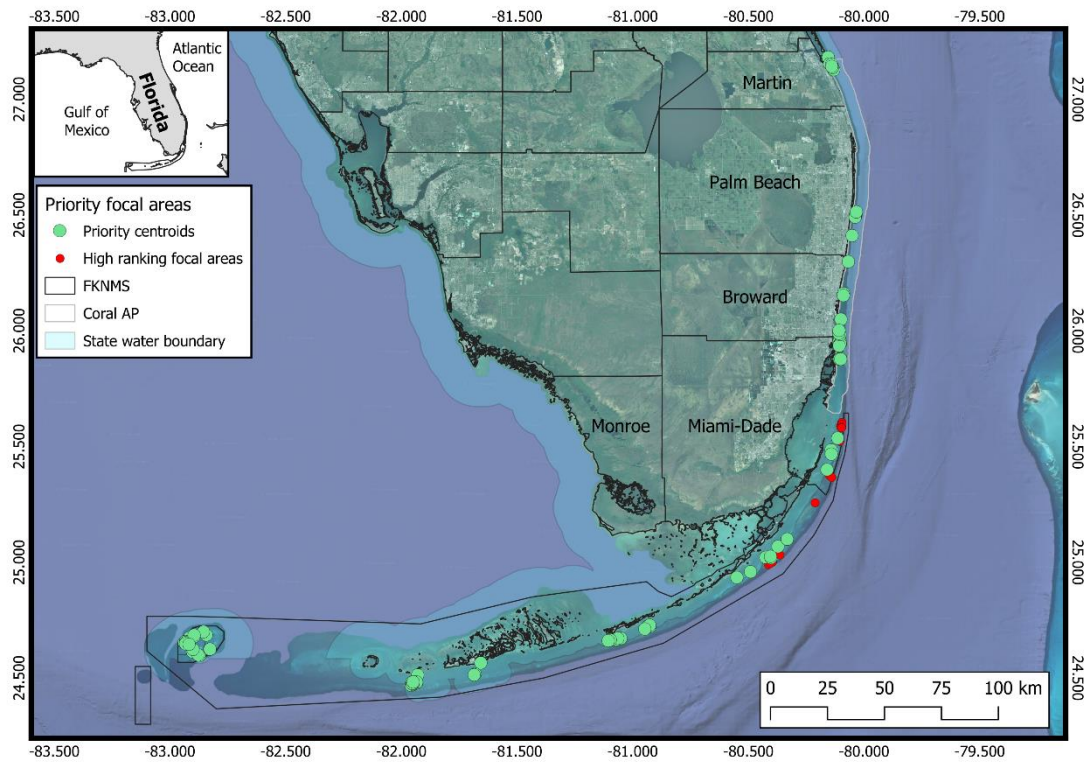


Geographic Focus Area Determination for Florida's Coral Reef Restoration & Recovery (FCR3) Initiative's Restoration Sites



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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 that underpin this ecologically and economically important resource. Governor DeSantis directed the establishment of Florida's Coral Reef Restoration and Recovery (FCR3) Initiative to support the long-term recovery of no less than 25% of FCR by 2050. Utilizing expert knowledge and the best available data, this project evaluated and selected 25% of the most suitable restoration area within state waters to ground-truth. We used Florida's Coral Reef Resilience Program's tier 1 strategy, which identified high larval connectivity areas with the presence of priority coral species, as a starting point. We then calculated 16 ecological and environmental metrics from in situ, satellite and modelled data to evaluate the suitability of 659 focal areas for coral restoration success. Focal area evaluation and ranking was conducted in a multi-step process and balanced coral demographics which reflect a reefs ability to support coral populations, with climate and water quality metrics known to influence coral survival. Metrics were spatially joined to focal areas, normalized within geographic areas and the focal area ranking score calculated from the magnitude and direction of influence of each metric. Priority focal areas for ground-truthing were selected as the top-ranking focal areas that accounted for 25% of the total area in state waters per county. 106 priority focal areas for ground-truthing were identified within state waters across the five FCR counties. A further 19 high priority focal areas were identified outside state waters that ranked above the 80th percentile overall. The recommended priority and high-ranking focal areas for ground-truthing are the locations on FCR where restoration activities using priority species are predicted to be most successful.

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 no less than 25% of FCR by 2050. Utilizing expert knowledge and the best available data, this project evaluated and selected 25% of the most suitable restoration area within state waters to ground-truth before restoration activities commence.

We used Florida's Coral Reef Resilience Program's tier 1 strategy, which identified high larval connectivity areas with the presence of priority coral species, as a starting point. We then calculated 16 ecological and environmental metrics from in situ, satellite and modelled data to evaluate the suitability of 659 tier 1 focal areas for coral restoration success. Focal area evaluation and ranking was conducted in a multi-step process and balanced coral demographic metrics which are known to reflect a reefs disturbance history and ability to support coral populations, with climate and water quality metrics known to influence coral survival. Metrics were spatially joined to tier 1 focal areas, normalized within geographic areas and the focal area ranking score calculated from the magnitude and direction of influence of each metric. Priority species density, species richness and mean colony diameter were determined to be the best predictors of restoration success and given extra weight in the calculation. Focal area ranks were calculated separately for the Kristin Jacobs Coral Aquatic Preserve, the Florida Keys and the Dry Tortugas due to differences in water quality metric calculations, then ranks compared within counties. Ranks were initially calculated for all focal areas and then recalculated only considering focal areas within state waters. Priority focal areas for ground-truthing were selected as the top-ranking focal areas that accounted for 25% of the total area in state waters per county. Any focal areas outside state waters that ranked above the 80th percentile overall regardless of county were also recommended for ground-truthing.

One hundred and six priority focal areas for ground-truthing were identified within state waters along FCR. Six priority focal areas were identified in Martin County, nine in Palm Beach County, 10 in Broward County, 19 in Miami-Dade County, and 62 in Monroe County. Evaluations identified a further 19 high-ranking focal areas outside state waters, 10 in Biscayne National Park and 9 in the Florida Keys National Marine Sanctuary, where restoration is most likely to be successful. Combined, the priority focal areas and high-ranking focal areas account for 25% of suitable tier 1 focal area for restoration.

The recommended priority focal areas and high-ranking focal areas are the locations on FCR where restoration activities using *Acropora cervicornis*, *Diploria labyrinthiformis*, *Montastraea cavernosa*, *Orbicella* spp. and *Pseudodiploria strigosa* are predicted to be most successful. Spatial comparisons with shoreline protection projections also suggest restoration in many of the priority focal areas would have positive benefit-to-cost ratios and provide protection from flooding under a hybrid reef scenario.

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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. 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.

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 will also prioritize enhancing shoreline protection and strengthening Southeast Florida's coastal economy. Final site selection for FCR3 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 Florida Keys National Marine Sanctuary (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. Initial discussions with experts and management determined that the base for this project was to use the focal areas identified in tier 1's four species model, which evaluated locations using *Acropora cervicornis*, *Montastraea cavernosa*, *Orbicella* spp, and *Pseudodiploria strigosa*. Utilizing expert knowledge and the best available data, this project evaluated and

refined the tier 1 focal areas (Figure 1) and selected 25% of the total area within state waters to ground-truth for FCR3 (Table 1).

