Restoring Seven Iconic Reefs

A Mission to Recover the Coral Reefs of the Florida Keys

NOAA
Coral Restoration Foundation
The Florida Aquarium
Reef Renewal
National Marine Sanctuary Foundation
UF IFAS University of Florida
Florida Department of Environmental Protection
Florida Fish and Wildlife Conservation Commission
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The Nature Conservancy

Cover images:
Coral Restoration Foundation (top),
The Florida Aquarium (bottom, left),
Reef Resilience Network (bottom, right).

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Introduction

Photo: Mac Stone.

Photo: Andy Newman.

For thousands of years, the calcium carbonate skeletons of millions of stony coral polyps have layered atop one another, building a natural structure that rises from the depths of the Atlantic Ocean floor and extends from Biscayne Bay south to the Dry Tortugas, fringing the Florida Keys coastline. These three-dimensional limestone cities of the sea are habitats teeming with underwater life, forming over one hundred miles of a bank barrier reef that supports the foundation of the Florida Keys marine ecosystem and economy. Unfortunately, just beneath the surface of the famous turquoise waters, decades of cumulative stressors have led to catastrophic decline of the region's coral reefs, the ecosystem that shapes the identity, culture, and economy of the Florida Keys.

Saving Florida Keys coral reefs will require a multi-pronged approach that considers impacts at local and global scales, requiring direct and informed local interventions to be implemented immediately to keep Florida Keys reef ecosystems from collapsing beyond a point at which the reef ecosystem can be restored (National Academy of Sciences, 2019).

In response to reef decline, the Florida Keys has become the world leader in coral restoration. While local efforts have had success at small spatial scales, the rate of restoration has not been able to keep up with the overall rate of reef health decline in the Florida Keys. In order to restore Florida Keys reefs to benefit generations to come, restoration efforts must be scaled up with focus at the ecosystem level and with long term resiliency in mind. Current work is showing that large-scale restoration of coral reefs is possible and by harnessing research for novel ecological and genetic intervention strategies, restored reefs can be more resilient (Baums et al., 2019, National Academy of Sciences, 2019). Active and targeted coral restoration and repopulation has the potential to reverse decline and rebuild coral populations allowing restored reefs to seed surrounding reef habitat (P.H.M. Maya et al., 2016).

Restoring Seven Iconic Reefs: A Mission to Recover the Coral Reefs of the Florida Keys is a comprehensive approach that uses the best available restoration science to improve reef ecological function by restoring diverse, reef-building corals to seven iconic reef sites in the Florida Keys National Marine Sanctuary. Informed by years of research, successful trials, and expertise from two dozen coral scientists and restoration practitioners, this scientific and collaborative plan will put Florida's reefs on track for recovery and demonstrate how restoration can support a vibrant, sustainable, local economy.

The Iconic Florida Keys

The Florida Keys Reef Tract is the only bank barrier coral reef in the continental United States, attracting nearly 5 million visitors each year who contribute $2.4 billion in sales annually in the Keys (TBD Economics, LLC, 2019). About half of those visitors arrive to Key West by plane or by ship, while the other half drive from the mainland on the two-lane Overseas Highway, the only road connecting the island chain (Tourist Development Council, 2018).

Diving, snorkeling, and sport fishing remain top recreational attractions in the Florida Keys and one out of every two jobs is connected to the marine ecosystem (TBD Economics, LLC, 2019). Islamorada is known

FLORIDA KEYS NATIONAL MARINE SANCTUARY

Florida Keys National Marine Sanctuary

Designated in 1990, Florida Keys National Marine Sanctuary protects 2,900 square nautical miles of marine habitat stretching from southern Miami to the Dry Tortugas. Since its inception almost 30 years ago, the sanctuary has implemented numerous regulations and strategies in the interest of the ecological health of the Keys:

- Installation of over 490 mooring buoys in order to reduce damage to reefs and seagrass beds from boat anchoring.
- The establishment of 18 Sanctuary Preservation Areas (SPAs) covering 4.87 sq nautical miles.
- The establishment of two Ecological Reserve Zones at Western Sambo Key and areas adjacent to Dry Tortugas National Park covering nearly 160 sq nautical miles.
- The management of 24 "no take" zones making up 6% of the total sanctuary area.

In 2002, state waters of the sanctuary were declared a No-Discharge Zone for vessels. Since then, new vessel pump-out facilities process wastewater that would otherwise go untreated into nearshore waters.

as the “Sport Fishing Capital of the World,” offering incredible fishing opportunities for deep-sea, backcountry, and fly-fishing.

The structure created by reef-building (stony coral) provides habitat for recreationally and commercially important fish species and a myriad of other animals, including spiny lobster, sea turtles, and eels. In addition to being productive ecosystems, Florida Keys reefs provide physical protection to the coastline. A barrier coral reef is exactly what it sounds like: the reef creates a barrier between the intense energy of the open ocean and the land. The physical structure of the corals create height on the reef which helps to dissipate or “break” wave energy before it reaches land, reducing the erosional impact of storm surge and flooding (Reguero et al., 2018).

Famous for towering old growth star coral colonies, and thickets upon thickets of elkhorn and staghorn coral colonies, the Florida Keys reefs offer world class diving opportunities that are quickly being dethroned as the coral cover of the reefs continues to decline.

“When people ask me what I love the most about the Florida Keys, I tell them it's right here! The only coral barrier reef in North America is right here in the United States. Some of the world’s best fishing, diving, and snorkeling is here in our own backyard.

“Thousands of jobs, millions of visitors, billions of dollars, and an entire marine ecosystem is supported by the Florida Keys each year. We all rely on the Florida Keys Reef Tract, in one way or another, it is a national treasure and we must do everything we can to protect it!”

- Captain Tony Young
Owner, Forever Young Charter Company

Photo: Will Benson.

“We’ve got over 14,000 dives between us from dives all throughout the Caribbean and one thing that stuck out to us about diving in the Florida Keys is how many fish are on the reefs here.

“With that said, we now are now at a crossroad. Our corals are struggling to survive, so we must either help our coral reefs by restoring their once great vibrancy or watch the density of our great fish populations dissipate into extinction.”

- Mike and Marcia Goldberg
Owners, Key Dives Dive Shop

Photo: Summit Foundation.

The Decline of the Iconic Florida Reefs

Similar to many environmental problems, the decline in coral cover on Florida Keys reefs cannot be blamed on a single cause. Locally, impacts to the reefs come from disease events, hurricanes, pollution, overfishing, misplaced boat anchors, and ship groundings. Globally, warming oceans threaten coral reefs as elevated ocean temperatures can cause bleaching in corals, compromising coral health. Over the last 40 years, local and global stressors have compounded to reduce healthy coral of Florida Keys reefs from covering more than 25% of reef habitat in the 1980s to only about 5% in 2019 with cover as low as 2%* at the seven iconic reef sites (FWC, 2018, A. Bruckner, personal communication, July 2019). Many of the Florida Key reefs have been degraded to point that high-relief communities supported by stony corals are shifting to communities dominated by nuisance species and thick mats of algae that trap sediment prohibiting successful settlement of new corals.

Unfortunately, the remaining populations of stony coral species are at such low numbers that successful sexual reproduction for many species in the Florida Keys is compromised (M.W. Miller, 2018, N. Knowlton, 2001). As the population of stony corals in the Florida Keys has declined, fewer male and female coral colonies remain in close enough proximity to one another to successfully reproduce.

Losing Florida Keys reefs will result in cascading effects to the region's economy and culture, which are firmly rooted in the local marine ecosystem. Without the support

Photo: Coral Restoration Foundation.

Coral Reproduction

Coral species reproduce in one of two ways. Some corals break apart, or fragment, and spread genetically identical clones, which, under favorable conditions, can attach to the reef and develop into new colonies. However, most stony corals reproduce sexually. Sexual reproduction is important to maintain genetic diversity of a species, which is especially important for large-scale coral restoration efforts. There are two modes of sexual coral reproduction: broadcast spawning and brooding.

Broadcast spawning occurs when the eggs of one coral colony come in contact with the sperm of another genetically different coral colony in close proximity within the water column and fertilization takes place. The larvae are carried by currents to neighboring reefs. For most broadcast spawning species, this only happens one night each year.

By contrast, brooding coral species have internal fertilization before releasing larvae into the water column.

Larvae from broadcast spawning may reside as plankton in the water column for up to several weeks, whereas brooded larvae may be immediately ready for settlement. Either way, the larvae settle on the seafloor and search for a suitable substrate. The following weeks are a crucial period for the tiny coral polyp. In order to avoid being overgrown by algae or being buried by sediment, the little coral has to grow quickly (SECORE International, n.d.).

**This figure represents the generalized % cover at the 7 Iconic Reef Sites based on preliminary data and observations from 2019 post-disease event. This is not a Florida Keys wide percentage and has not yet been verified by official data from the State of Florida.*

of a healthy reef system, the last surviving corals will succumb to the effects of stressors and no longer be able to provide the structure, habitat, and beauty for which Florida Keys reefs are known. Lacking a draw for tourists, the economic sector that is currently centered around the reef economy may be forced to shift, fundamentally changing the culture of the Florida Keys.

Photo: Gena Parsons.

The decline of Florida Keys reefs has not gone unnoticed, and the call for a comprehensive restoration strategy from the Florida Keys community has gained momentum. The Florida Keys Sanctuary Advisory Council, a diverse group of community stakeholders, has been tracking the rapid decline of the reefs, evaluating outcomes of pilot restoration efforts, and requesting an effort to scale up restoration since 2011.

The urgency for restoration increased in 2018, following the severe impacts from Hurricane Irma and the extent of mortality caused by the widespread outbreak of stony coral tissue loss disease (SCTLD). In April 2019, NOAA gathered a group of more than 25 local researchers, restoration practitioners, and members of several state and federal agencies to answer that call. Over the course of the next six months, that group created a first of its kind restoration mission, Restoring Seven Iconic Reefs: A Mission to Recover the Coral Reefs of the Florida Keys.

> "The reef is the lifeblood of the community, culture, and economy of the Florida Keys, losing it is not an option. We need a plan to turn things around and we need it now."
>
> - Russell Post
> Owner, Ocean Sotheby's
> International Realty
> in the Florida Keys

Mission: Iconic Reefs is not a new regulatory action, rather it is a plan designed to complement other management efforts to put Florida Keys reefs on a path to recovery.

The Restoration Mission

Local restoration efforts have refined coral propagation and coral gardening techniques and have had some success with coral survivorship and reproduction, however, these efforts have only included a few species and are not sufficient in scale and scope to rehabilitate the structure, diversity, and function of the reef system. Mission: Iconic Reefs uses a phased implementation strategy focusing on genetic diversity and resiliency to restore multiple foundational coral and non-coral species in multiple habitat types across seven reefs.

The reef sites represent the iconic diversity and productivity of the Florida Keys reef tract, spanning the full geographic range of the region, a variety of habitats, and a range of human uses. Sites chosen for this effort also have a history of restoration outplant success, or characteristics that lend themselves to a high probability of success.

Each of the reef sites is unique, comprised of multiple, distinct types of habitat supporting different micro-ecosystems. To create a targeted strategy for each reef location, habitat specific zones were identified at each reef site, with restoration targets and coral outplants tailored to each reef zone.

After clearing portions of reef surfaces of nuisance and invasive species, the Plan will restore multiple stony coral species such as elkhorn, staghorn, star, brain, and pillar corals throughout different habitat zones. Additionally, long-spined sea urchins and Caribbean king crab, once abundant on Florida Keys reefs, will be reintroduced to aid in keeping the reef free from excess algae following continued research and development. Urchin and crab grazers can reduce competition between corals and algae, enhancing the potential for natural recruitment of coral larvae. At the same time, a workforce of professional and volunteer divers will take care of debris removal and repair of damaged corals as part of a suite of local management efforts to ensure that our investment lasts for generations.

Photo: Reef Renewal.

What about water quality?

Regionally, efforts are being made to address water quality impacts, which have contributed to the on-going decline. Regional and local water quality improvements need to occur in parallel for long term success and survivability of restoration efforts.

Proactive coral restoration is still essential to begin rebuilding and re-establishing reproductively viable populations that can withstand environmental stressors.

Coral spawning at The Florida Aquarium's land-based coral facility. Photo: The Florida Aquarium.

