
Mean relief height	Mean.relief
Stony coral cover	SC
Macroalgal/ cyanobacterial cover	Macro
Palythoa caribaeorum cover	PL
Rubble/ sand cover	Rub.sand

Ground-truthing Standard Operating Procedures for FCR3 Restoration Sites

Site selection

All priority focal area sites are predetermined and include a centroid position with GPS coordinates and a polygon which defines the site. Surveyors should begin at the centroid position and survey within the polygon. Prior to starting the ground-truthing survey, it is therefore essential that each surveyor familiarizes themselves with the polygon size and orientation. When completing the surveys, divers should descend close to the centroid position, very briefly explore the area immediately around the centroid position and determine a representative area to survey. If suitable habitat is not found at the centroid position, surveyors should first attempt to locate coral habitat by searching in a 50 m radius around the GPS coordinate. If no suitable habitat is found within this area attempt a different section of the polygon, recording the GPS coordinates. Repeat as needed. Once, suitable habitat is identified within the polygon, record the GPS coordinates and conduct ground-truthing surveys.

Ground-truthing

Two types of ground-truthing survey will be conducted: benthic transect surveys and a roving diver survey. Each benthic transect survey includes a Line Point intercept (LPI) survey, a belt transect survey, turf algal height measurements and relief height measurements. Each roving diver survey includes a priority coral species survey, *Diadema antillarum* survey and an overall site assessment.

For priority focal areas smaller than 10 hectares in size (approximately 500 m x 500 m), a minimum of 3 benthic transect surveys and 1 roving diver survey must be conducted. For priority focal areas greater than 10 hectares in size, a minimum of 6 benthic transect surveys and 2 roving diver surveys must be conducted in different sections of the polygon.

Benthic Transect Surveys

Equipment: Survey datasheets, 30m fiberglass tape, measuring stick (e.g., 50cm long PVC pipe with ruler attached), 4cm measuring tool (if available), calipers.

Metadata: Site number/name, date, transect number, identifier (if transect split record buddy), site notes (if necessary, list and photograph key features of the site), transect bearing.

Transect setup (Figure 1): Once suitable habitat has been found, as described above under site selection, benthic transects should be laid out haphazardly along the reef, a minimum of 5 meters apart. The transects must be completed over reef substrate where restoration activities are possible on most of the substrate. Avoid large patches of sand or rubble, particularly in first 10m, and if the end of the 30m transect is off the side of the reef, change the transect start position or direction. It is permissible to have small sand patches (e.g., approximately < 2 m diameter) within LPI transects, but these should be avoided for the first 10 m where belt transect surveys will be conducted.

Randomly select the start position and secure the transect tape to a non-living feature on the substrate or using a weight. Roll the tape out 30m, if necessary, in the direction of the prevailing current. Stretch the tape as taut as possible and if needed tie or secure the end to a non-living feature. Begin survey. If there is strong current or surge perpendicular to the transect then limit transect movement by securing the transect at the halfway point using a non-living feature or weight.

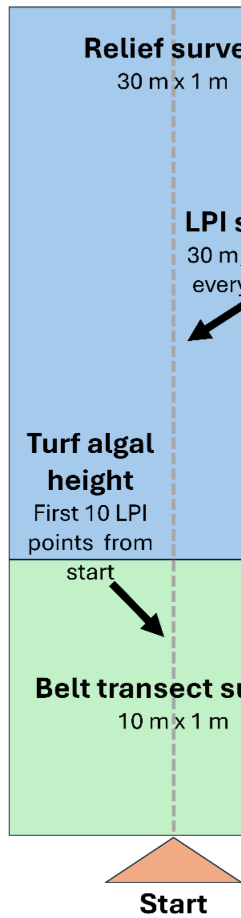

Figure 3. Benthic transect setup. The transect tape (grey dashed line) defines the center point. The belt transect is conducted in the first 10 m x 1 m (0.5 m either side of the transect tape). The line point intercept (LPI) survey is conducted over the full 30 m transect, with turf algal height

Recommended survey order: Complete relief measurements on the way back to the start position and check that the transect tape is relatively straight. Adjust/secure if needed. Next, from 0 m, conduct LPI survey, recording turf algal height measurements for the first 10 turf algal points. Ideally, we want turf measurements in the first 10 m surveyed to compare to juvenile stony coral abundance. When you return to the transect end, roll up the tape from 30m to 10m, then complete the belt transect. Upon completion roll up transect tape and conduct another transect if needed.