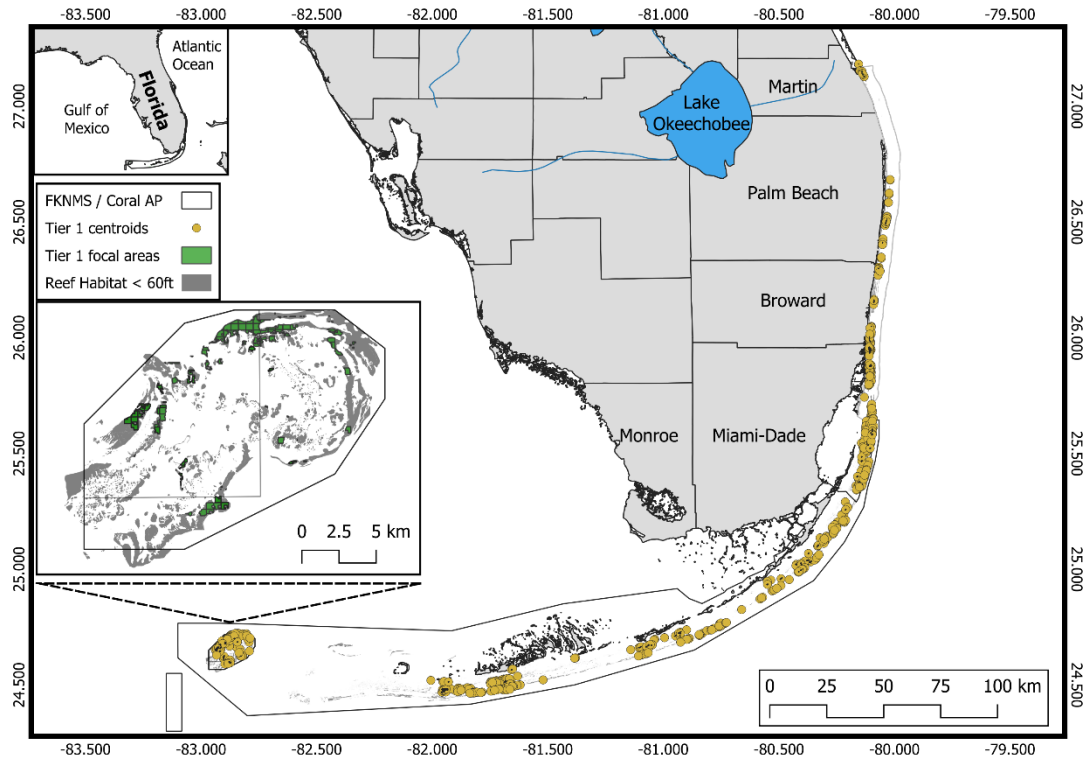


Figure 1. Tier 1 focal areas (green boxes) and centroids (yellow circles) across Florida's Coral Reef. Inset top left: Florida peninsula. Inset middle left: Dry Tortugas National Park with reef habitat in dark grey, and tier 1 focal area centroids.

Table 1. Number of focal areas and total area of focal areas identified in tier 1 four species model. Note, many tier 1 focal areas were outside state waters. The suggested survey area for ground-truthing was determined as 25% of the total tier 1 focal area within state waters. * Due to the low number, it is recommended that all focal areas in Martin County are ground-truthed.

County	Number of focal areas	Total tier 1 area (hectares)	Tier 1 area in state waters (ha)	Suggested survey area (ha)
Martin	6	73.90	73.90	73.90*
Palm Beach	33	51.68	51.68	12.92
Broward	28	88.51	88.51	22.13
Miami-Dade	192	770.52	524.05	131.37
Monroe	406	2013.57	1563.18	397.91

2. Methods

After discussions with experts and management, it was determined that this project would use existing environmental and ecological data to evaluate the probability of coral restoration success in the tier 1 focal areas. Using satellite, modelled and in situ data sources, we quantified metrics previously identified to influence coral survival and health (e.g., temperature, water quality, disease) or current coral demographic data (e.g., coral density), which gives insight into a location's suitability for restoration, across FCR (Table 2). These metrics were then summarized in each tier 1 focal area and ranked to identify priority focal areas which are predicted to maximize restoration success. The priority focal areas could then be compared to the tier 2 effort being undertaken by The Nature Conservancy, which assessed focal areas based upon their benefit to shoreline protection, fisheries and tourism.

Table 2. Metric = evaluation metrics; Data type = type of data used to calculate metric; Source = data source or project which collected the data. DRM = Disturbance Response Monitoring, NCRMP = National Coral Reef Monitoring Program, CREMP = Coral Reef Evaluation and Monitoring Project, SECREMP = Southeast Florida Coral Reef Evaluation and Monitoring Project, NOAA CRW = NOAA Coral Reef Watch, SFWQA = Southeast Florida Reef Tract Water Quality Assessment Project, SERC = Southeast Environmental Research Center; 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	Data type	Source	Influence on restoration	Rationale	Reference
Priority species density	In situ	DRM NCRMP	Positive (2x)	Recruitment and survival of priority coral species	
Species richness	In situ	DRM NCRMP	Positive (2x)	Supports coral diversity	
Mean colony diameter	In situ	DRM NCRMP	Positive (2x)	Supports coral colony growth	
All species density	In situ	DRM NCRMP	Positive	Supports coral colony survival	
Coefficient of variation	In situ	DRM NCRMP	Positive	Supports a range of colony sizes, including sexual recruits and colony growth to large sizes	
Change in priority species abundance	In situ	CREMP SECREMP	Positive	Directly supports priority coral species recruitment and survival	

Skewness	In situ	DRM NCRMP	Negative	Limited recruitment, growth or survival of colonies	
Kurtosis	In situ	DRM NCRMP	Negative	Limited colony growth into larger size classes	
Bleaching score	In situ	DRM NCRMP	Negative	Increased coral bleaching risk	
Maximum DHW	Satellite	NOAA CRW	Negative	Increased risk of bleaching and direct mortality ^{1,2,3}	¹ Hughes et al. 2017 ² Jones et al. 2020 ³ Toth et al. 2021
Mean DHW	Satellite	NOAA CRW	Negative	Increased risk of bleaching and mortality ^{1,2,3}	¹ Hughes et al. 2017 ² Jones et al. 2020 ³ Toth et al. 2021
SST trend	Satellite	NOAA CRW	Negative	Increased susceptibility to future bleaching and mortality ^{1,2,3}	¹ Hughes et al. 2017 ² Jones et al. 2020 ³ Toth et al. 2021
Maximum DIN	In situ	SEWQA SERC	Negative	Increased disease/bleaching susceptibility ^{4,5} . Algal overgrowth ^{6,7,8}	⁴ Lapointe et al. 2019 ⁵ Vega Thurber et al. 2014 ⁶ Lapointe 1997 ⁷ Fabrizius 2005 ⁸ Jones et al. 2025
Maximum NH ₃	In situ	SEWQA SERC	Negative	Colony immune suppression ⁸ . Increased disease/bleaching susceptibility ^{8,9} . Reduced fecundity ¹⁰	⁸ Jones et al. 2025 ⁹ Palacio-Castro et al 2025 ¹⁰ Ward & Harrison 2000
Mean SiO ₄	In situ	SEWQA SERC	Negative	Increased freshwater input ¹¹ . Increased macroalgal abundance ¹²	¹¹ Tréguer and De La Rocha 2013 ¹² Jones & Gilliam 2024
Disease probability	Modelled	Jones et al. 2025	Negative (0.5x)	Increased disease susceptibility ⁸	⁸ Jones et al. 2025

2.1. Environmental data

Satellite data from National Oceanic and Atmospheric Administration Coral Reef Watch (NOAA CRW 2018) was used to calculate three metrics associated with spatiotemporal variation in heat stress across FCR. Maximum annual degree heating week (DHW) data was extracted from 2015 to 2024 at 5 km resolution across FCR. Maximum DHW at each FCR pixel was calculated as the maximum annual DHW over the period and mean DHW calculated as the mean of the maximum DHW from 2015 to 2022. This period was chosen as the 2023 marine heatwave overly influenced mean DHW, leading to covariance between mean and maximum DHW. To reflect climate change driven ocean warming, the mean sea surface temperature (SST) trend was calculated at each FCR pixel from monthly SST data between 1986 and 2024. A linear model with year x pixel was fitted, and the linear trend extracted.

Disease probability was calculated following Jones et al. (2025). Briefly, a predictive binomial generalized linear mixed model (GLMM) was created using environmental conditions identified as significantly affecting stony coral tissue loss disease (SCTLD) susceptibility in *Montastraea cavernosa* (Equation 1).

$$\text{Disease probability} \sim \text{Maximum temperature} + \text{Maximum PAR} + \text{Three-month mean temperature} + \text{Maximum chlorophyll-a} + \text{Three-month mean PAR} + \text{Maximum temperature: Maximum chlorophyll-a} + \text{Maximum chlorophyll-a: Three-month mean PAR} \quad (1)$$

The most recent available environmental data was used to predict spatial variation in disease susceptibility across FCR. Monthly chlorophyll-a concentrations and PAR were extracted from NASA's Modis aqua satellite from 2021 to 2024. The maximum chlorophyll-a concentration and maximum PAR were calculated as the mean of the maximum annual values at each satellite location. The three-month mean PAR was calculated as the mean annual PAR value at each satellite location. Maximum and three-month mean temperatures were calculated using in situ data from 2021 to 2022 at Coral Reef Evaluation Monitoring Project (CREMP) and Southeast Florida Coral Reef Evaluation and Monitoring Project (SECREMP) sites, as data was only available in the Florida Keys until mid-2023. The maximum temperature was calculated as the mean of the annual maximum at each site and the three-month mean as the mean temperature in the summer months (July, August and September). The environmental regime was then calculated at each Florida Reef Resilience Program's (FRRP) Disturbance Response Monitoring (DRM) site surveyed throughout FCR in 2023 (n = 423) using a spatial join between the closest one to three satellite or CREMP/SECREMP sites, depending on distance between sites. This current environmental regime was used in the fitted disease susceptibility GLMM, with *M. cavernosa* abundance at the DRM site used as the weights. No random effect structure was incorporated to give equal chance of disease prevalence across FCR.