Strong genetic diversity is the underpinning of resilience and adaptation, however for some species included in this effort, the populations have declined to a point that it appears there may not be enough underlying genetic diversity in the broodstock population to support the level of production that will be required. For example, the current stock of elkhorn coral in the Florida Keys does not contain enough genetic diversity to produce all of the 130,000+ corals needed as part of this mission. To ensure genetic diversity and resilience of the restored corals, new genotypes that support long-term resilience to future stressors, will be bred in land-based coral nurseries and outplanted to the reef as part of a Genetic Diversity Plan that will be part of each reef's specific Implementation Plan.

Photo: The Florida Aquarium.

Each reef's Implementation Plan will also address the level of site preparation and maintenance that will be required prior to and after outplanting corals. Determination of which species of algae or other potential nuisances to be removed and in what quantities will be made by experts who are familiar with the local ecology of each reef and restoration best practices. Depending on the species and size of corals being outplanted, and condition of the reef site, more or less site preparation and continued maintenance will be necessary to support coral growth and health.

Elkhorn coral

(*Acropora palmata*)

A large, fast-growing species, its branching structure creates habitat for a wide variety of fish and invertebrates species. Elkhorn coral is not susceptible to stony coral tissue loss disease (SCTLD) and is already widely cultured for restoration throughout Florida, making it a key focal species for Phase 1.

Star Coral

(*Orbicella spp., Montastrea cavernosa*)

Slow-growing species that form enormous boulders, making them critical foundational species on Florida reefs. Restoration practitioners use a strategy called microfragmentation to increase star coral growth rates, but research is still needed to scale up this process. Most star corals will be outplanted in Phase 2.

Pillar Coral

(*Dendrogyra cylindrus*)

A rare but important species, it creates complex habitat for reef-dwelling species. Unfortunately, pillar coral is highly susceptible to SCTLD. Samples of healthy Florida pillar coral colonies have been placed in aquaria to preserve their genetic diversity amid the disease outbreak. Scientists are using these colonies to learn how to propagate this species for restoration. Most will be outplanted during Phase 2.

Staghorn coral

(*Acropora cervicornis*)

A fast growing species that contributes to reef development and provides habitat for many other species. It is well-studied and widely cultured for restoration, and is not susceptible to SCTLD,Therefore an important target species for Phase 1.

Brain Coral

(*Pseudodiplora spp., Colpophyllia natans, Diploria labyrinthiformis*)

Important foundational species, forming medium to large boulder-shaped colonies. Brain corals are not widely propagated for restoration, however these slow-growing species are good candidates for microfragmentation. Most brain corals will be outplanted in Phase 2.

Phase 1 and Phase 2

The phased plan allows active restoration to begin immediately while allowing for ongoing research and development. During Phase 1 of the Plan, coral cover across the seven iconic reef sites will be restored to an average of 15%, and by the end of Phase 2, coral cover will be restored to an average of 25%.

Photo: Coral Restoration Foundation.

Phase 1 consists of approximately 6 years of active outplanting of clusters of elkhorn, star, brain, pillar, and staghorn coral to the reefs. Initial action during Phase 1A will include the restoration of elkhorn coral species, a fast growing species that has not been susceptible to the stony coral tissues loss disease that is currently afflicting Florida and Caribbean stony corals. Elkhorn coral clusters outplanted in year 1 will reach reproductive maturity in 3-5 years. Immediately returning structure to the reefs will create habitat and wave energy abatement. Habitat creation will increase populations of other marine organisms living on the reef, improving ecosystem function and stability to support future phases of outplanting. Phase 1B can operate concurrently with Phase 1A and will improve diversity on the reef by restoring star, brain, pillar, and staghorn corals as well as supplementing long-spined sea urchins and Caribbean king crab. Natural reproduction and recruitment is not accounted for in the target coral restoration goals identified for each reef, therefore, it is possible that benefits from natural processes will also be seen on the restored reefs during the life of the Plan, further increasing coral cover.

Current knowledge regarding propagation of long-spined sea urchin and king crab is limited, and as such, this activity is proposed only if research and development trials during Phase 1B prove successful. As trials are completed, population targets will be developed and necessary adjustments will be made under adaptive management plans.

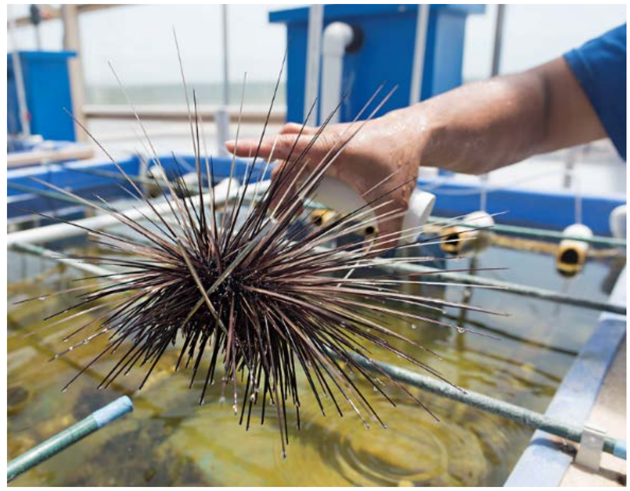


Photo: Josh Patterson, University of Florida.

Phase 2 consists of approximately 12 years of active outplanting of elkhorn, star, brain, pillar, and staghorn corals in addition to the outplanting of other small stony corals such as finger and blade coral, adding diversity to the reefs. Depending on resource availability, Phase 1A, Phase 1B, and Phase 2 can be implemented concurrently, sequentially, or a combination thereof.

The Methods

Describing this effort at a high-level is simple, but the core of any successful plan is its details. The section below provides an overview of the details that the team worked through to create the plan. A closer look at the approach and the math that supports our recommendations can be found in *Appendix I- Methods*.

A results-based approach was used to create Mission: Iconic Reefs, whereby the scope for restoration was developed with an ultimate goal of restoring the reef to a self-sustaining system.

Site Selection

The first step in the process of building the scope for restoration in the Plan was to select sites that are spread across the Upper, Middle, and Lower Keys that represent the best of Florida Keys reefs, and demonstrate how restoration can support a vibrant, sustainable local economy into the future. The seven reef sites selected for the Plan were narrowed from a larger list of 37 potential restoration sites that were evaluated based upon characteristics such as likelihood of success, biodiversity and habitat composition, connectivity to other habitat types, allowable and compatible human uses, and current enforcement and compliance activities.
Sites were selected based on the best available site-specific information, with the understanding that global-scale stressors such as climate change could affect the suitability of some sites for restoration in the future. Selecting sites representative of multiple reef types across a wide geographic range can help spread the risk of large-scale impacts. Additionally, consistent monitoring and adaptive management can aid in better understanding and responding to potential future climate impacts at each site.

Figure 1: Seven Florida Keys reefs selected for Mission: Iconic Reefs.

Mapping and Measuring Habitat Zones

After selecting the seven reef locations that include patch, mid-channel, and fore reef zones, the next step in the development process of the restoration plan was to identify the different habitat types, the amount of hardbottom habitat at each site, and to quantify the restorable area at each site by zone. Each reef site has its own unique composition of reef habitat zones, sandy areas, and depth ranges. Using a combination of three-dimensional imagery (LiDAR), aerial imagery, and satellite imagery, habitat zones as shown in Figure 2 that support different species of stony corals and restoration techniques were identified at each reef site. For detailed maps of each reef site please see *Appendix II- Reef Habitat Mapping Data*.

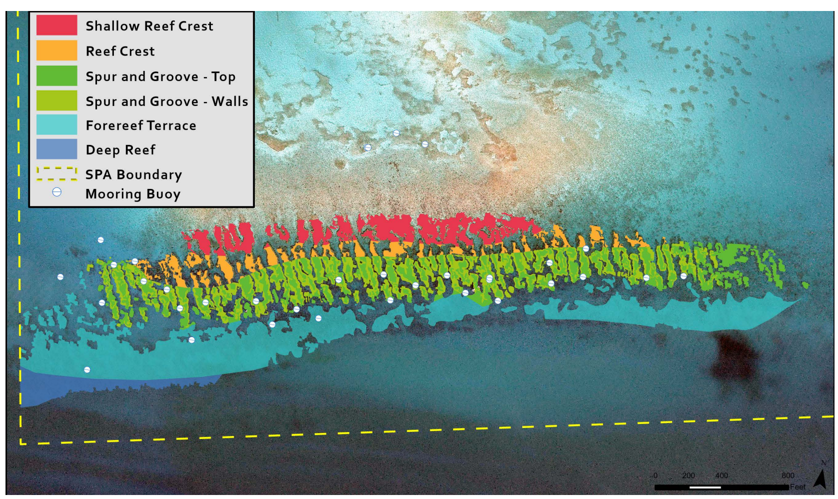


Figure 2: Habitat zonation for Looe Key Iconic Reef Site.

In-person verification was needed to refine the area of each habitat zone's boundaries that was identified from the imagery. Over a period of several months, a groundtruthing campaign was undertaken to estimate the percentage of reef habitat in each zone, taking into account void spaces and sandy areas, and to estimate the proportion of the reef habitat that would be restorable. Field data were used to ensure conditions estimated using imagery were consistent with actual conditions in each habitat zone, and to further refine the footprint of the existing reef structure. In all, between the seven reef sites, coral reef scientists vetted more than 120 locations to verify the amount of restorable reef area within each habitat zone. Restorable area was defined as *the proportion of reef habitat that is devoid of desirable species and otherwise suitable for restoration, or that can be prepared for restoration*. For more information about habitat zonation, mapping and field verification, please see *Appendix I-Methods*.

Target Percent Cover

With the groundtruthing effort complete and restorable areas estimated for each habitat zone, target percent coral cover and number of coral and non-coral organisms (grazers) needed for restoration could be calculated. Within each habitat zone and reef site, experts in local reef ecology estimated the goal for target percent coral cover by the end of Phase 2. These values were further refined based on existing literature on Florida Keys reef structure. Percent cover targets consider the unique biology and ecology of the coral types and habitat zones and are tailored to each site's unique characteristics. Target species composition was based on the composition of the reef prior to coral die-offs that have occurred since the 1980s. Based on site characteristics, overall percent cover targets for each reef site were further refined into percent cover targets for each species group to be outplanted within a given zone as shown in Figure 3. For target percent cover and restorable area calculations for each reef site, please see *Appendix II- Reef Habitat Mapping Data*.

Looe Key		Phase 1		Phase 2		Total
Zone	**Restorable Area (m2)**	Target % Cover	# of Corals	Target % Cover	# of Corals	Total Target % Cover
Shallow Reef Crest	3,620	5.00%	876	5.00%	710	10.00%
Reef Crest	6,733	20.25%	7,109	14.25%	7,518	34.50%
Spur and Groove - Top	20,294	13.60%	23,085	6.65%	20,645	20.25%
Spur and Groove - Sides	19,910	1.50%	10,490	5.00%	28,469	6.50%
Forereef Terrace	6,094	9.66%	5,912	9.84%	10,814	19.50%
Deep Reef	787	3.75%	322	4.75%	708	8.50%
TOTAL	**57,438**		**47,794**		**68,864**	
				GRAND TOTAL	**116,658**	

Figure 3: Looe Key Reef target increase in coral cover by habitat zone and phase.

Existing techniques available for propagating each coral type targeted for restoration were also considered. This informed the proportion of effort toward restoration of each species group in Phase 1 and Phase 2. For example, propagation techniques for elkhorn and staghorn corals are well-developed, therefore greater effort was shifted toward outplanting these in Phase 1.

Number of Corals

Using the Phase 1 and Phase 2 target percent coral goals for each coral species in each habitat zone, the number of corals needed for each phase could be determined. For example, in the reef crest habitat zone at the Looe Key restoration site, the overall target coral cover for elkhorn coral is 27.50%, with 20.00% cover restored by the end of Phase 1 and 7.50% cover restored by the end of Phase 2. To calculate the number of corals needed to restore the elkhorn species in Phase 1, the target cover of 20% for elkhorn coral in Phase 1 was applied to the reef crest habitat zone restorable area of 6,733 m^2 resulting in a restorable area target of 1,347 m^2 for elkhorn coral. To achieve a total cover of 1,347 m^2 for elkhorn coral in the Looe Key reef crest zone by the end of Phase 1, approximately 6,518 corals should be outplanted. The number of coral outplants needed to achieve this target was calculated using the initial size of an outplant cluster, factoring in annual growth rates and average mortality figures that were determined using data from local restoration practitioners. Corals will be outplanted to the reefs as clusters of several colonies. The clusters will fuse together to form one larger, reproductive coral colony. The number of corals detailed in Figure 3 and in *Appendix II* materials represent the number of clusters of which each cluster will contain several coral colony fragments.