Relief survey

After rolling out the transect tape, collect relief measurements within a 30 m x 1 m belt transect as you work back to the start. Within alternating $1m^2$ subplots (50cm either side of the transect tape), measure the highest relief feature (including live stony corals and *Xestospongia muta*) from the seafloor to the top of the feature. For instance, relief height should be measured between the 0 m and 1 m mark, then again from the 2 m to 3 m mark and so on. The 15 relief measurements are recorded to the nearest cm. Adjust the transect tape as needed as you complete the rugosity measurements to establish the transect.

<u>Line Point Intercept (LPI) survey</u>

Beginning at the start of the transect, at 25 cm intervals along the transect tape, identify the benthic taxa directly underneath the tape according to the broad benthic categories listed below. Identify points objectively and avoid bias to favored substrates. If a point intercepts with the canopy cover of a soft branching organism (e.g., arborescent gorgonians or foliose macroalgae) or a benthic organism encrusting a dead soft branching organism (e.g., *Millepora* spp. overgrowing a gorgonian branch) then record the benthic taxa underneath that feature. Points intercepting the holdfast/attachment of such taxa are valid and should be recorded.

Benthic categories and descriptions:

1. **Stony Coral** (identified to species)
2. ***Millepora* spp.**
3. **Substrates** should be identified as:
    a) **Bare substrate**: uncolonized consolidated hardbottom or coral skeleton which is attached to the benthos. Can have a shallow veneer of sand < 2.5 cm deep
    b) **Rubble**: loose substrate or coral skeleton with grain size > 2.5 cm and moveable
    c) **Sand**: loose substrate ≤ 2.5 cm grain size and ≥2.5 cm depth
4. **Turf algae**: visible algal tufts or filaments
5. **Macroalgae**: Fleshy algae e.g., *Dictyota* spp., *Halimeda* spp.
6. **Crustose coralline algae (CCA)**
7. **Seagrass**
8. **Cyanobacteria**
9. **Gorgonians**:
    a) **Branching**: arborescent gorgonians. Record basal attachment only, not canopy cover
    b) **Encrusting**: *Briareum asbestinum* when maximum length > height and *Erythropodium caribaeorum*
10. **Sponges**
11. ***Palythoa caribaeorum***
12. **Other** – e.g., hydroids, anemones, corallimorphs, zoanthids other than *P. caribaeorum*, bryozoans, tunicates

Turf algae height: The first 10 points which intercept turf algae should be measured with calipers to the nearest millimeter. Use the pointed base of the calipers to ensure measurements are taken from the underlying hardbottom to the top of the blade/filament.

Belt transect survey

Between the start of the transect and the 10 m mark, conduct a coral demographic belt transect survey. The belt transect center is defined by the transect tape and the belt transect should encompass 50 cm either side of the transect tape to total 10 m x 1 m. Within the belt transect, record to species and measure every live adult stony coral colony (≥ 4 cm maximum diameter) and tally to species, or the lowest taxonomic unit, every live stony coral colony juvenile (< 4cm maximum diameter).

A live colony is defined as any coral colony with any amount of living tissue within the belt transect. For each adult colony, measure the maximum diameter and height to the nearest centimeter and assess the colony health status. The maximum diameter is defined as the widest area of skeletal growth. The height should be measured from the lowest point of skeletal growth to the highest point of skeletal growth. For both adult and juvenile colonies, attempt to identify the colony boundary and include this in the maximum diameter measurement. If isolates of a large colony are found, record the maximum diameter of the entire colony as closely as possible and estimate the percent partial colony mortality. This is particularly important to avoid recording adult colonies that have shrunk due to partial colony mortality as juveniles.