Three water quality metrics which either directly influence coral health (Vega Thurber et al 2014; Lapointe et al. 2019; Jones & Gilliam 2024; Jones et al. 2025; Palacio-Castro et al. 2025) or are proxies for freshwater input were quantified using data collected as part of

the Southeast Florida Reef Tract Water Quality Assessment Project (SEWQA) and in the Florida Keys by the Southeast Environmental Research Center (SERC). Maximum dissolved inorganic nitrogen (DIN) concentration, which encompasses nitrate, nitrite and ammonia, and maximum ammonia concentration, where measurements encompass NH_3 and free NH_4^+ ions, were calculated as the mean of the maximum annual concentration at each reef site. In the Kristin Jacobs Coral Reef Aquatic Preserve (Coral AP), maximum concentration was calculated as the mean of the maximum from 2021 to 2024 from bottom samples collected at reef sites. In the Florida Keys, maximum concentration was calculated as the mean of the maximum from 2021 to 2022. Mean silicate concentration, which reflects freshwater input (Tréguer and De La Rocha 2013) and has been related to increased macroalgal abundance on FCR (Jones & Gilliam 2024), was calculated as the mean monthly silicate concentration between 2021 and 2024 in the Coral AP and between 2021 and 2022 in the Florida Keys.

For each metric, inverse distance weighted interpolation was conducted in QGIS at 0.05° resolution with a distance coefficient, which controls the spatial rate of decay, of 10. Interpolations for maximum DHW, mean DHW and SST trend were used for visualization only. Interpolations for disease probability and the three water quality metrics, maximum DIN, maximum NH_3 and mean SiO_4 were used to quantify metric values across FCR at 0.05° resolution. The interpolated raster layer was then converted to centroid positions in QGIS.

2.2. Ecological data

Benthic monitoring data collected as part of CREMP, SECREMP, DRM and the National Coral Reef Monitoring Program (NCRMP) were compiled across FCR from 2005 to 2023. In each project, coral colonies are identified to species, measured and health status (e.g., bleaching presence) assessed along belt transects at fixed (CREMP/SECREMP) or random (DRM/NCRMP) sites. To create ecological metrics, only coral colonies equal to or greater than 4 cm maximum diameter were included and data were pooled to the site level.

To reflect bleaching history, a bleaching score was calculated at each DRM and NCRMP site, which weighted bleaching prevalence by coral community composition (equation 2).

$$\text{Bleaching score} = \frac{(\sum(\text{Bleaching prevalence}_i \times \text{Susceptibility}_i))}{\text{Species richness}} \quad (2)$$

Where, for each species at a site bleaching prevalence equals the number of bleached colonies (≥ 4 cm) of species i (totally or partially bleached) divided by the total number of colonies (≥ 4 cm) of species i . Each species was assigned a bleaching susceptibility score of 1, 2 or 3 (Table 3) based upon data from Wagner et al. (2010), Smith et al. (2013) and Jones and Gilliam (unpublished). Rare species lacking detailed bleaching susceptibility data were omitted.

Table 3. Coral species bleaching susceptibility and score based upon literature review and in situ field studies.

Bleaching susceptibility	Bleaching score	Species
High	3	<i>Agaricia agaricites</i> , <i>Acropora cervicornis</i> , <i>A. palmata</i> , <i>A. prolifera</i> , <i>Stephanocoenia intersepta</i> , <i>Siderastrea radians</i>
Medium	2	<i>Colpophyllia natans</i> , <i>Diploria labyrinthiformis</i> , <i>Montastraea cavernosa</i> , <i>Mycetophyllia aliciae</i> , <i>Orbicella faveolata</i> , <i>O. annularis</i> , <i>O. franksi</i> , <i>Porites astreoides</i> , <i>P. porites</i> , <i>P. divaricata</i> , <i>P. furcata</i>
Low	1	<i>Dichocoenia stokesii</i> , <i>Eusmilia fastigiata</i> , <i>Madracis decactis</i> , <i>Meandrina meandrites</i> , <i>Pseudodiploria strigosa</i> , <i>P. clivosa</i> , <i>S. siderea</i> , <i>Solenastrea bournoni</i>

Coral density, priority species density (*C. natans*, *D. labyrinthiformis*, *M. cavernosa*, *O. annularis*, *O. faveolata*, *O. franksi* and *P. strigosa*) and species richness were calculated at each DRM and NCRMP site surveyed from 2020 to 2023. Multiple size structure metrics, which reflect disturbance history and coral population health, were also quantified at each DRM and NCRMP site surveyed from 2020 to 2023. Mean colony diameter was calculated from untransformed data, coefficient of variation ($CV = \log_{10}(\text{standard deviation})/\log_{10}(\text{mean})$), skewness and kurtosis were calculated from size frequency distributions of the log10-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 change in priority species density from 2013 to 2023 was calculated at each CREMP and SECREMP site. This captures spatial variation in recruitment and mortality, with the latter in particular, crucial for restoration success. The change in priority species density was calculated as the relative change in priority species abundance to account for differences in density (Equation 3).

$$\text{Relative change (\%)} = ((T_1 - T_0)/T_0) \times 100 \quad (3)$$

Where, T1 is the summed abundance of priority species at each site in 2023 and t0 is the abundance in 2013.

2.3. Focal area evaluation and ranking

Focal areas evaluation and ranking was conducted in a multi-step process (Figure 2). First, the centroid position of the tier 1 focal areas was calculated. Next, the 16 environmental and ecological metrics were spatially joined to nearby tier 1 focal areas for evaluation, scoring and ranking. Maximum DHW, mean DHW, SST trend, disease probability and water quality (DIN, NH₃ and SiO₄) in a tier 1 focal area were calculated by averaging the value of the two closest satellite or raster points following a nearest neighbor join within 0.05 degrees of the tier 1 focal area centroid. No water quality data was available for the

Dry Tortugas, therefore those tier 1 focal areas were evaluated separately to the rest of Monroe County. The relative change in priority species abundance in a tier 1 focal area was calculated by averaging the closest two CREMP/SECREMP sites after an unrestricted nearest neighbor spatial join. All other ecological metrics were calculated using a spatial join to up to 20 DRM/NCRMP sites within 1.5 km. If no DRM or NCRMP surveys had been conducted within 1.5km of a tier 1 focal area then the focal area was omitted from evaluation. Tier 1 focal areas under 1-hectare total potential restorable area (100m²) in Miami-Dade and Monroe counties were also omitted as it was determined these were too small to be cost-effective for FCR3.



Figure 2. Focal area evaluation and ranking flow chart.

Once all focal area 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 between 0 and 1, which was more suitable for ranking focal areas. Data were normalized separately for the Coral AP, Florida Keys and Dry Tortugas. Prior to normalization, 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).

The direction and magnitude of influence of each metric on the focal area rank was determined by literature review and expert opinion. Priority species density, overall density, species richness, mean colony diameter, coefficient of variation and change in priority species abundance were considered to be positive metrics and added. Skew, kurtosis, bleaching score, max DHW, mean DHW, SST trend, max DIN, max NH₃, mean SiO₄ and disease probability were considered to be negative metrics and subtracted. Priority species density, species richness and mean colony diameter were determined to be the most important factors and double weighted. Disease probability was only calculated on *M. cavernosa*, so it was down weighted to 50% importance. All other metrics were given equal weighting (100%). The total score a focal area could attain was 9 if it was the top-ranking focal area for all positive metrics and the lowest scoring metric for all negative metrics, and the lowest, -9.5, if it scored highly on all negatively associated metrics.

Focal area ranks were calculated for the Palm Beach, Broward, Miami-Dade, the Florida Keys and Dry Tortugas separately due to differences in the calculation of or lack of water quality metrics. Ranks were initially calculated for all focal areas and then recalculated only considering focal areas within state waters. Priority focal areas for ground-truthing were selected as the top-ranking focal areas that accounted for 25% of the total area in state waters per county. Any focal areas outside state waters that ranked above the 80th percentile overall regardless of county were also recommended for ground-truthing. All maps were created in QGIS version 3.38 (QGIS development team 2024).

3. Results

One hundred and six priority focal areas for ground-truthing were identified within state waters along FCR (Figure 3). Evaluation identified a further 19 high-ranking focal areas outside state waters, in Biscayne National Park and the Florida Keys National Marine Sanctuary (FKNMS), where restoration success is predicted to be successful. Combined, the priority focal areas and high-ranking focal areas account for 25% of suitable tier 1 focal area for restoration (Table 4). Priority focal areas were identified in all subregions except North Palm Beach, where the majority of reef habitat is deeper than 20 m depth, beyond that considered suitable for FCR3.