Beginning with reef locations that meet certain criteria to support restoration goals, including human-use goals, sets the stage for a successful plan. Developing a restoration resource budget from the ground-up, working to methodically calculate actual reef habitat that is restorable, and following literature and local knowledge in conjunction with the best available restoration science has resulted in a scientifically-based plan for restoration.

The Plan

		Phase 1 A/B ACTION: Add rapid-growing corals DURATION: 5-7 Years of Work 10-YR GOAL: ~15% cover			**Phase 2** ACTION: Add slower-growing corals DURATION: 10-12 Years of Work 20-YR GOAL: ~25% cover	
Region	Reef	Restorable Area (sq m)	# of Corals Planted	# of Grazers Added	# of Corals Planted	# of Grazers Added
Upper Keys	Carysfort Reef	125,890	112,228	94,982	93,026	94,982
	Horseshoe Reef	12,223	16,139	5,696	19,556	5,696
Middle Keys	Cheeca Rocks	12,414	12,209	15,517	21,783	15,517
	Sombrero Reef	13,461	11,842	10,096	13,267	10,096
Lower Keys	Looe Key Reef	57,438	47,794	43,078	68,864	43,078
	Newfound Harbor	8,447	4,599	11,066	9,429	11,066
	Eastern Dry Rocks	36,337	30,667	21,633	35,917	21,633
	Subtotal	266,209	235,479	202,068	261,842	202,068

Figure 4: Number of corals and grazers to be added to each reef site during Phase 1 and during Phase 2.

Propagation and Production

To produce the nearly 500,000 clusters of stony corals required to fulfill the target increases in coral cover in Phase 1 and Phase 2, corals will be propagated in land and ocean-based coral nurseries. In addition to annual expected mortality, redundancy is built into the number of coral clusters needed to account for potential mortality events caused by hurricanes or disease. This is reflected in the survivorship calculation, which drives the number of coral clusters needed to restore each habitat type. Furthermore, the corals selected for propagation are the genetic survivors of previous Caribbean coral disease and thermal bleaching events, adding to the resiliency of the ecosystem.

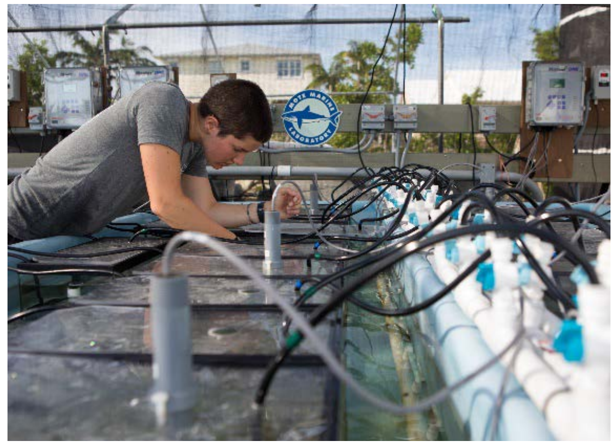


Photo: Mote Marine Laboratory & Aquarium.

Photo: Coral Restoration Foundation.

For corals that are propagated asexually using fragmentation, it is estimated that each coral fragment will grow in the coral nursery for approximately one year before being outplanted as part of a cluster to the reef. Among the several Florida organizations involved in coral restoration, there are already ocean-based nurseries throughout the upper, middle, and lower keys as well as land-based facilities located in the Florida Keys and in multiple Central and South Florida locations. This existing infrastructure can be leveraged during Phase 1A and Phase 1B to begin immediate propagation of corals. Together, these facilities are currently producing tens of thousands of stony corals per year. Infrastructure will be expanded to scale-up the production of corals to meet the total demand across Phases 1 and 2.

Photo: Coral Restoration Foundation.

Site Preparation and Outplanting

Prior to outplanting corals to a reef site, the substrate will be prepped by removing marine debris and invasive and nuisance species, such as thick mats of fleshy algae, turf algae, and Palythoa, from the reef. Palythoa is an organism that creates “mats” on available substrate and is a fierce competitor for space on the reef, readily overgrowning corals and preventing settlement of coral recruits (Ladd et al., 2019). By removing these species, the growing corals won't have to expend as much energy fighting for reef space. Each reef's Implementation Plan will be specific with regard to which nuisance species will be removed to so as not to leave the substrate exposed to more erosion.

After a reef site has been prepped, clusters of corals will be outplanted to the site. The number of corals per cluster will vary by species. Each species of stony coral being restored as part of the Plan has different rates of growth, different husbandry requirements, and varying turn-over rates during the nursery process. While the process for restoring each species will generally follow the same path, the time and labor during each step of the process can vary considerably from one species to another. As each of the species chosen for restoration play a different role in the ecological function and heritage of the Florida Keys reef system, it is important that they are all included in the Plan, making this a truly unique and unprecedented approach.

Maintenance, Monitoring, and Adaptive Management

From the time that the first round of corals are outplanted onto the reef sites, regular maintenance of the restored sites will begin. Similar to tending a garden, routine maintenance at each site will be a necessary step towards successful restoration of reef function, structure, and diversity. Monthly maintenance will include removal of nuisance species, coral predators, and marine debris, and the reattaching of damaged and disconnected corals.

In addition to regular site maintenance, ongoing performance monitoring and adaptive management will ensure that successes and failures can be incorporated into upcoming steps, providing a process for continuous improvement. Permanent monitoring plots will be established and comprehensive monitoring of 20% of each habitat zone in each site track progress toward the restoration goals. Adaptive management actions will be incorporated as needed based upon monitoring results.

Restoration Requirement by Species (# of Mature Corals)

Coral Restoration Components	Phase 1	Phase 2	Total
Elkhorn Coral	*104,152*	*26,264*	130,417
Star Coral	*50,616*	*89,505*	140,121
Brain Coral	*30,660*	*51,957*	82,617
Pillar Coral	*1,869*	*2,248*	4,118
Staghorn Coral	*48,181*	*15,244*	63,425
Other Small Stony Coral	*0*	*76,624*	76,624
Other	*0*	*0*	0
Totals	**235,479**	**261,842**	**497,321**

Figure 5: Stony coral restoration requirements by species.

Other Components

	Phase 1	Phase 2	Total
Sea Urchins (# of Animals)	188,107	188,107	376,213
Caribbean King Crab (# of Animals)	13,962	13,962	27,923
Site Preparation (# of Days)	1,089	544	1,633
Monitoring (# of Days)	1,775	1,775	3,549

Figure 6: Other restoration plan components by phase.

Community Engagement

Photo: Coral Restoration Foundation.

Mission: Iconic Reefs is designed to utilize local businesses designated as Blue Star Operators to further build community and visitor engagement. Blue Star operators are committed to responsible tourism, promoting responsible and sustainable diving and fishing practices in Florida Keys National Marine Sanctuary. Mission: Iconic Reefs will benefit from local marine stewards and encourages community involvement, mobilizing volunteers to assist with invasive species removal and long-term nursery and outplant maintenance. In addition to utilizing community involvement if fully implemented this plan will create hundreds of new jobs in Monroe County.

Iconic Reefs Implementation

Bringing together all of the components of the Plan including the propagation and outplanting of hundreds of thousands of stony corals and grazers, the expansion of land and ocean based infrastructure, research and development, and reef site preparation and maintenance will require a redirection of existing efforts as well as novel resources. Mission: Iconic Reefs will be supported through many public and private funding streams and executed by multiple organizations using a partnership approach. We propose that this public-private partnership be coordinated by collection of stakeholders, managers, and citizens and be known as the Florida Keys Restoration Council.

As this restoration strategy looks at the total requirements necessary to achieve the Plan's goals, it is important to also present a high level budget estimate so interested parties can evaluate their potential for involvement. To provide a sense of scale of the Plan, a detailed breakdown of estimated costs for the major line items of Mission: Iconic Reefs can be found in *Appendix III- Cost Estimate*. The Cost Estimate was developed based on real-world experience with large scale restoration projects in the Florida Keys and includes considerations for economies of scale and process improvements that result in additional savings to be expected when executing a project of this scale.

Phase 1
ACTION: Add rapid-growing corals
DURATION: 5-7 Years of Work
10-YR GOAL: ~15% cover

Region	Reef	Total
Upper Keys	Carysfort Reef	$45,803,168
	Horseshoe Reef	$5,781,215
Middle Keys	Cheeca Rocks	$5,050,929
	Sombrero Reef	$4,989,497
Lower Keys	Looe Key Reef	$19,976,449
	Newfound Harbor	$2,453,280
	Eastern Dry Rocks	$13,214,134
	Subtotal	**$97,268,672**

Figure 7: Estimated total cost for Phase 1 of Mission: Iconic Reefs.

The average cost to restore one square meter of reef under this plan is comprised of 70% for coral and non-coral species restoration, 25% for monitoring, maintenance, and adaptive management, and 5% for site preparation. As expected, the highest proportion of cost is for species restoration and it is in this area that the most opportunity exists for process improvements and technological advances. Restoration practitioners, NOAA, and other partners are actively working on efforts to further increase efficiency beyond what is estimated in the current Plan. Partners executing this project are committed to rapidly operationalizing new techniques with the hope of incrementally reducing costs and using those savings to execute the Plan faster.

Each component of the Plan is critical to improving the ecosystem function of the seven iconic Florida Keys reefs so that the reefs can once again provide habitat for countless marine organisms, provide our coastal communities with protection from storms and support ample tourism opportunities.

Conclusion & How You Can Help

Restoring Seven Iconic Reefs: A Mission to Recover the Coral Reefs of the Florida Keys is a unique and achievable strategy to restore seven reef sites located in one of America's most iconic natural places. As a region that is sustained by its productive coastline, drawing in millions of tourists each year, the Florida Keys community understands the issue and its urgency, and asked for bold action to restore Florida Keys coral reefs. The strategies outlined in Mission: Iconic Reefs use the best available restoration science and allow for research and development to occur concurrently with phases of active construction. Supported by the existing work of local partners, the Plan can start immediately while the necessary increases in capacity, infrastructure, and production are established over the next few years. Mission: Iconic Reefs will foster a new economic sector for the Florida Keys region, centered around this innovative and crucial effort. This sector will not only sustain the reef, it will create new economic opportunities throughout the region and sustain the existing marine economy. By supporting the implementation of Mission: Iconic Reefs, you can help create a lasting legacy, a physical and financial safety net for the Florida Keys, and be a part of a vision that is sure to inform restoration efforts worldwide.

Photo: Coral Restoration Foundation.

Appendix I. Methods

Overall Effort

Mission: Iconic Reefs is a product of a public/private partnership of subject matter experts from government, academia, and the private sector to evaluate the opportunities and plan for comprehensive reef-scale restoration in the Florida Keys National Marine Sanctuary. That group, comprised of over two dozen experts representing over ten organizations, convened multiple times over six months to craft a bold vision for restoration.

The expert group was guided by its past experience in reef-scale restoration planning, input from the Florida Keys National Marine Sanctuary Advisory Council, and the principles outlined in the recently published Manager's Guide to Coral Reef Restoration Planning & Design from The Nature Conservancy.

The group worked methodically to first narrow the sites under consideration and then map different habitat zones at each reef in detail. This allowed the team to analyze historical, current, and potential coral condition at each site. The site goals and maps were ground truthed in the field to further refine restoration targets. All of this information and the collective experience of restoration practitioners in the Florida Keys over the past 15 years was used to develop an approach that calculates the restoration requirements for each reef and zone over the course of an initial ten year effort (Phase 1) and a longer-term 20 year target (Phase 2). This Plan will not end with outplanting: to ensure long-term success, the team affirmed the need for long-term site stewardship, monitoring, adaptive management, and resources for disaster recovery.