The health status assessment should record the percentage of old colony mortality, percentage and cause of recent mortality (e.g., disease or predation) and any incidence of bleaching. Mortality should be recorded as a percentage and recorded to the closest 5%, unless mortality is very small (i.e., < 5%) or large (i.e., > 95%), in which case measure it to the closest whole number. Old mortality is defined by the absence of corallite structure and/or overgrowth by algae or another living organism. Recent mortality is defined as white skeleton, or a very thin film coating over the skeleton, with intact calyx structure and no living tissue. Recent mortality must be accompanied by a condition code in the notes section which details the cause of recent mortality, if known. Please include colonies that are 100% recently dead.

Possible recent mortality causes include:
PRD = Predation
TRS = Thermal Stress
WPL = White Plague Disease
WBD = White Band Disease
WPX = White Pox Disease
RTL = Rapid Tissue Loss
BBD = Black Band Disease
RBD = Red Band Disease
YBD = Yellow Band Disease
DSD = Dark Spot Disease
OGI = Overgrowth/Interaction by an organism which is causing mortality
ABR = Abrasion
DAM = Damage
UNK = Unknown cause

CIL = Ciliates
CDL = Cliona delitrix
CLN = unknown Cliona species

Bleaching should be recorded as PAL = Paling, PBL = Partial colony bleaching, BLH = Whole colony bleaching. If the suspected cause of this is not related to thermal stress, the recorder should note the suspected cause of color loss in the notes/conditions column. Diseases or conditions which do not result in tissue loss, e.g., Dark Spot Disease (DSD) or *Cliona delitrix*, can be listed as conditions in the conditions/notes column.
Juvenile colonies which are not attached to the substrate should not be recorded. Adult coral colonies that are unattached should be recorded if they cannot be moved by gentle pressure. For example, do not record a small, unattached *Acropora cervicornis* branch if it moves when gentle pressure is applied, but do record a medium-large, unattached boulder coral colony if it does not move under gentle pressure.

Roving diver survey

Equipment: Survey datasheets, measuring stick (e.g., 50cm long PVC pipe with ruler attached)

Metadata: Site number/name, date, survey duration, identifier, maximum survey depth, minimum survey depth, site notes (make note of site condition, particularly any excessive damage e.g., sheared *Xestospongia muta*, an abundance of trash, discarded fishing gear/lobster pots etc.)

Priority coral species survey

The surveyor will complete a 45-minute timed swim around the site, starting from the centroid position (or first area of suitable reef habitat), where they search for FCR3 priority restoration species (*Acropora cervicornis*, *A. palmata*, *Colpophyllia natans*, *Diploria labyrinthiformis*, *Montastraea cavernosa*, *Orbicella* spp., and *Pseudodiploria strigosa*). Divers should follow a defined search pattern (e.g., U-shaped pattern, expanding circle) to cover as much reef area within the priority focal area as possible, while minimizing overlap.

During the survey, the surveyor will tally by size class all adult priority species colonies observed (≥ 4 cm maximum diameter). Colonies should be quickly assessed for health status and bleaching, disease and predation tallied by species independently of size class. The disease type should be noted when tallying disease. If there are multiple disease types per species, tally by the disease type within the box if possible or use multiple data sheets. Bleaching includes partial or whole colony bleaching only and should be tallied together in the respective column.

Diadema antillarum survey

During the roving diver survey, surveyors must tally the abundance of *Diadema antillarum* within the surveyed area. The surveyor should perform this survey simultaneously with the priority coral species survey and not alter their search pattern excessively to search for *D. antillarum*.

Overall site assessment

While completing the roving diver survey, the surveyor must complete an overall site assessment. During this, the surveyor should assess the sites suitability for restoration activity, including noting habitat suitability, the condition of coral colonies and if there is any excessive damage, trash or discarded fishing gear etc. within the surveyed area. If there is no excessive trash or discarded fishing gear, please record as such. The surveyor should also record in detail any defining features of the site, e.g., high reef complexity, large sand patches (>5 m diameter) etc. Upon completing the assessment, the surveyor, likely after discussion with the other divers, should assign the site an overall expert rank, on a 1 to 5 scale, where 1 = unsuitable for restoration (e.g., excessive damage and limited available substrate), 3 = moderately suitable for restoration, with some reservations (e.g., multiple large sand patches), 5 = highly recommended for restoration activity.