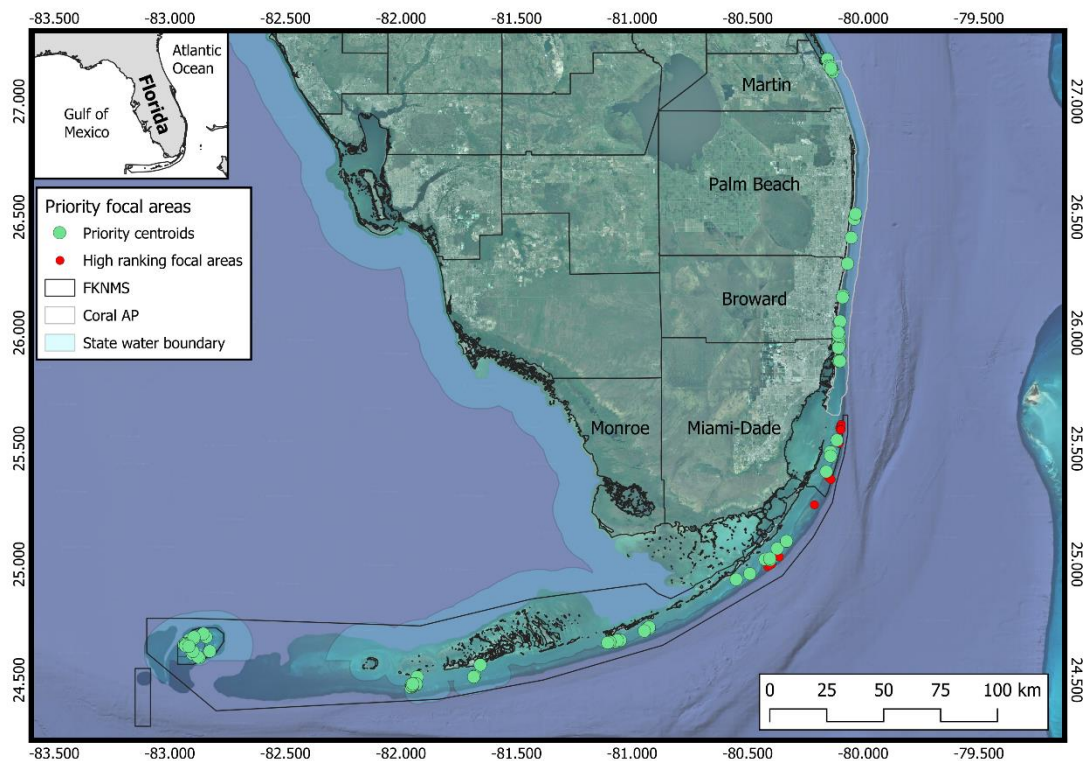


Figure 3. Recommended priority focal areas to ground-truth to account for 25% of suitable tier 1 focal area. Each green circle is the centroid position of a priority focal area within state waters. Red circles show high-ranking focal areas outside state waters which are recommended to be ground-truthed.

Table 4. Recommended distribution, number and size of priority focal areas to ground-truth to account for 25% of suitable tier 1 focal area.

County	Subregion	Number of priority focal areas	Priority focal area to ground-truth (hectares)	High-ranking focal areas outside state waters	High-ranking focal area (ha)
Martin	Martin	6	73.90	0	0
Palm Beach	South Palm Beach	9	13.33	0	0
Broward	Deerfield	1	2.02	0	0
Broward	Broward-Miami	9	21.90	0	0
Miami-Dade	Broward-Miami	15	109.33	0	0
Miami-Dade	Biscayne	4	13.14	10	40.73
Monroe	Upper Keys	7	35.34	8	39.28
Monroe	Middle Keys	10	27.48	1	2.53
Monroe	Lower Keys	18	98.09	0	0
Monroe	Dry Tortugas	27	236.99	0	0

All six tier 1 focal areas in Martin County are recommended for ground-truthing (Figure 4). Five of these are inside the Coral AP, with the other 1.5 km north of St Lucie Inlet. The southern two priority focal areas are either side of the SECREMP site MC1.

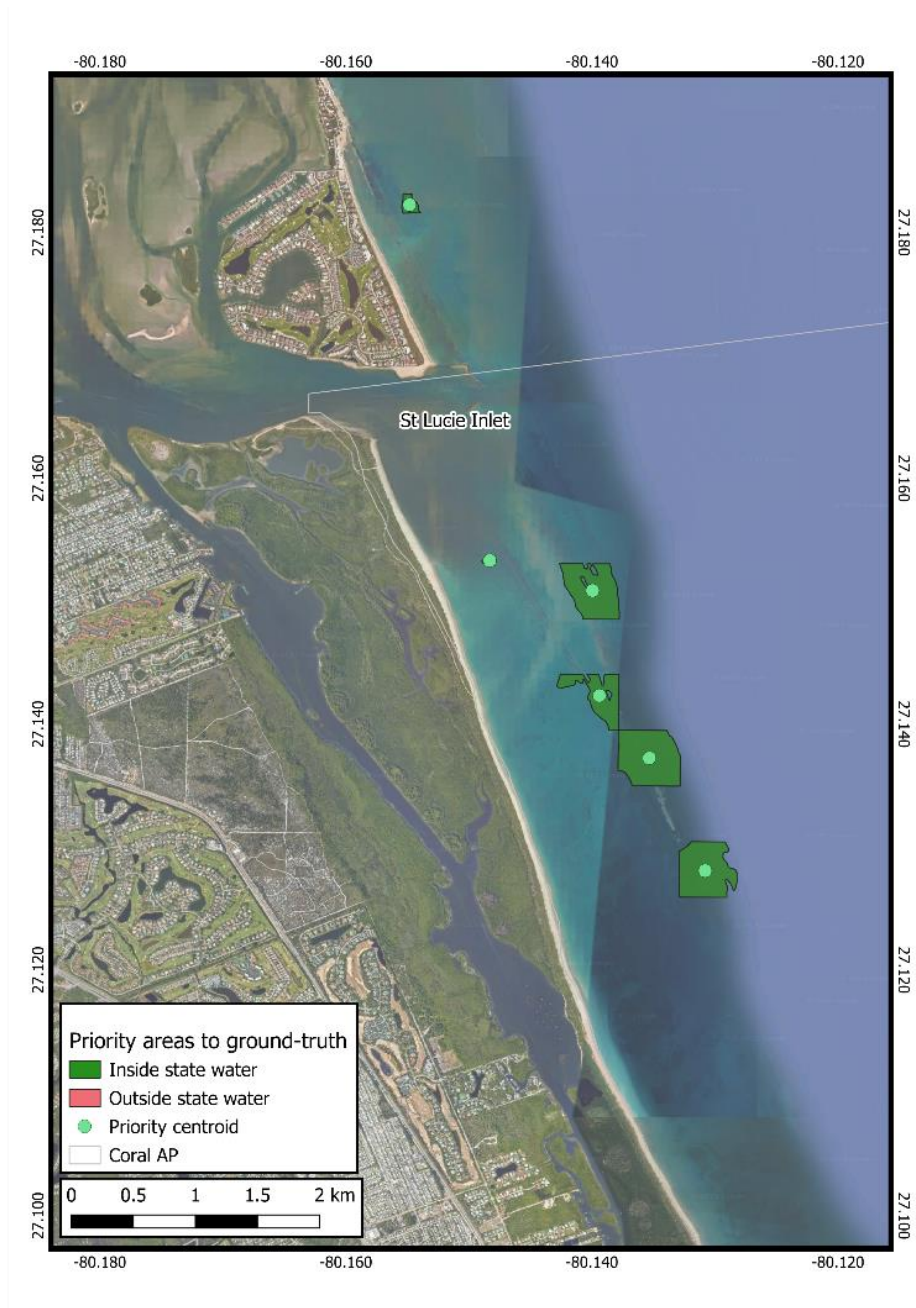


Figure 4. Priority focal areas to ground-truth in Martin County. Restoration is predicted to be most likely successful in green areas with centroid points shown.

All nine priority focal areas in Palm Beach County are on the outer reef in South Palm Beach (Figure 5). Eight are on the linear outer reef habitat with one on spur and groove habitat. Priority focal areas off Gulf Stream are on the same reef line, starting 250 m north, as SECREMP site PB4.