Site Selection

Overview

Significant declines in coral health from a number of stressors prompted the Florida Keys National Marine Sanctuary Advisory Council (SAC), representing users and constituents, to identify 37 areas within FKNMS as high priorities for coral restoration. NOAA and partners undertook a process to refine that recommendation and develop a plan that could be implemented by a broad coalition of resource managers, restoration practitioners and the public.

Approach

As part of the Mission: Iconic Reefs planning effort, NOAA hosted two dozen coral restoration practitioners and managers to identify comprehensive, non-resource-constrained restoration strategies and to narrow the list of 37 high priority areas within the FKNMS (Table 1). The team was also asked to rank the most important criteria for reef restoration that the sites should host (Table 2). The most important criteria identified were: 1) biodiversity and habitat, 2) ecological services - diversity, 3) sustainability and connectivity, 4) likelihood of success, and 5) genetic health/complexity. The team considered the ranked criteria and specific information about each site. Also discussed were current conditions, habitat, history, ecological and research potential importance, accessibility, constituent use, and community support. Sites with significant constituent support were prioritized if they met the other guiding criteria. Seven sites were chosen with geographic representation in the Upper, Middle, and Lower Keys; these sites include patch, mid-channel, and offshore reefs.

Sites were selected based on the best available information regarding site characteristics, however practitioners and managers recognize that global-scale stressors such as climate change could affect the suitability of some sites for restoration in the future. To address this uncertainty, the team selected sites from multiple reef types (i.e. patch and fore reefs), located across a broad geographic range. This strategy could help to mitigate the risk of large-scale disturbance, particularly if one site type or geographic location is more susceptible to a given stressor than others. Post-restoration monitoring will also provide information on climate impacts at each site, which can feed back into adaptive, site-specific restoration planning.

Table 1. The 37 high priority areas from which the 7 iconic reef sites were selected.

Upper Keys	**Turtle Reef, Pennekamp (East Ocean Reef)**	Mid-Channel patch reef - State Waters
	Carysfort Reef - North	Reef Margin/Fore Reef
	Elbow Reef, North (Elpis)	Reef Margin/Fore Reef
	Key Largo Dry Rocks	Reef Margin/Fore Reef
	French Reef	Reef Margin/Fore Reef
	Molasses Reef - North Wellwood Restoration	Reef Margin/Fore Reef
	Molasses Reef	Reef Margin/Fore Reef
	Snapper Ledge	Reef Margin/Fore Reef
	Davis Reef	Reef Margin/Fore Reef
	Hen and Chickens	Mid-Channel patch reef
Middle Keys	**Cheeca Rocks**	Inshore Patch Reef
	South of Lower Matecumbe	Reef Margin/Fore Reef
	Caloosa Rocks	Inshore Patch Reef
	Tennessee Reef	Reef Margin/Fore Reef
	South of Little Duck Key	Spur and Groove. Seagrass
	Coffins Patch	Offshore Patch Reef
	South of Key Colony Beach/Marker 48	Mid-Channel Patch Reef
	Delta Shoal	Reef Margin/Fore Reef
Lower Keys	**Sombrero Key**	Reef Margin/Fore Reef
	Newfound Harbor SPA	Inshore Patch Reef
	Looe Key Reef SPA	Reef Margin/Fore Reef
	American Shoal Reef	Reef Margin/Fore Reef
	Pelican Shoal	Reef Margin/Fore Reef
	Hawk Channel Patch Reefs 1	Mid-Channel Patch Reef
	Boca Chica Patch Reefs	Inshore Patch Reef
	Key West Patch Reefs	Inshore Patch Reef
	Western Sambo 1	Reef Margin/Fore Reef
	Western Sambo 2	Reef Margin/Fore Reef
	Eastern Dry Rocks 1 (general SPA area)	Reef Margin/Fore Reef
	Rock Key 1 (general SPA area)	Reef Margin/Fore Reef
	Sand Key 1	Reef Margin/Fore Reef
Marquesas	**Cottrell Key**	Backcountry, Hardbottom
	Man Key Patch Reefs	Inshore Patch Reefs
	Western Dry Rocks	Reef Margin/Fore Reef
	Boca Grande Patch Reef	Inshore Patch Reefs
Tortugas	**East of DTNP Pulaski Shoals**	Coral Reef slope, hardbottom
	Dry Tortugas National Park	

Table 2. Ranking of criteria important to selecting a restoration site by 18 reviewers.

What criteria are most important for reef restoration?	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	TOTAL
Ecological Services: Shoreline protection	3	2	1	3	3	3	1	3	2	3	1	3	3	1	1	1	1	1	36
Ecological Services: Fisheries habitat	2	3	2	3	3	2	3	3	1	3	2	2	2	2	2	2	1	3	**41**
Ecological Services: Tourism value (both aesthetics and stewardship potential)	2	3	3	3	2	2	3	2	3	2	1	2	1	1	3	1	2	2	38
Ecological Services: Ecological diversity	3	2	3	2	3	2	3	3	3	3	3	3	3	3	1	3	3	3	**49**
Likelihood of success	3	?	3	3	3	?	3	3	3	3	3	3	3	3	3	3	2	2	**46**
Biodiversity and habitat (what can be built, not necessarily what is already there)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	**53**
Sustainability/connectivity	3	3	3	3	3	3	3	2	3	3	3	2	2	3	3	3	2	2	**49**
Sufficient size	2	2	2	2	2	2	2	1	2	3	3	2	2	2	2	2	3	1	37
Allowable/compatible uses (at time of restoration)	2	2	2	2	1	?	2	2	2	1	1	1	2	?	2	1	2	1	26
Suitability as reference areas/monitoring sites	1	2	2	2	2	1	1	1	2	2	2	2	2	?	3	2	2	2	31
Facilitation of enforcement and compliance	1	1	3	1	1	1	1	1	2	2	2	1	1	3	3	2	2	2	30
Adjacent habitats appropriate for restoration	2	2	2	1	1	2	2	2	1	2	2	1	2	1	2	2	1	1	29
Genetic health/complexity	3	1	3	2	3	3	3	3	3	2	2	1	3	3	2	2	2	2	**43**
Ability to manage uses within restoration area (closures, removal of buoys etc.)	2	2	3	2	2	2	2	1	3	1	1	1	2	3	3	2	3	2	37
Interest of community or other partners with resources	2	3	3	2	2	2	2	1	3	1	1	2	2	3	3	1	3	1	37
Geographic separation	1	3	2	1	2	1	2	2	2	1	2	2	3	2	3	1	1	1	32
Adequate information about habitat across the entire reef area	1	1	2	2		?	1	1	2	1	2	1	3	2	1	1	1	1	23

Outcome

The seven identified reefs (Table 3) are the starting point for this bold and ambitious plan to restore the diverse and economically valuable marine ecosystem of the Florida Keys. These sites represent what was once the best of the Florida Keys, and will demonstrate how restoration can support a vibrant, sustainable local economy into the future.

Table 3. The seven "iconic" reef sites.

	Reef Complex	Habitat Type
Upper Keys	**Carysfort Reef Complex**	Reef Margin/Fore Reef
	Horseshoe Reef	Mid-Channel Patch Reef
Middle Keys	**Cheeca Rocks**	Inshore Patch Reef
	Sombrero Key	Reef Margin/Fore Reef
Lower Keys	**Looe Key**	Reef Margin/Fore Reef
	Newfound Harbor Patches	Inshore Patch Reef
	Eastern Dry Rocks	Reef Margin/Fore Reef

Mapping and Field Verification

Overview

Identification of potentially restorable reef habitat (hereafter referred to as hardbottom) within selected potential restoration sites was completed in three steps: 1) define and map hardbottom reef habitat, 2) refine and ground truth reef habitat mapping classifications, and 3) generate summary statistics. For each site, hardbottom habitats were identified based on configuration (derived from LiDAR where coverage existed) and remotely-sensed imagery (i.e., aerial and satellite images). Expert knowledge and imagery helped define hardbottom habitats at sites without LiDAR. For all sites, hardbottom habitats were further refined and confirmed using georeferenced underwater images and site visits.

Approach

Habitat mapping to support identification of potentially restorable reef habitats and zones included both mapping classification using remote sensing data and in-water validation. The most recent LiDAR bathymetric data were compiled (1 m resolution; NGS 2016); LiDAR coverage included five of seven sites. Summary statistics (e.g., max, mean, min) of depth, planar area, and surface area were calculated from the bathymetry at sites within the LiDAR coverage. Draft hardbottom habitat was categorized using supervised classification habitat mapping in e-Cognition software. Hardbottom areas were further classified into categories such as low relief reef, high relief reef, spur and groove tops, and spur and groove sides. Figure 1 is an example of this process. For the two sites without LiDAR bathymetry coverage (i.e., Cheeca Rocks and Newfound Harbor), draft habitat types were identified using remote sensing (i.e., aerial and satellite imagery) and local expertise.

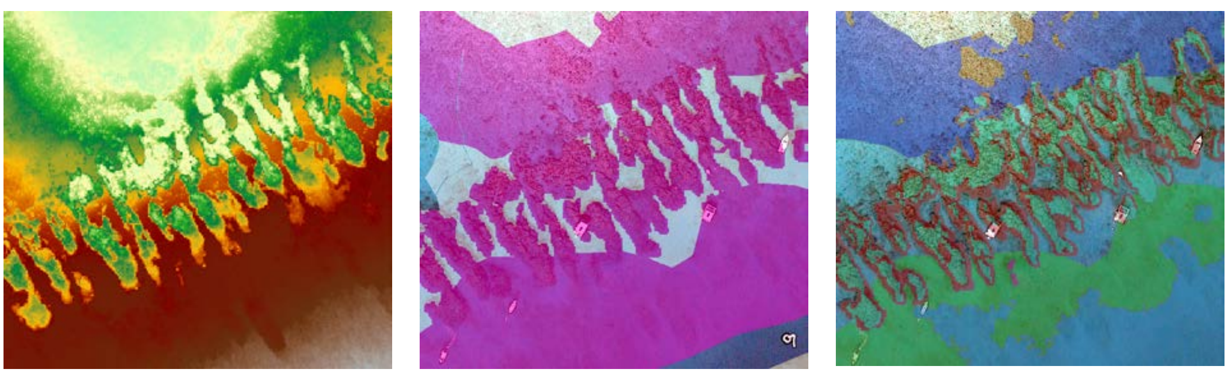


Figure 1. Example of hardbottom identification and categorization from Sombrero Key. Using the best available LiDAR bathymetry (shown above far left) and other derived data surfaces, such as rugosity, areas of hardbottom (shown as pink in middle image) and not hardbottom (white regions in middle image) were identified at each site. Using a supervised classification approach with e-Cognition and additional processing of LiDAR, aerial and satellite imagery, and ground verification data, hardbottom habitats were further refined and classified into specific categories (shown by various colors in the far right image, including: rubble, spur and groove tops, spur and groove sides, deep reef).

Groundtruthing of hardbottom reef habitat classifications was performed using recent (post-Hurricane Irma 2017) georeferenced photos, photomosaics, and videos shared from coral restoration practitioners, coral reef monitoring efforts (e.g., NOAA's National Coral Reef Monitoring Program 2018), and other government researchers. Additional field data for groundtruthing were provided by the field team (120 reference locations), which collected photos both at pre-identified coordinates and at additional geo-referenced locations selected during the field effort. The field team also provided expert local knowledge of habitats at reef sites based on site visits. Georeferenced photos were then imported into ArcPro and compared to mapped hardbottom habitat classifications. Reef classifications were refined based on groundtruthing data.