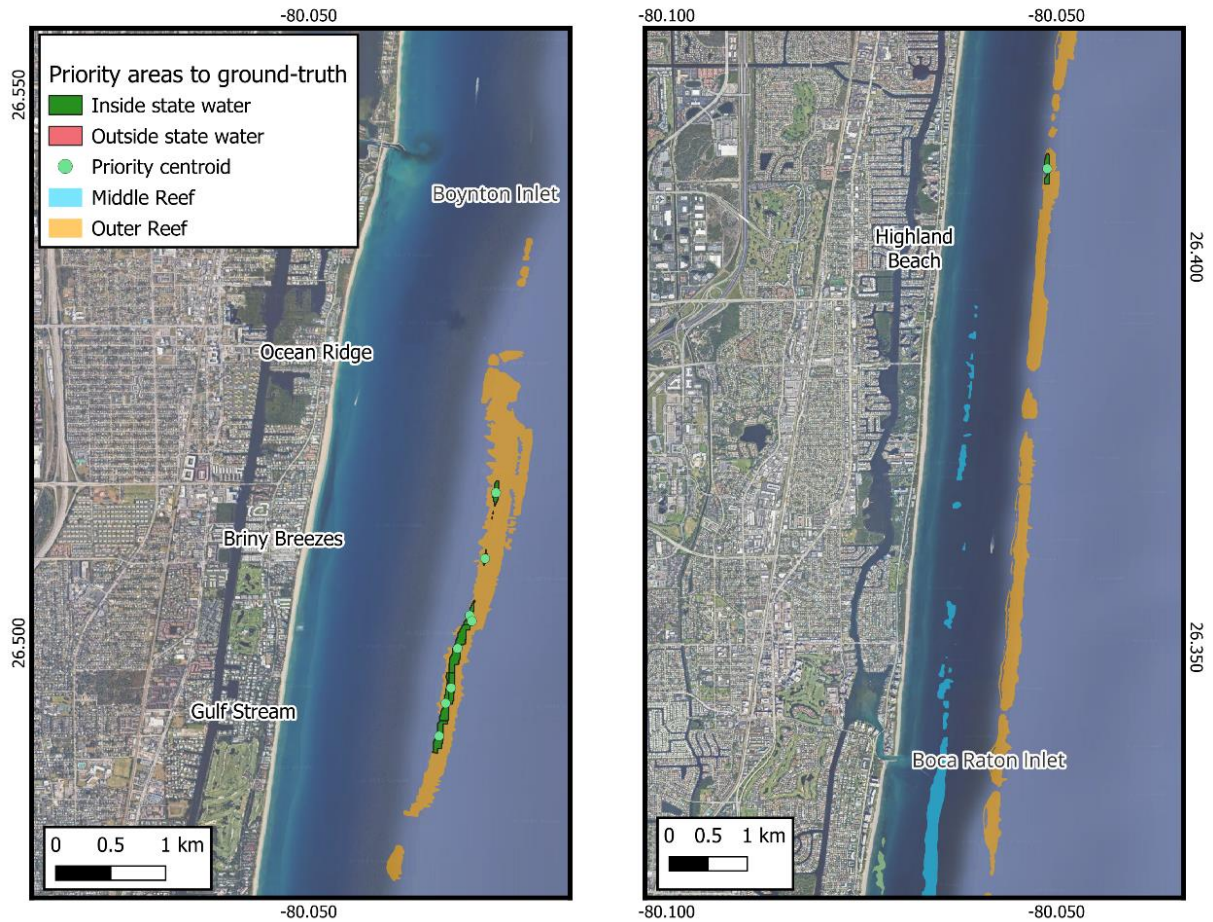


Figure 4. Priority focal areas to ground-truth in Palm Beach County. Restoration is predicted to be most likely successful in green areas with centroid points shown.

Priority focal areas for Broward County are on the nearshore ridge complex, linear inner reef and linear middle reef (Figure 6). The middle reef priority focal area is off Hillsboro Beach, 250 m south of SECREMP site BC5. Three priority focal areas are on the inner reef habitat off northern Fort Lauderdale. One priority focal area is offshore Dania Beach on the inner reef, one is on the inner reef offshore Hallandale Beach/Hollywood and four are on reef ridge shallow habitat off Hollywood Beach.

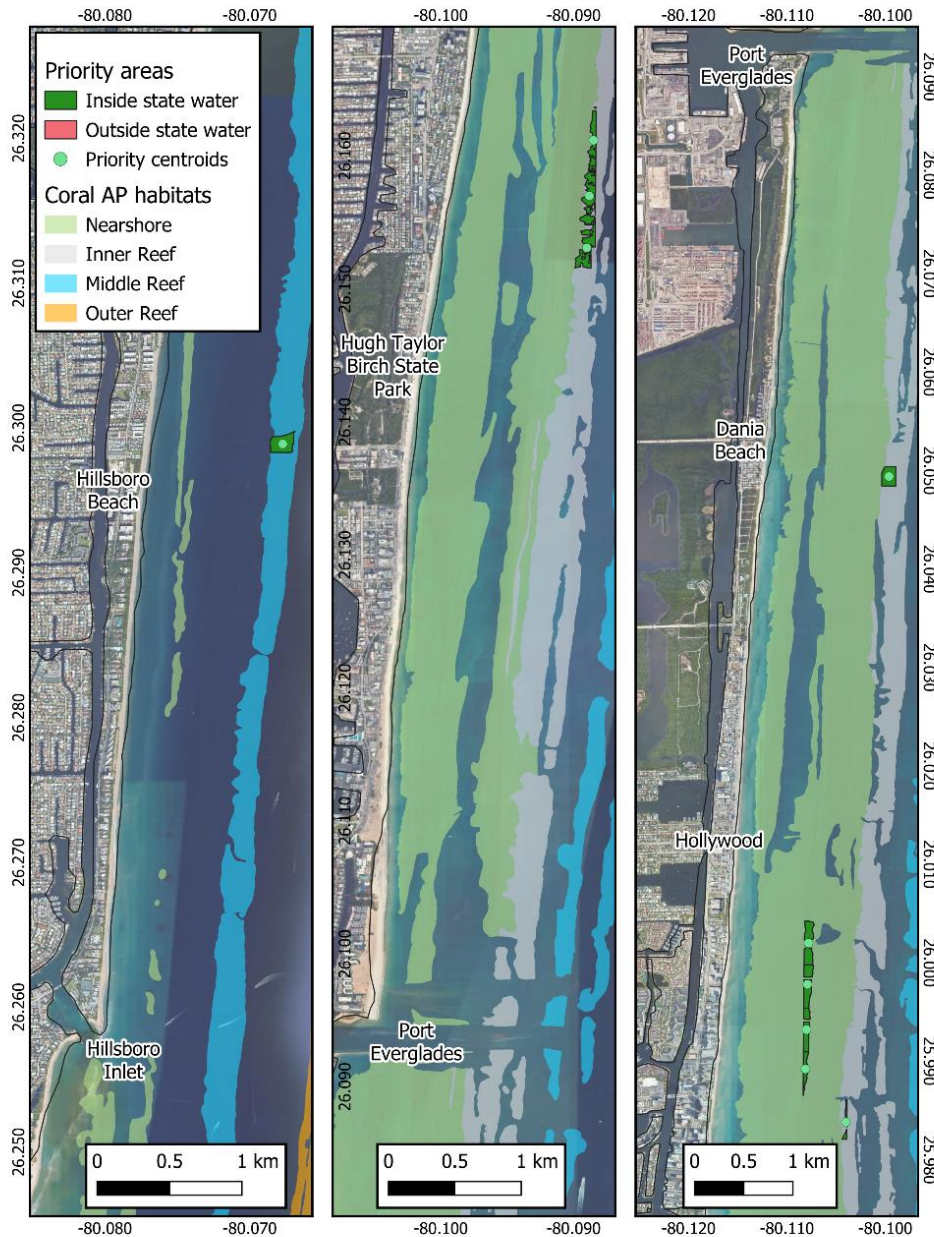


Figure 5. Priority focal areas to ground-truth in Broward County. Restoration is predicted to be most likely successful in green areas with centroid points shown.

Priority focal areas for Miami-Dade County are on the nearshore ridge complex and linear inner reef around Haulover Inlet and on patch reefs in Biscayne (Figure 7). The northern priority focal areas were also recommended by local experts (D. Lirman, Pers comms 4/18/25). All tier 1 focal areas on spur and groove habitat in Biscayne are outside state waters, but six of these ranked in the 80th percentile of all tier 1 focal areas on FCR and are recommended for ground-truthing. A further four high-ranked patch reefs (moderate relief, isolated reef structure habitat) were outside state waters. All priority focal areas in Biscayne are within Biscayne National Park.

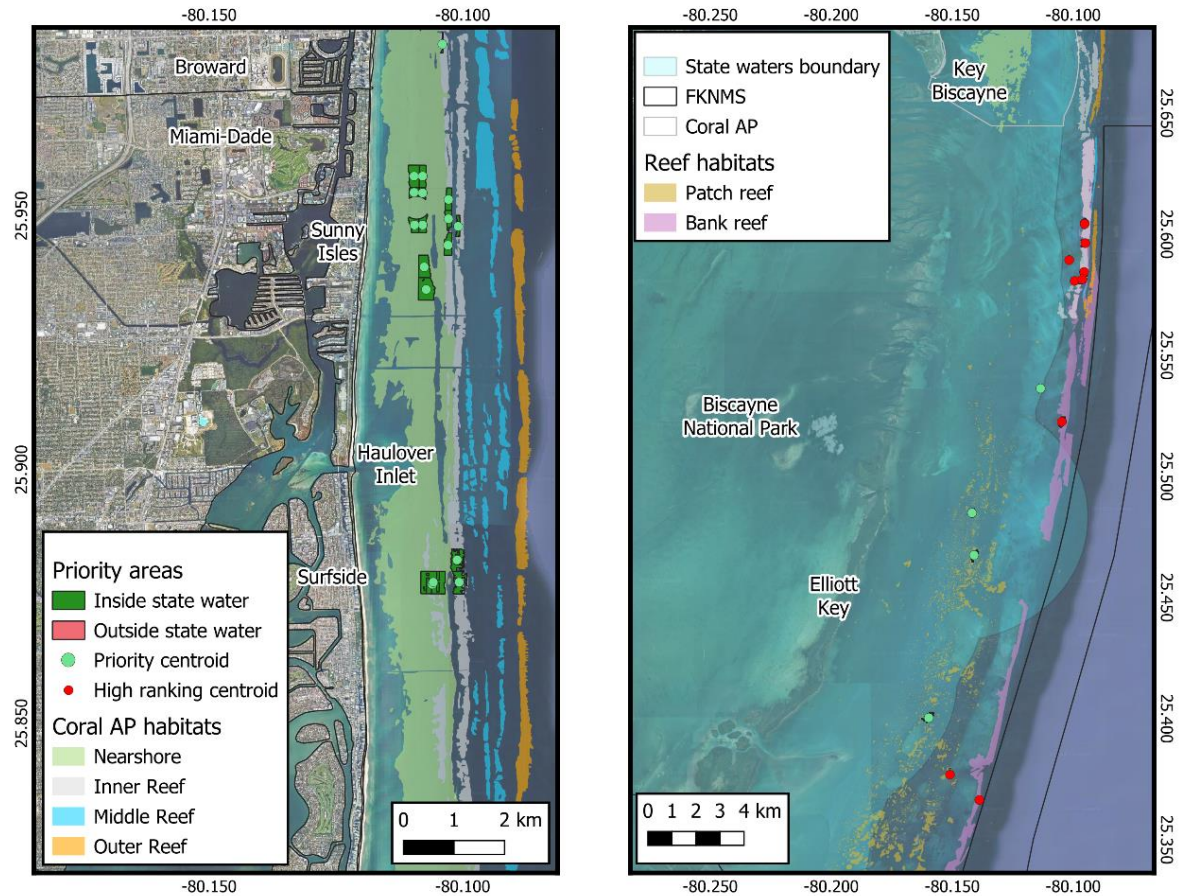


Figure 6. Priority focal areas to ground-truth in Miami-Dade County. Restoration is predicted to be most likely successful in green areas with centroid points shown or outside state waters in red areas with centroid points shown. The left panel shows priority focal areas in the Broward-Miami subregion. The right panel shows priority focal areas in the Biscayne subregion.

Priority focal areas within state waters in the Upper Keys are all on patch reefs (Figure 8). All tier 1 focal areas on spur and groove habitat were outside state waters, but several rank in the 80th percentile on FCR in or near Molasses Reef Sanctuary Preservation Area (Figure 8, right panel). Two patch reefs 5km south of the Horseshoe Reef, one of the Mission: Iconic Reefs (M: IR), scored highly. One patch is entirely inside state water; the other is partially inside state water. Three patch reefs inshore of the Key Largo Dry Rocks-Grecian Rocks Sanctuary Preservation Area are also high-ranking focal areas outside state waters. The southern priority focal area in the Upper Keys is in Hen and Chickens Sanctuary Preservation Area.

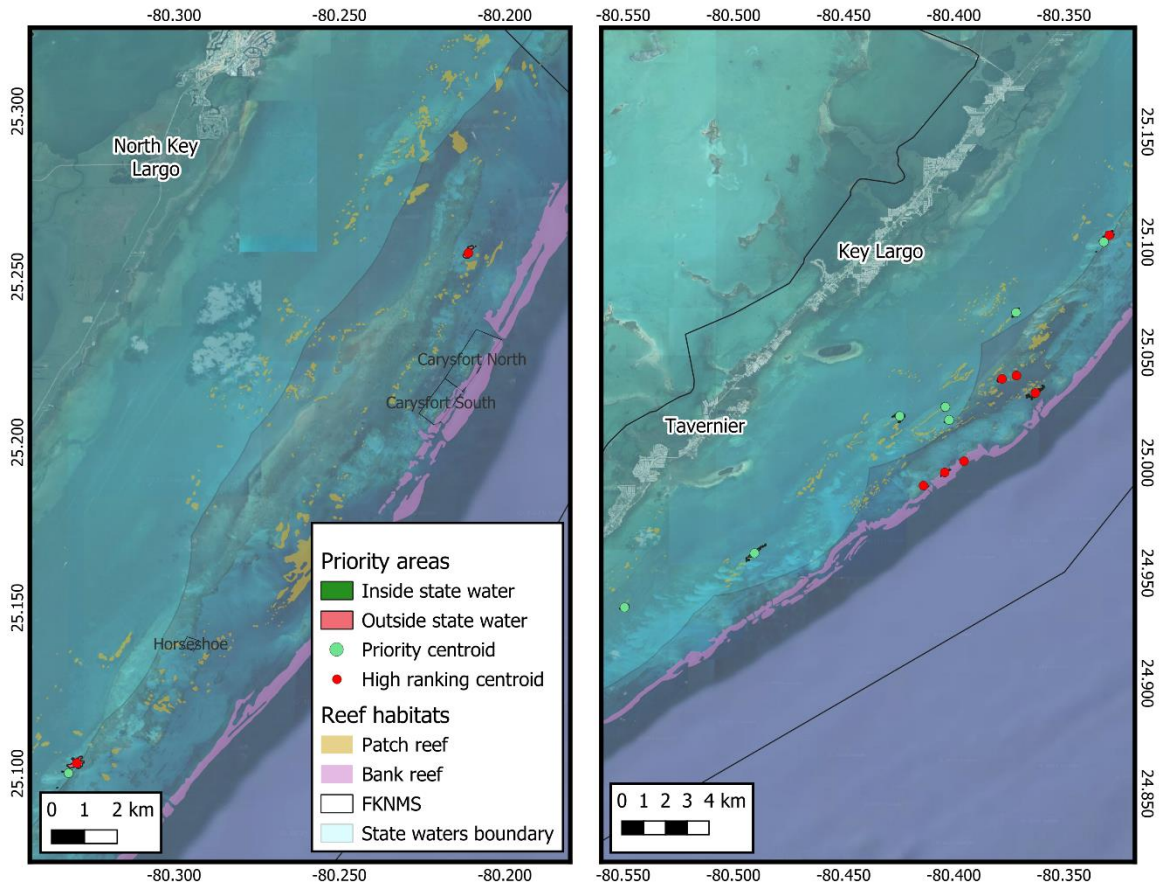


Figure 7. Priority focal areas to ground-truth in the Upper Keys, Monroe County. Restoration is predicted to most likely successful in green areas with centroid points shown or outside state waters in red areas with centroid points shown. The left panel shows priority focal areas in the northern portion of the Upper Keys. The right panel shows priority focal areas in the lower portion of the Upper Keys to Mid-Upper Keys transition. Mission: iconic reefs locations shown for context.

There are 10 priority focal areas in the Middle Keys and one high-ranking focal area which is partially in state waters (Figure 9). All priority focal areas in the Middle Keys are patch reefs off Marathon, with several in the Turtle Shoal Sanctuary Preservation Area. No tier 1 focal areas on spur and groove habitats in the Middle Keys are recommended as priority focal areas for ground-truthing.