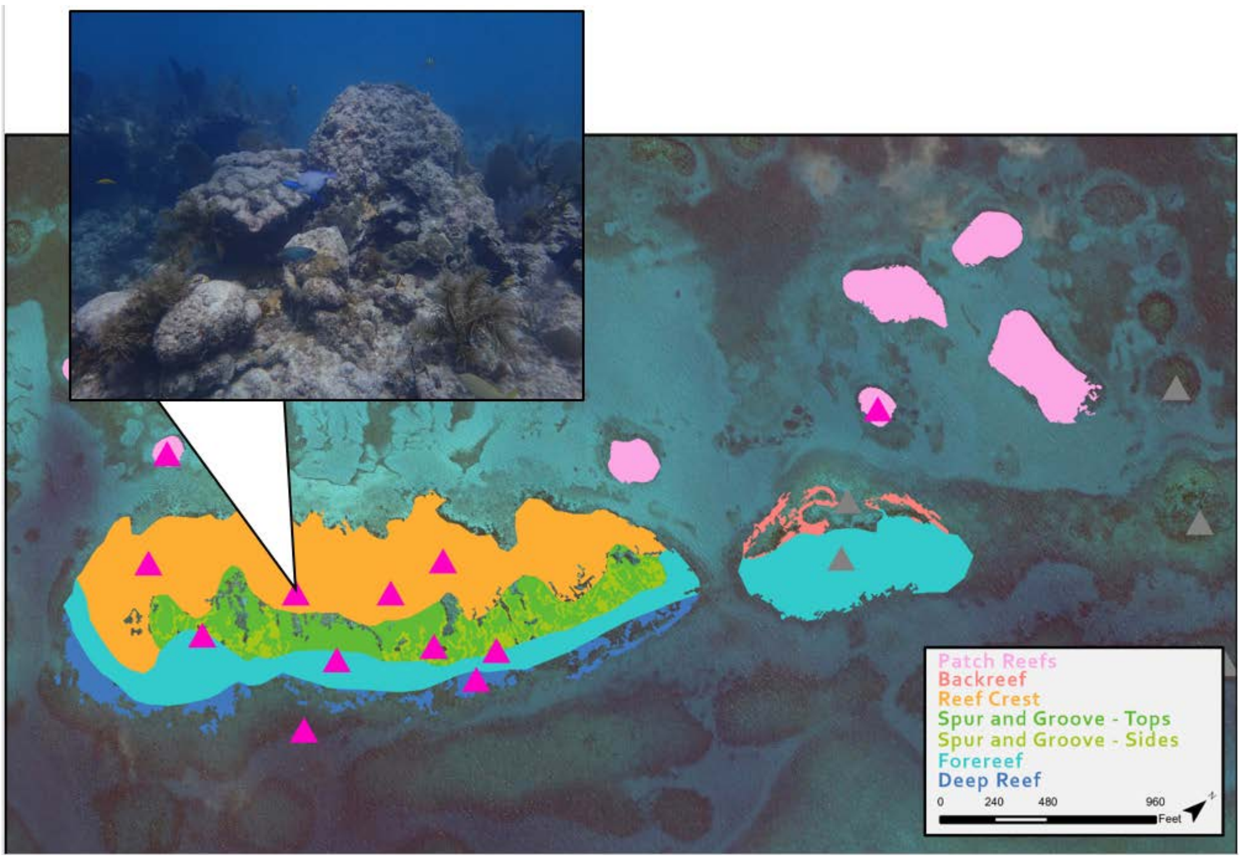


Figure 2. Example of a georeferenced photo used to classify hardbottom habitat at Carysfort Reef. Each pink triangle represents a site where photos were provided.

Outcome

The habitat mapping efforts identified and classified reef hardbottom habitats and reef surface areas. These data were then used to identify reef zones and calculate reef restoration area.

Zonation

Overview

Restoration zones were delineated based on expert local knowledge and refined based on bathymetry, habitat mapping, management zones, field validation, and consideration of potential restoration options. Zones were initially outlined by a panel of local experts, and subsequent refinements were presented to this panel for comment. For each site, the proportion of reef habitat and proportion of restorable reef was applied to the total area of each zone to determine the final proposed restoration area.

Approach

Zones for potential restoration options were initially identified by experts at the first in-person project meeting. Coral reef scientists, managers, and coral restoration practitioners discussed the ecological zonation and coral species distributions (historic and present) for each potential site in relation to potential coral restoration actions. Experts outlined and drafted potential restoration zones at each site using an interactive pen (eBeam Edge), Google Earth, and ArcGIS. Experts referenced local expertise, Google Earth aerial imagery, bathymetric LiDAR depth ranges, long-term coral monitoring, and current coral restoration efforts. After the meeting, draft zones were refined by removing gaps between zones, identifying depth ranges within zones, comparing depths with target species and with coral monitoring data, adjusting zones along bathymetric contours, and adjusting draft zones in reference to current FKNMS management zonation (e.g., boundaries of Sanctuary Preservation Areas). For each site, draft restoration zonation was then cross-referenced with the hardbottom habitat classifications and field validation for further refinement. During the field groundtruthing effort, a field team provided estimates on proportion of reef habitat (i.e., the percentage of the mapped habitat that is actually hardbottom) within each zone, and proportion of restorable reef (i.e., the percentage of reef habitat that is devoid of desirable species and otherwise suitable for restoration) within each zone.

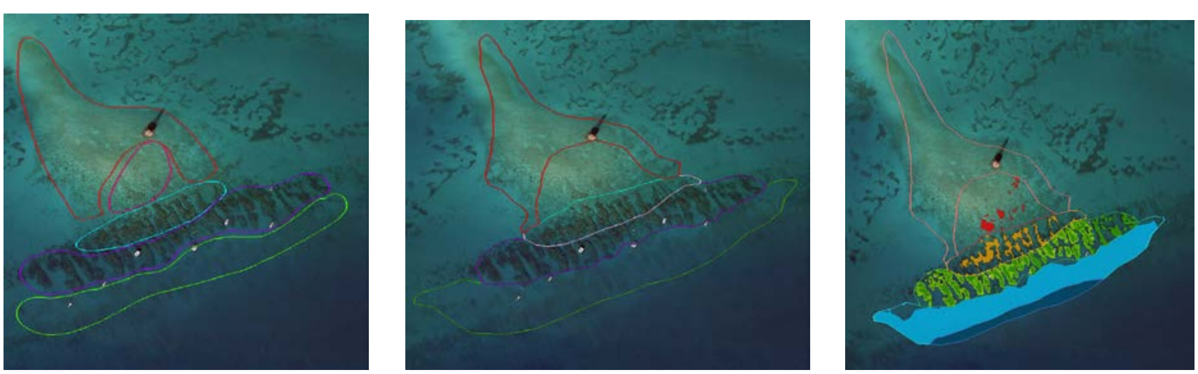


Figure 3. An example of the zonation approach at Sombrero Reef: Initial delineation based on expert knowledge (left); refined zones that fully encompass hardbottom habitats and eliminate gaps but do not include ground-validation (center); final zonation including priority restoration hardbottom habitats (right).

For each final zone, the proposed restoration area was calculated from the mapped surface area (m^2), the proportion of reef habitat, and an estimate of restorable reef area.

Outcome

This zonation process resulted in the identification of restoration zones at each reef site. For spur and groove reefs, zones included shallow reef crest, reef crest, spur and groove (tops of spurs), spur and groove (sides of spurs), forereef terrace, deep reef, patch reef, back reef, and rubble zones. For inshore patch reefs, zones included reef crest, forereef terrace, patch reef, shallow and deep boulder coral zones, and back reef. In general, these zones are compliant with the 2012 federal Coastal and Marine Ecological Classification Standard. Restoration areas were calculated for each site based on habitat classification (i.e., area), zonation, reef habitat coverage (%), and proportion of restorable reef (%).

Zone Targets by Phase

Overview

A foundational element of this effort was to identify achievable restoration targets for each reef site. Literature and expert opinion informed the identification of target percent coral cover for each zone within each reef site. These targets took into consideration the unique biology and ecology of the species and zones. Further, the existing techniques for propagating particular corals were considered, informing the timing at which they would be appropriate to be employed. Together, this information resulted in overall and phased targets for percent coral cover in each of the zones within each reef. The team also identified targets for how much of the restorable area may receive grazers to control algal growth. This decision was based on historical data, status of propagation techniques, and expert opinion.

Approach

As a first step, the scientific literature was consulted to identify historical data on the cover (%) of corals and grazers at each reef site. As expected, the literature did not yield information for the same spatial scales and habitat zones being considered. However, for most reef sites, there was some information to provide a historical perspective. This information served as the initial discussion point for the participants. From there, the realities of the existing conditions and achievable results based on existing techniques, individual species life histories, and ecology of the zones were considered. A consensus of coral percent cover target was then selected for each zone. Similarly, a target for the percentage of restorable area to receive grazers was also set. It became apparent that interim targets should also be identified, given the reality that 20 years of active restoration would likely be required to achieve selected targets.

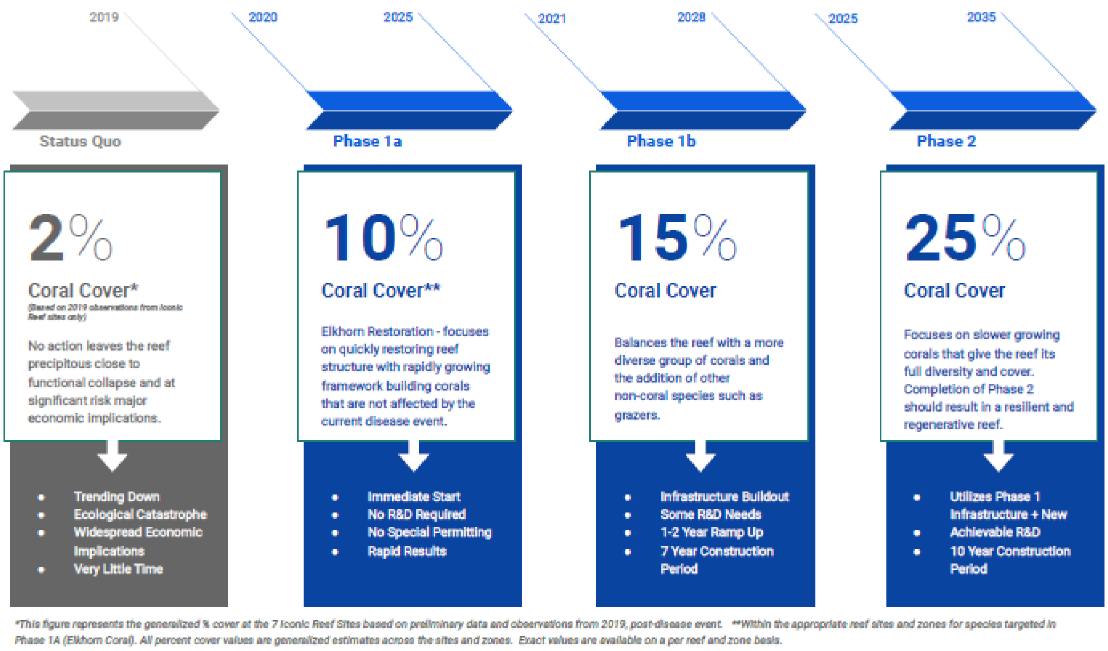


Figure 4. Depiction of the phased approach to meeting the overall targets at a reef site.

Thus, a phased approach to achieving the targets was identified (see Figure 4). The overall targets were apportioned into two phases, based on the same considerations identified above. The overall targets were further refined by identifying focal coral species groups for restoration: elkhorn coral, star coral, brain coral, pillar coral, staghorn coral, and other small stony coral. A percent cover target was assigned for each species group. For example, reef sites and zones where it is appropriate to focus on elkhorn coral outplanting were heavily apportioned to Phase 1 because the techniques are established and will increase coral cover relatively quickly. In contrast, small stony coral targets were primarily apportioned to Phase 2 due to the need to continue developing propagation techniques. Table 4 provides an example of the results of target setting and apportionment for one zone at one reef.

Table 4. Example of apportionment of the percent cover targets by species within a zone at a reef site.

	Completion Target	**Phase 1 (10 Years)**	**Phase 2 (20 Years)**
Target % Cover Increase	**19.75%**	**16.83%**	**2.92%**
Elkhorn Coral	*10.00%*	*10.00%*	*0.00%*
Star Coral	*2.00%*	*0.50%*	*1.50%*
Brain Coral	*1.00%*	*0.25%*	*0.75%*
Pillar Coral	*0.25%*	*0.08%*	*0.17%*
Staghorn Coral	*6.00%*	*6.00%*	*0.00%*
Other Small Stony Coral	*0.50%*	*0.00%*	*0.50%*

Outcome

This step in the process resulted in the production of percent cover targets for each coral species group by zone by reef site for all of the seven iconic reef sites.

Requirements Calculations

Overview

To define the scope, scale, and effort required for the restoration of the reef sites, three core metrics were identified: 1) the level of effort necessary to prepare a site for restoration; 2) the number of corals by species group that would be necessary to achieve a particular site's goals; and 3) the number of grazers (herbivores such as sea urchins and crabs) that will be necessary to prevent algal overgrowth. These requirements were calculated by looking at the restorable area of each zone relative to the restoration targets for each zone and the expected survival and growth of the restored organisms. Results are presented as the number of coral colonies or number of animals (for herbivores) that are necessary within each zone at each site.

Approach

Step 1: In order to calculate restoration requirements, the team took the results of the reef by zone mapping and the site verification surveys to determine an area of restorable habitat per zone for each reef (see Table 5).

Table 5. Example of the reef by zone mapping results.

Reef	Zone	Min Depth (m)	Max Depth (m)	Surface Area (m2)	% Reef Habitat	% Restorable	Restoration Area (m2)
Looe Key	Shallow Reef Crest	-0.7	-4.4	17,236	70%	30%	3,620
	Reef Crest	-1.6	-7.7	10,688	90%	70%	6,733
	Spur and Groove - Top	-1.9	-9.5	32,212	90%	70%	20,294
	Spur and Groove - Sides	-2.1	-9.6	36,871	90%	60%	19,910
	Forereef Terrace	-6.1	-12.7	67,708	60%	15%	6,094
	Deep Reef	-9.7	-14.7	8,746	60%	15%	787
	Backreef	-0.8	-3.2	753	50%	0%	0
	Totals			**174,214**			**57,438**

Step 2: Site preparation requirements were determined by considering all of the elements on a reef that would need to be addressed prior to restoration could begin. These consist of biotic elements that are currently occupying the substrate in areas identified to be restored (e.g., *Palythoa* spp., turf algae). A matrix was developed to qualitatively rank each element in terms of its abundance within each reef zone at each site. These individual element rankings resulted in

a final site preparation score indicating the level of effort necessary to prepare the site to receive restoration (i.e., coral outplants).

Step 3: The next step was to determine the number of organisms required to achieve restoration targets for each reef and zone identified above. A worksheet was created for each reef and a set of calculations were run for each zone. This work took the “Restorable Area” of each zone and multiplied it by the “Target % Cover Increase” for each species group and each phase of work within the zone. This resulted in an “Area of Restored Coral” necessary to achieve the “Completion Target” (see Table 6).

Table 6. Example worksheet for calculating the required number of corals by species for one zone at one reef site.

Zone	**3 - Looe Key - Spur and Groove - Top**								
Restorable Area (sq mi)	20,294	*Coral Restoration Component*							
	Completion Target	**Phase 1 (10 Years)**				**Phase 2 (20 Years)**			
Target % Cover	**20.25%**	**13.60%**	**Area of Restored Coral (sq m)**	**Restoration Requirement (clusters/heads)**	**Method**	**6.65%**	**Area of Restored Coral (sq m)**	**Restoration Requirement (clusters/heads)**	**Method**
Elkhorn Coral	*10.00%*	*8.00%*	1,623	7,587	Combination asexual outplanting & sexual propogation	*2.00%*	406	1,592	Combination asexual outplanting & sexual propogation
Star Coral	*2.00%*	*1.00%*	203	7,128	Reskinning substrate	*1.00%*	203	5,494	Reskinning substrate
Brain Coral	*1.00%*	*0.50%*	101	3,564	Reskinning substrate	*0.50%*	101	2,747	Reskinning substrate
Pillar Coral	*0.25%*	*0.10%*	20	607	Asexual outplanting	*0.15%*	30	**634**	Asexual outplanting
Staghorn Coral	*6.00%*	*4.00%*	812	3,929		*2.00%*	406	1,592	
Other Small Stony Coral	*1.00%*	*0.00%*	0	0	Reskinning substrates	*1.00%*	203	8,585	Reskinning substrates
Other	*0.00%*	*0.00%*	0			*0.00%*	0		

Step 4: To determine the number of outplanted coral colonies or clusters necessary to achieve the target “Area of Restored Coral” values set per zone at each site, average growth and expected mortality values per species group were considered. The area occupied by an outplanted colony (or cluster) was estimated using the formula for the area of a circle, πr^2 (see Figure 5).

Values for initial colony (or cluster) diameter (d) at the time of outplanting were determined for each species group through discussion with practitioners and restoration experts with local knowledge. From these diameters, the radius (r) at the time of outplanting was calculated as $r = 0.5(d)$. The area of a given colony at the time of outplanting (e.g., at year 1) was therefore equal to πr^2.

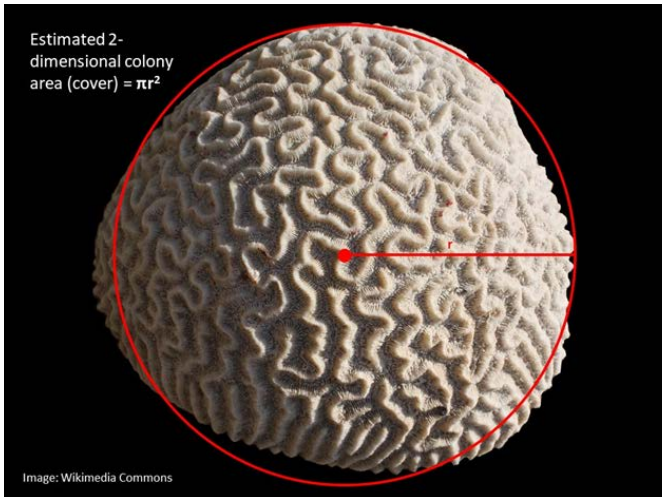


Figure 5. Image depicting how the estimated area of a coral outplant was calculated using the formula for the area of a circle.

Practitioners and restoration experts also estimated annual growth rates per species group (estimated annual increase in colony diameter [d_i]). The annual increase in colony radius (r_i) was calculated as $r_i = 0.5(d_i)$. After one year of growth (e.g., at year 2), an outplanted colony's size was calculated as $\pi(r + r_i)^2$. After n years of growth (e.g., at year n+1), an outplanted colony's size was calculated as $\pi(r+(n*r_i))^2$.

Using these equations, estimated areal coverage of a colony from a given species group could be calculated based on the year in which the colony would be outplanted and the number of years of growth expected within a given time frame. Phase 1 (10 years) is used as an example throughout this section; however, values for Phase 2 (20 years) were generated using the same methods.

Phase 1 includes 6 years of active outplanting. Therefore, as an example, elkhorn colonies outplanted in year 4 were estimated to cover an area of $\pi(r+(6*r_i))^2$ by the end of Phase 1. Using initial colony size and growth values developed by experts, this equates to an estimated cover of 0.5 m^2 for each elkhorn coral colony outplanted in year 4 by the end of Phase 1. Estimated areas at the end of Phase 1 were generated for colonies from each species group for each year that colonies were expected to be outplanted (e.g. years 1-6 of Phase 1).

For fast-growing species (e.g. staghorn and elkhorn corals), the maximum area was set at 1 m^2. At a size of 1 m^2, colonies are expected to grow into neighbors and/or undergo asexual fragmentation, ultimately forming continuous thickets.

For slower-growing species (e.g., star, brain, and small stony corals), a three year lag in growth was incorporated into these calculations to account for the time necessary for fragments in a cluster to fuse into a single colony (E. Muller, pers. comm.). As a result, areas for star, brain, and small stony coral colonies outplanted at year 1 were calculated assuming 7 total years of growth as a 25 cm-diameter colony (estimated diameter post-fusion) rather than 10 total years of growth for the full duration of Phase 1.

Figure 6 below illustrates the relative sizes of corals outplanted at years 1-6 at the conclusion of Phase 1, as calculated using the method above (coral C1 = a coral outplanted at year 1). Corals outplanted at year 1 occupy greater area (and have a greater contribution to overall Area of Restored Coral compared to those outplanted in later years (which would have less years to grow post-outplant during the 10-year Phase 1 period).

Summation of the areas of corals C1-C6 provided a Total Area value per species group for the full Phase 1 period. Subsequent calculations assume that, for each species group, equal numbers of colonies would be outplanted during each year of the 6 year active outplanting portion of Phase 1.

Next, the Area of Restored Coral previously generated was adjusted to account for expected mortality among outplants. A value of 35% expected survival throughout the duration of Phase 1 was applied for each species group. The adjusted values for Area of Restored Coral were divided by the Total Area for a given species group, then multiplied by the total number of years of outplanting expected (e.g., 6 years for Phase 1). This calculation generated the number of corals (or clusters) required (i.e., Restoration Requirement). The full equation used to generate Restoration Requirements was therefore:

Restoration Requirement for Species Group X = ([Area of Restored Coral/Expected Survival]/Total Area for Species Group X) * Number of Years of Active Outplanting

An example of the use of this equation for Phase 1 is provided for elkhorn coral in the shallow reef crest zone at Looe Key:

Area of Restored Coral: 181 m^2
Expected Survival: 0.35
Total Area for Phase 1 Elkhorn Coral: 3.54 m^2
Number of Years of Active Outplanting: 6
Restoration Requirement = ([181/0.35]/3.54) * 6 = 876 colonies

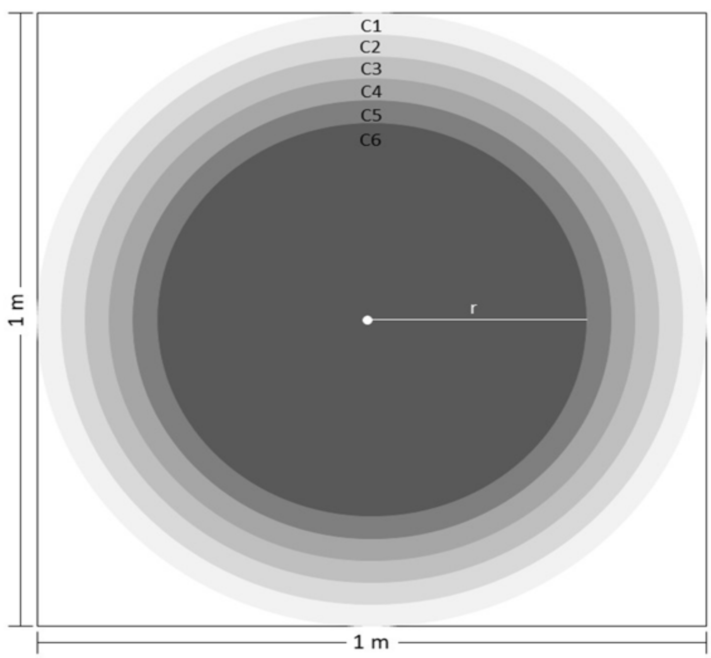


Figure 6. An illustration of the relative sizes of corals outplanted at years 1-6 at the conclusion of Phase 1. C1 represents a coral outplanted at year 1, C2 represents a coral outplanted at year 2, etc. The line marked as r represents the radius of colony C6. Corals outplanted earlier occupy greater area at the conclusion of Phase 1, as they have had more time to grow following outplanting.

Step 5: The calculations outlined above allowed us to estimate the number of Coral Heads/Clusters that would need to be outplanted for each species group in each phase in order to achieve our Completion Target after taking into consideration coral growth and mortality.

Step 6: In addition to the outplanting of corals, we also estimated the number of grazers (i.e., long-spined sea urchins and Caribbean king crab) to be added to each site. The return of grazers to the reef is necessary to help return the reef from an algae dominated environment to a coral dominated environment. However the use of grazers in reef restoration is still in its infancy and much needs to be done to both advance their propagation and survival in addition to testing their effectiveness. Since this plan lays out a 20 vision for restoration of these sites it was necessary to take some still in development activities, such as the restoration of grazers, and project the requirements associated with the effort, even though the action is less ready than other project components.

This calculation was conducted by applying the target percent of restorable area to the restorable area for each zone at each site. Then a target number of individuals per square meter was applied to the target area. For sea urchins, a target of 3 per m^2 was applied to 50% of the restorable area. For crabs, a target density of 1.5 per m^2 was applied to 50% of the restorable area of patch reef sites only. Last, the results were apportioned between Phase 1 and Phase 2, in equal proportions. The results are the number of long-spined sea urchins and Caribbean king crabs required by reef zone per site and per phase.