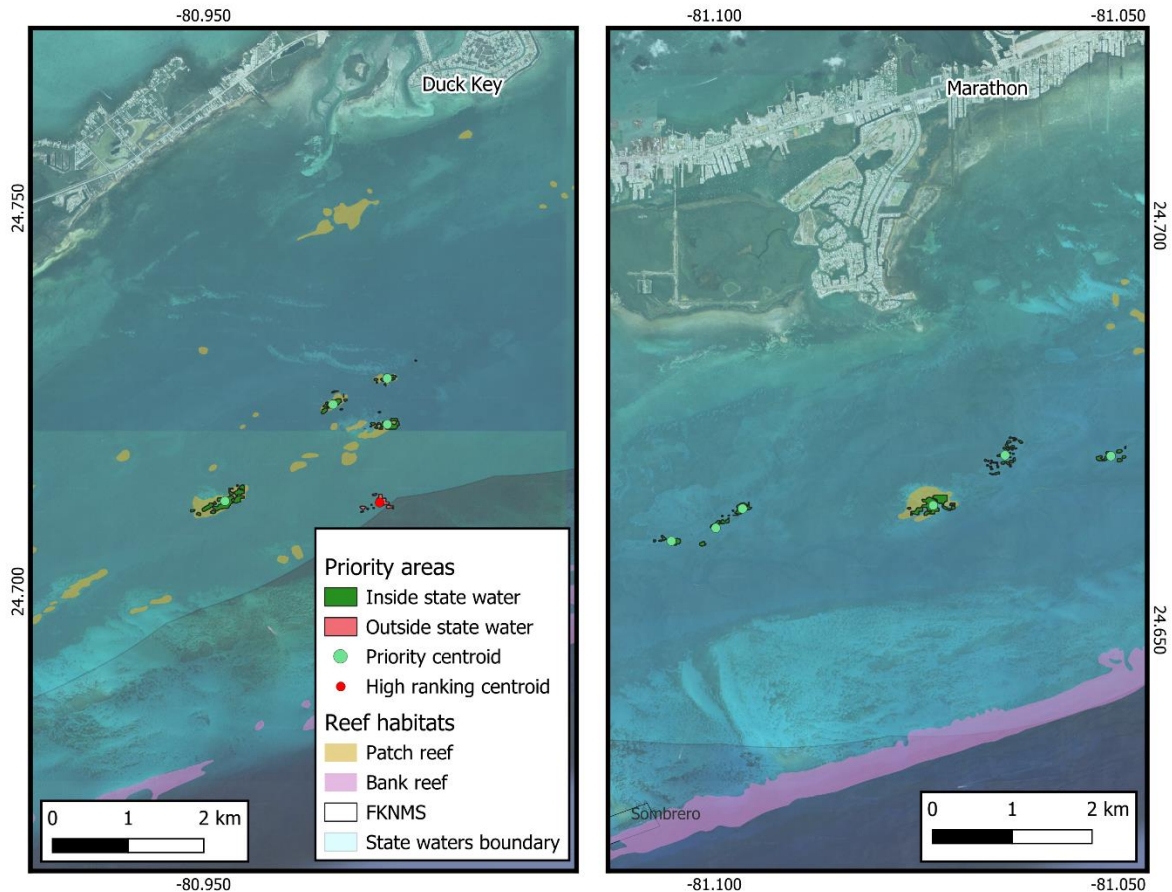


Figure 8. Priority focal areas to ground-truth in the Middle Keys, Monroe County. Restoration is predicted to be most likely successful in green areas with centroid points shown or outside state waters in red areas with centroid points shown. The left panel shows priority focal areas in the in or near the Turtle Shoal Sanctuary Preservation Area in the Middle Keys. The right panel shows priority focal areas off the southern portion of Marathon. Mission: iconic reefs locations shown for context.

All priority focal areas in the Lower Keys are on isolated patch reefs (Figure 10). Two are very close inshore, off Boca Chica Key and the Key West National Wildlife Refuge. The remaining priority focal areas are in two clusters: one 4.5 km off Boca Chica Key, the other 14 km west of Key West off the Key West National Wildlife Refuge. No tier 1 focal areas on spur and groove habitats in the Lower Keys are recommended as priority focal areas. Eastern Dry Rocks is located between the two panels pictured in Figure 10.

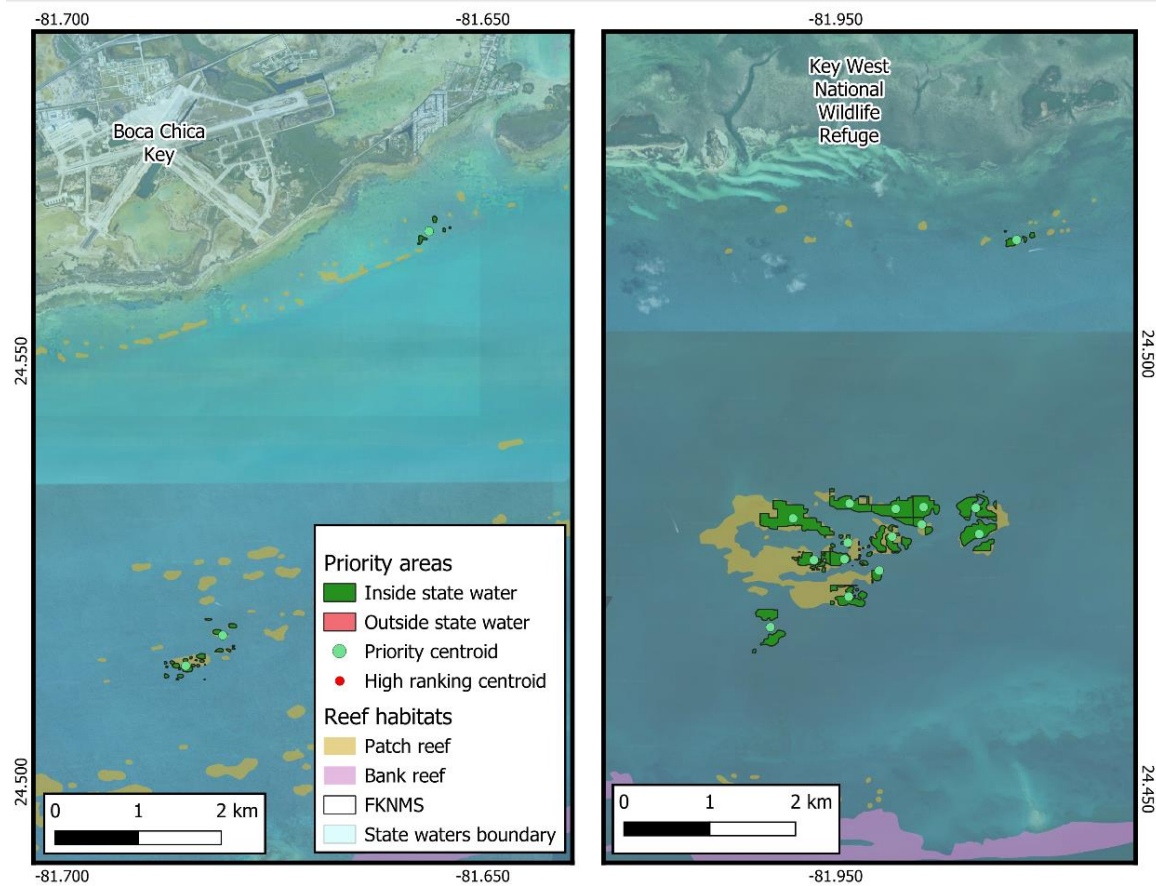


Figure 9. Priority focal areas to ground-truth in the Lower Keys, Monroe County. Restoration is predicted to be most likely successful in green areas with centroid points shown. The left panel shows priority focal areas off Boca Chica Key. The right panel shows priority focal areas offshore of the Key West National Wildlife Refuge.

All priority focal areas to ground-truth are located within the Dry Tortugas National Park and most within the Research Natural Area (Figure 11). The majority of the priority focal areas are in the west of the National Park, north-west of Loggerhead Key on contiguous low and moderate relief habitats near the CREMP site Temptation Rock. Three further priority focal areas are between Garden Key and Loggerhead Key. The tier 1 focal areas in the north-east of the National Park ranked low in evaluation.

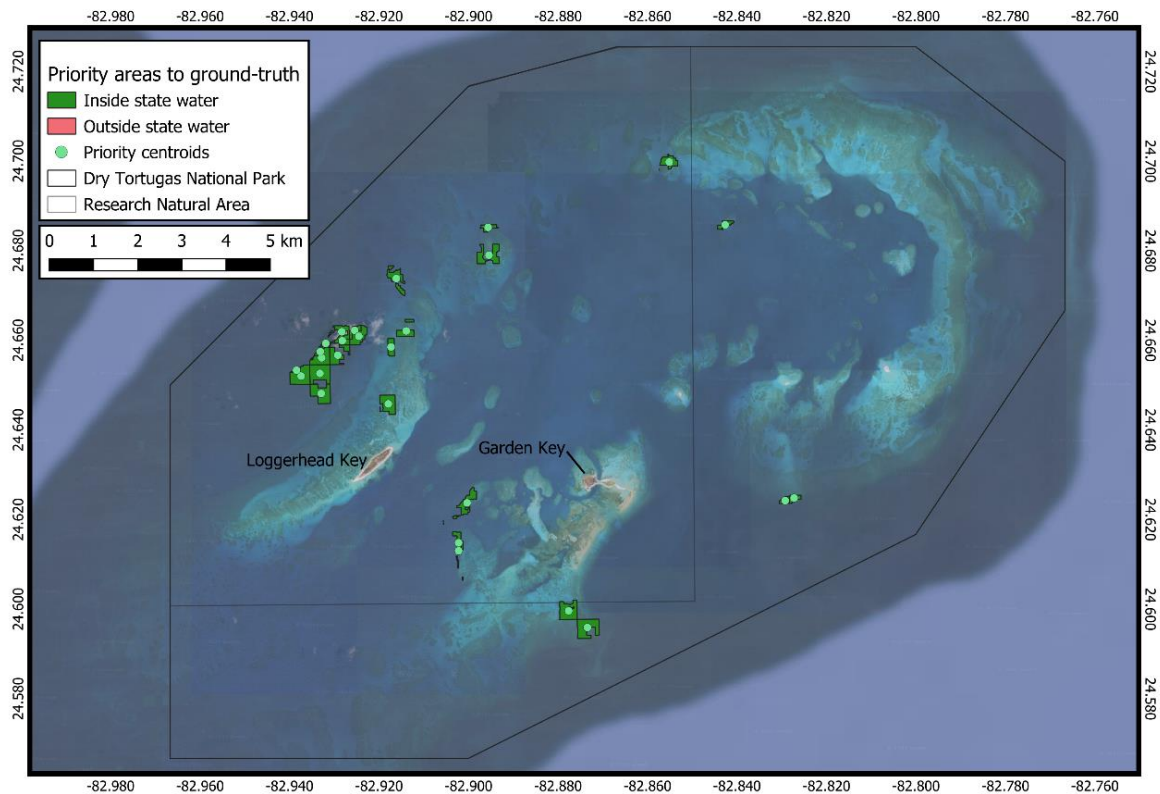


Figure 10. Priority focal areas to ground-truth in the Dry Tortugas. Restoration is predicted to be most likely successful in green areas with centroid points shown.

4. Discussion and Management Recommendations

The recommended priority focal areas and high-ranking focal areas are the locations on FCR where restoration activities using *Acropora cervicornis*, *Diploria labyrinthiformis*, *Montastraea cavernosa*, *Orbicella* spp. and *Pseudodiploria strigosa* are predicted to be most successful. Focal area determination refined the tier 1 strategy (FCRRP 2024), which used larval connectivity modelling and coral monitoring data, by combining modelling, satellite, in situ monitoring data and expert knowledge. The evaluation process balanced coral demographic metrics which are known to reflect a reefs disturbance history and ability to support coral populations (e.g., Bak & Meesters 1998; Dietzel et al. 2020, Pisapia et al. 2020), with climate and water quality metrics known to influence coral survival

(Hughes et al. 2017; Lapointe et al. 2019). Many of the priority focal areas are therefore locations which are currently comparatively healthy and are predicted to be less impacted by future climate change driven ocean warming and coral disease. It should be stressed, however, that ground-truthing of the priority focal areas, which will be conducted in FY25/26, is crucial to adequately evaluate the locations for FCR3.

Spatial comparison with shoreline protection projections (Storlazzi et al. 2025) suggest restoration in many of the identified priority focal areas would have positive benefit-to-cost ratios (BCRs) and provide protection from flooding under a hybrid reef scenario. In particular, priority focal areas off Palm Beach, northern and southern Broward County, northern Miami-Dade County and in the Upper Keys overlap with BCR protections above 15, over a 30-year lifespan (Storlazzi et al. 2025), the highest estimated. Flood projections under an ecological restoration scenario, solely coral outplants over a 25 m cross-shore distance, also suggest restoration in some priority focal areas, particularly those off Hollywood in Broward County and Sunny Isles in Miami-Dade would reduce coastal flooding (Storlazzi et al. 2021).

A consideration for the final stage of FCR3 site evaluation is how to treat groups of closely spaced, or adjoining, priority focal areas, particularly those comprising many small polygons. In this project, and in the tier 1 strategy, polygons were considered independent when determining focal areas. Moving forward, it may be prudent to combine smaller priority focal areas in close proximity to each other when evaluating these against larger areas, to maximize resources and meet the FCR3 goals. Ground-truthing of priority focal areas in FY25/26 will shed light on the possibility and suitability of this.

5. References

Bak RP, Meesters EH (1998) Coral population structure: the hidden information of colony size-frequency distributions. *Marine Ecology Progress Series*, 162, 301-306.

Dietzel A, Bode M, Connolly SR, Hughes TP (2020) Long-term shifts in the colony size structure of coral populations along the Great Barrier Reef. *Proceedings of the Royal Society B*, 287(1936), 20201432.

Fabricius KE (2005) Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Marine Pollution Bulletin* 50: 125-146

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

Hughes TP, Kerry JT, Álvarez-Noriega M, Álvarez-Romero JG, Anderson KD, Baird AH, Babcock RC, Beger M, Bellwood DR, Berkelmans R, Bridge TC (2017) Global warming and recurrent mass bleaching of corals. *Nature* 543(7645):373-7.

Jones NP, Figueiredo J, Gilliam DS (2020) Thermal stress-related spatiotemporal variations in high-latitude coral reef benthic communities. *Coral Reefs* 39:1661-1673

Jones NP, Gilliam DS (2024) Temperature and local anthropogenic pressures limit stony coral assemblage viability in southeast Florida. *Marine Pollution Bulletin* 200:116098

Jones NP, Dutton S, Shilling EN, Fuess L (2025) An integrative approach to identify and experimentally validate environmental variables which affect SCTL outcomes. Award no. C40115. Florida Department of Environmental Protection. Miami, FL, 1-38

Lapointe BE (1997) Nutrient thresholds for bottom-up control of macroalgal blooms on coral reefs in Jamaica and southeast Florida. *Limnology and Oceanography* 42:1119-1131

Lapointe BE, Brewton RA, Herren LW, Porter JW, Hu C (2019) Nitrogen enrichment, altered stoichiometry, and coral reef decline at Looe Key, Florida Keys, USA: a 3-decade study. *Mar Biol* 166:108

QGIS Development Team (2024) QGIS Geographic Information System. QGIS Association. <http://www.qgis.org>

Palacio-Castro AM, Kroesche D, Enochs IC, Kelble C, Smith I, Baker AC, Rosales SM (2025) Genotypes of *Acropora cervicornis* in Florida show resistance to either elevated

nutrients or disease, but not both in combination. PLoS ONE 20(3): e0320378. <https://doi.org/10.1371/journal.pone.0320378>

Pisapia C, Edmunds PJ, Moeller HV, Riegl BM, McWilliam M, Wells CD, Pratchett MS (2020) Projected shifts in coral size structure in the Anthropocene. In *Advances in marine biology* (Vol. 87, No. 1, pp. 31-60). Academic Press.

R Core Team (2024). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.

Smith TB, Brandt ME, Calnan JM, Nemeth RS, Blondeau J, Kadison E, Taylor M, Rothenberger P (2013) Convergent mortality responses of Caribbean coral species to seawater warming. *Ecosphere* 4(7):1-40.

Storlazzi, C.D., Reguero, B.G., Cumming, K.A., Cole, A.D., Shope, J.B., Gaido L., C., Viehman, T.S., Nickel, B.A., and Beck, M.W., 2021, Rigorously valuing the coastal hazard risks reduction provided by potential coral reef restoration in Florida and Puerto Rico: U.S. Geological Survey Open-File Report 2021–1054, <https://doi.org/10.3133/ofr20211054>

Storlazzi CD, Reguero BG, Alkins KC, Shope JB, Gaido-Lassarre C, Viehman TS, Beck MW (2025) Hybrid coral reef restoration can be a cost-effective nature-based solution to provide protection to vulnerable coastal populations. *Science Advances*, 11(3), eadn4004.

Toth LT, Precht WF, Modys AB, Stathakopoulos A, Robbart ML, Hudson JH, Oleinik AE, Riegl BM, Shinn EA, Aronson RB (2021) Climate and the latitudinal limits of subtropical reef development. *Scientific Reports* 11: 1-15

Tréguer PJ, De La Rocha CL (2013) The world ocean silica cycle. *Annual review of marine science*, 5(1), 477-501.

Vega Thurber RL, Burkepile DE, Fuchs C, Shantz AA, McMinds R, Zaneveld JR (2014) Chronic nutrient enrichment increases prevalence and severity of coral disease and bleaching. *Global change biology* 20:544-554

Wagner DE, Kramer P, Van Woesik R (2010) Species composition, habitat, and water quality influence coral bleaching in southern Florida. *Marine Ecology Progress Series*, 408, 65-78.

Ward S, Harrison P (2000) Changes in gametogenesis and fecundity of acroporid corals that were exposed to elevated nitrogen and phosphorus during the ENCORE experiment. *Journal of Experimental Marine Biology and Ecology* 246(2), pp.179-221.