As noted above the target grazer numbers were calculated to get a general sense of the scale required for future relocation or aquaculture work, including costs associated with such efforts. We recognize that substantial gaps in knowledge exist with regard to propagation and population enhancement of long-spined sea urchins and Caribbean king crabs. This activity is proposed only if research and development trials prove successful. As trials are completed, site-specific population targets will be developed and necessary adjustments will be made under adaptive management plans.

Outcome

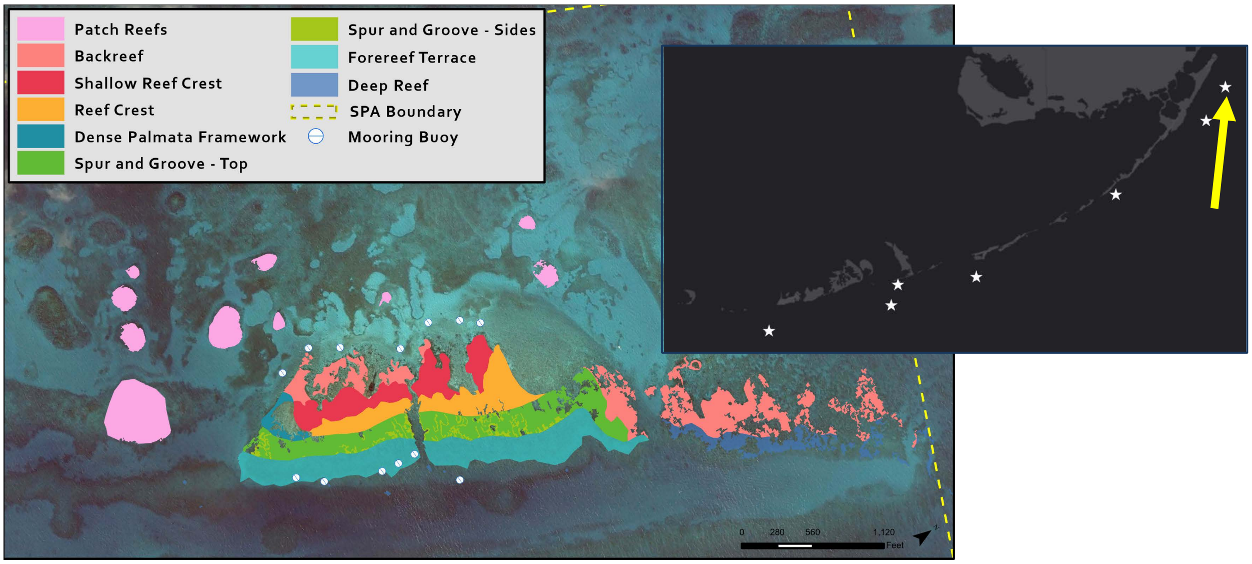
This work allowed us to calculate restoration requirements by species group within each zone at each site. This provided restoration targets to inform the level of effort necessary across the Iconic Reefs. However, it is important to note that the calculated values should not be considered absolute. Each reef site, or sections within sites, will have site-specific implementation plans that are informed by this overall effort but further refined for use within a given site. These plans will consider the reef on a section by section (spur by spur) basis, and targets, methodology, performance criteria, monitoring, and controls may be adjusted accordingly.

Conclusion

This document lays out the methods by which the team selected sites, mapped appropriate reef zones for restoration, identified the types and number corals required, and identified the types and numbers of grazers required. It provides the details on how the overall plan was developed and provides the context for the detailed electronic worksheets.

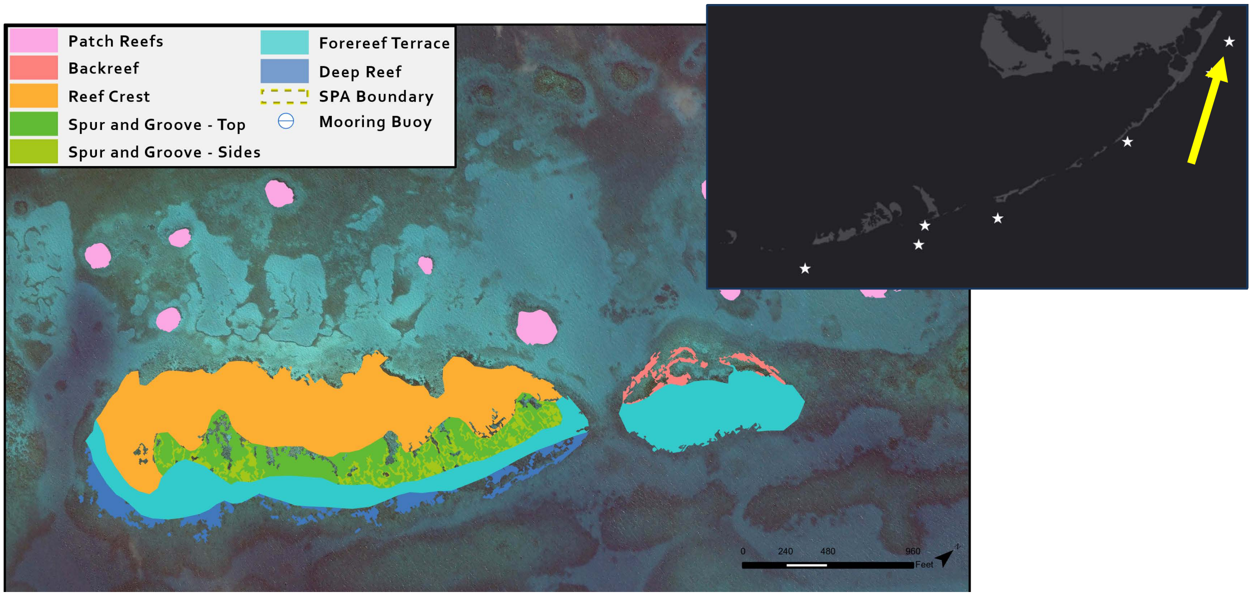
Appendix II. Reef by Reef Habitat Mapping and Summary

Carysfort North



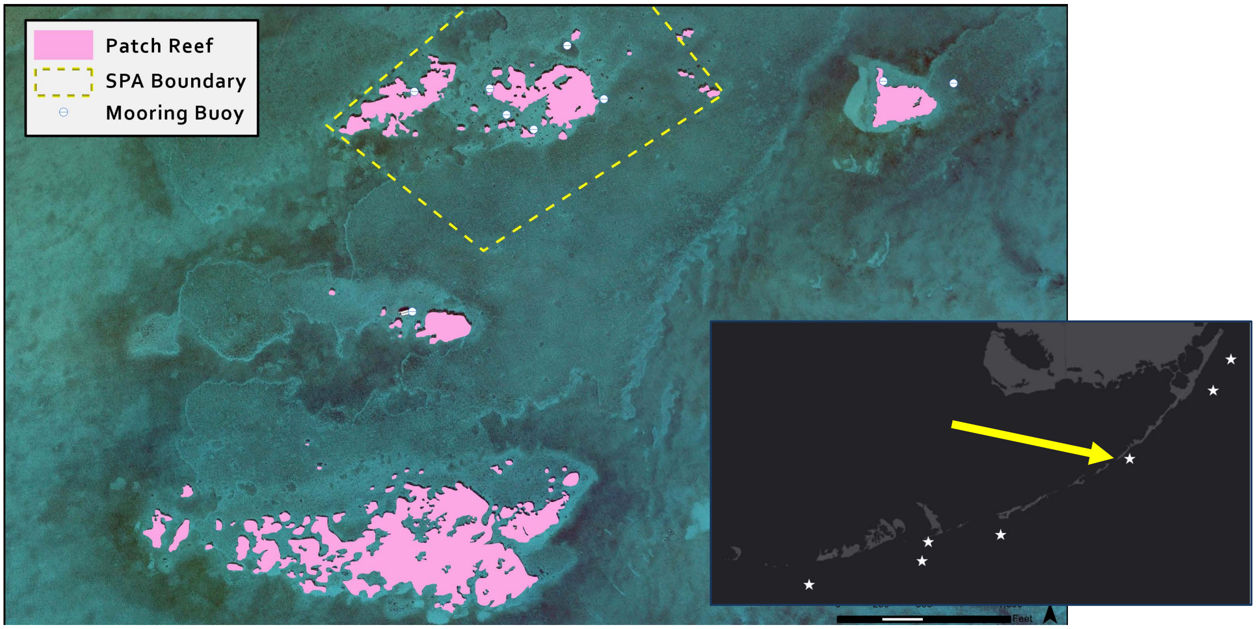
Carysfort North Site Totals							
Total Mapped Area (sq m)	**259,601**						
Restorable Area of Reef (sq m)	**54,088**						
Restoration Requirement (# of Mature Corals)				**Other Components**			
Coral Restoration Components	**Phase 1**	**Phase 2**	**Total**		**Phase 1**	**Phase 2**	**Total**
Elkhorn Coral	*22,049*	*4,450*	26,499	Sea Urchin Additions (# of Animals)	40,177	40,177	80,354
Star Coral	*5,877*	*13,589*	19,465	Caribbean King Crab Additions (# of Animals)	2,419	2,419	4,838
Brain Coral	*3,278*	*6,532*	9,811	Site Preparation (# of Days)	173	87	260
Pillar Coral	*485*	*686*	1,172	Monitoring (# of Days)	361	361	721
Staghorn Coral	*12,740*	*2,188*	14,928				
Other Small Stony Coral	*0*	*12,081*	12,081				
Other	*0*	*0*	0				
Totals	**44,429**	**39,526**	**83,955**				

Carysfort South



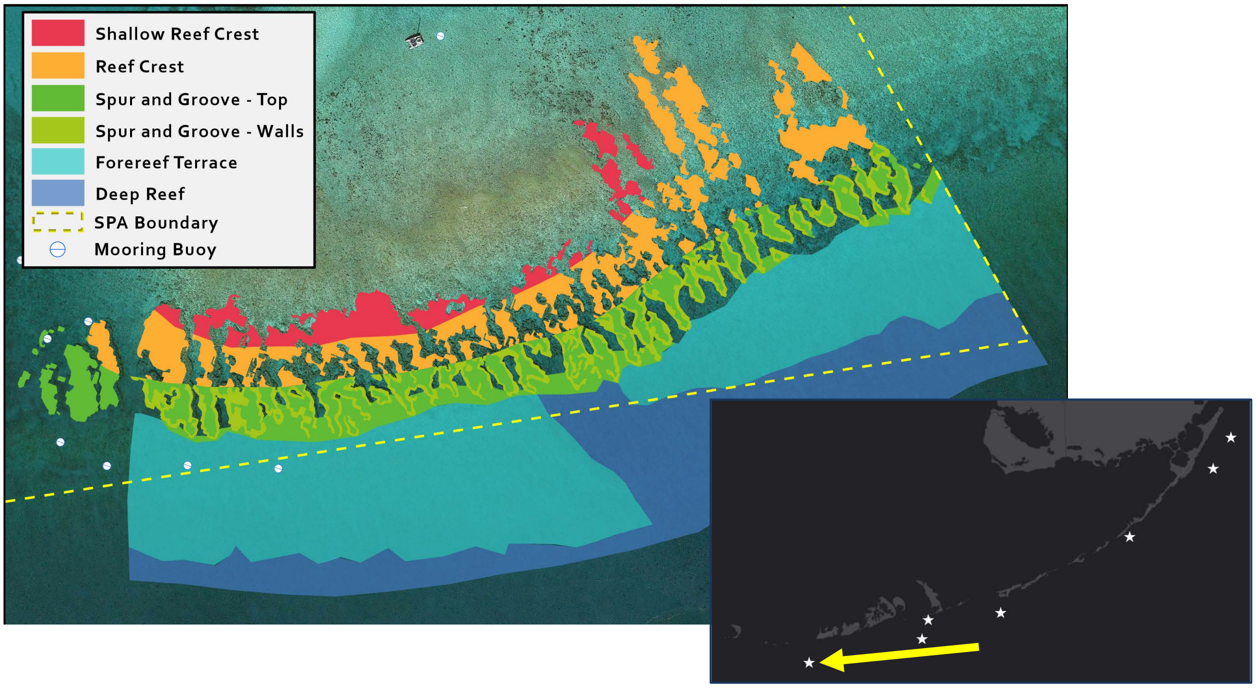
Carysfort South Site Totals							
Total Mapped Area (sq m)	**257,778**						
Restorable Area of Reef (sq m)	**71,802**						
Restoration Requirement (# of Mature Corals)				**Other Components**			
Coral Restoration Components	**Phase 1**	**Phase 2**	**Total**		**Phase 1**	**Phase 2**	**Total**
Elkhorn Coral	*40,576*	*10,539*	51,114	Sea Urchin Additions (# of Animals)	52,386	52,386	104,772
Star Coral	*5,269*	*12,184*	17,453	Caribbean King Crab Additions (# of Animals)	0	0	0
Brain Coral	*3,076*	*5,752*	8,828	Site Preparation (# of Days)	233	117	350
Pillar Coral	*317*	*448*	765	Monitoring (# of Days)	479	479	957
Staghorn Coral	*18,562*	*3,065*	21,626				
Other Small Stony Coral	*0*	*21,512*	21,512				
Other	*0*	*0*	0				
Totals	**67,800**	**53,500**	**121,299**				

Cheeca Rocks



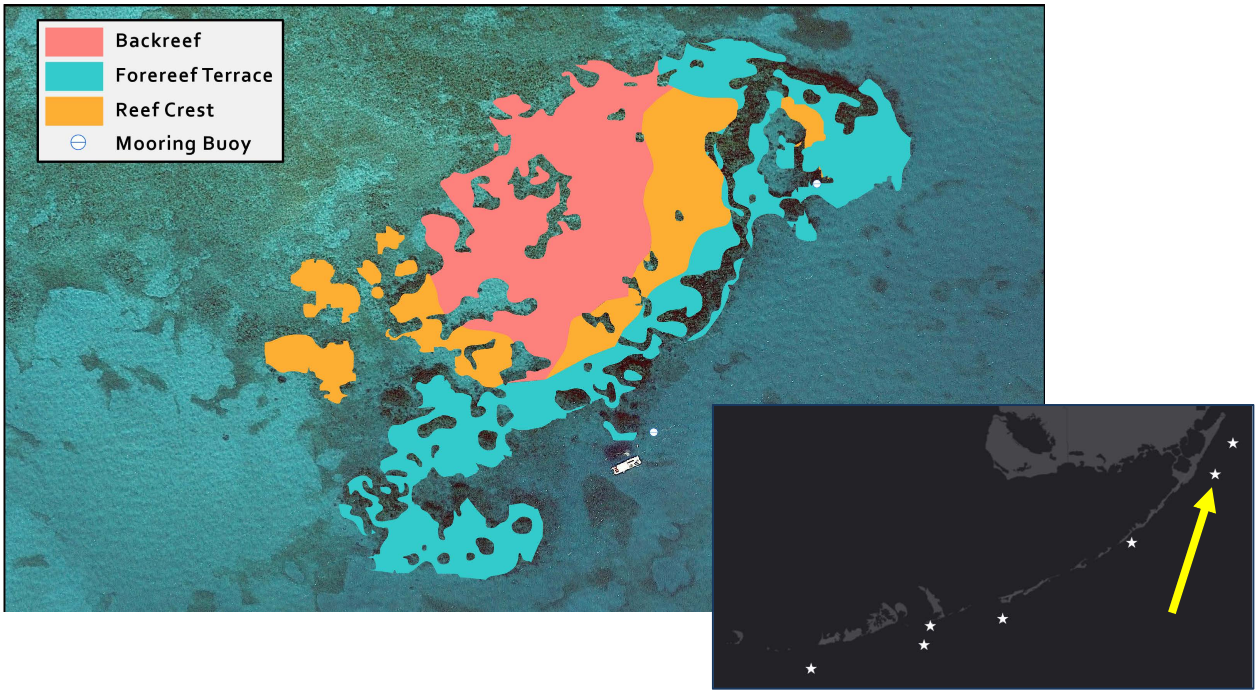
Cheeca Rocks Site Totals							
Total Mapped Area (sq m)		**82,759**					
Restorable Area of Reef (sq m)		**12,414**					
Restoration Requirement (# of Mature Corals)				**Other Components**			
Coral Restoration Components	**Phase 1**	**Phase 2**	**Total**		**Phase 1**	**Phase 2**	**Total**
Elkhorn Coral	*0*	*0*	0	Sea Urchin Additions (# of Animals)	9,310	9,310	18,621
Star Coral	*7,195*	*11,259*	18,454	Caribbean King Crab Additions (# of Animals)	6,207	6,207	12,414
Brain Coral	*5,014*	*7,898*	12,913	Site Preparation (# of Days)	31	16	47
Pillar Coral	*0*	*0*	0	Monitoring (# of Days)	83	83	166
Staghorn Coral	*0*	*0*	0				
Other Small Stony Coral	*0*	*2,626*	2,626				
Other	*0*	*0*	0				
Totals	**12,209**	**21,783**	**33,992**				

Eastern Dry Rocks



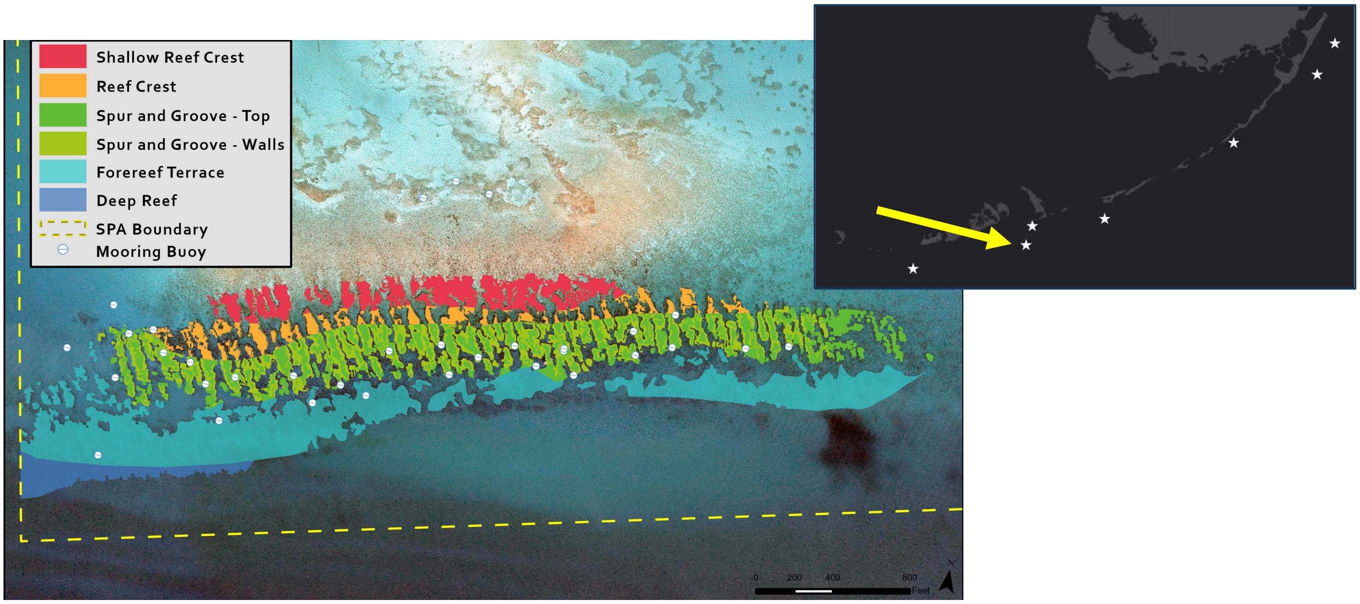
Eastern Dry Rocks Site Totals							
Total Mapped Area (sq m)	**166,797**						
Restorable Area of Reef (sq m)	**36,337**						
Restoration Requirement (# of Mature Corals)				**Other Components**			
Coral Restoration Components	**Phase 1**	**Phase 2**	**Total**		**Phase 1**	**Phase 2**	**Total**
Elkhorn Coral	*15,302*	*4,403*	19,705	Sea Urchin Additions (# of Animals)	21,633	21,633	43,266
Star Coral	*6,126*	*8,320*	14,445	Caribbean King Crab Additions (# of Animals)	0	0	0
Brain Coral	*3,989*	*6,461*	10,450	Site Preparation (# of Days)	302	151	452
Pillar Coral	*323*	*337*	660	Monitoring (# of Days)	242	242	484
Staghorn Coral	*4,927*	*4,373*	9,300				
Other Small Stony Coral	*0*	*12,024*	12,024				
Other	*0*	*0*	0				
Totals	**30,667**	**35,917**	**66,585**				

Horseshoe Reef



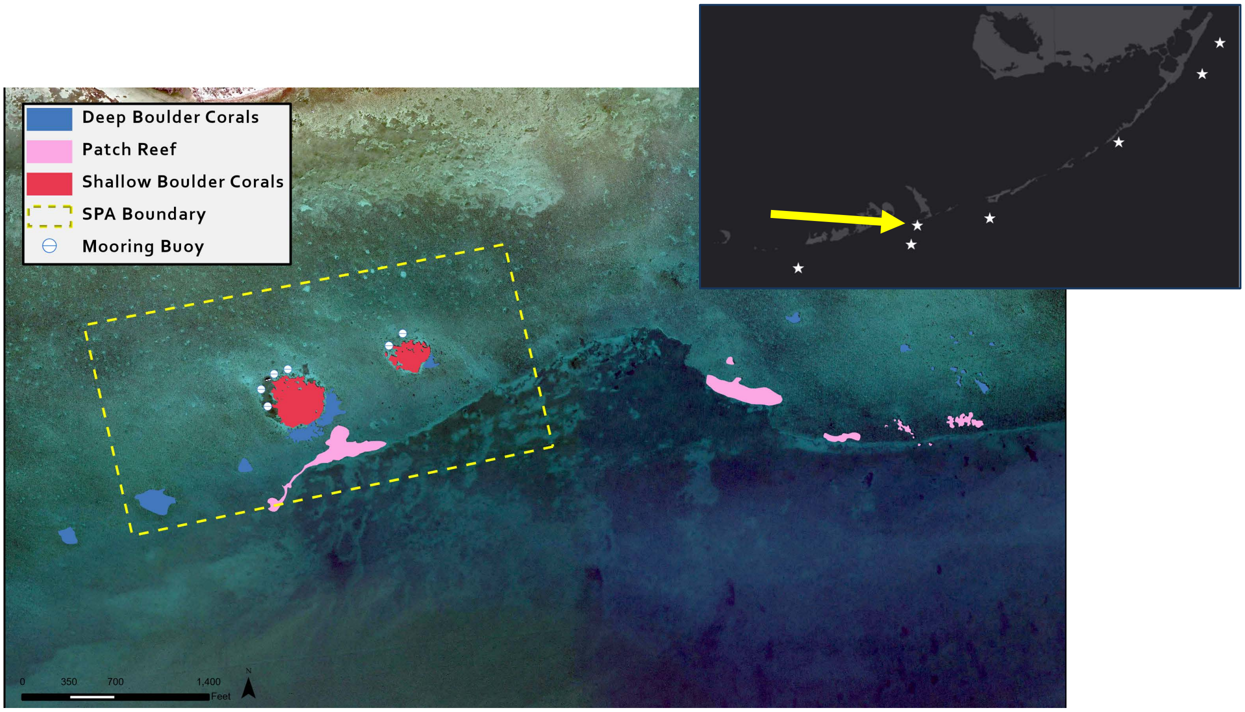
Horseshoe Site Totals							
Total Mapped Area (sq m)		**35,029**					
Restorable Area of Reef (sq m)		**12,223**					
Restoration Requirement (# of Mature Corals)				**Other Components**			
Coral Restoration Components	**Phase 1**	**Phase 2**	**Total**		**Phase 1**	**Phase 2**	**Total**
Elkhorn Coral	*6,382*	*1,686*	8,068	Sea Urchin Additions (# of Animals)	4,584	4,584	9,167
Star Coral	*3,871*	*6,725*	10,596	Caribbean King Crab Additions (# of Animals)	1,112	1,112	2,225
Brain Coral	*3,271*	*6,140*	9,411	Site Preparation (# of Days)	34	17	51
Pillar Coral	*0*	*0*	0	Monitoring (# of Days)	81	81	163
Staghorn Coral	*2,615*	*462*	3,077				
Other Small Stony Coral	*0*	*4,543*	4,543				
Other	*0*	*0*	0				
Totals	**16,139**	**19,556**	**35,695**				

Looe Key



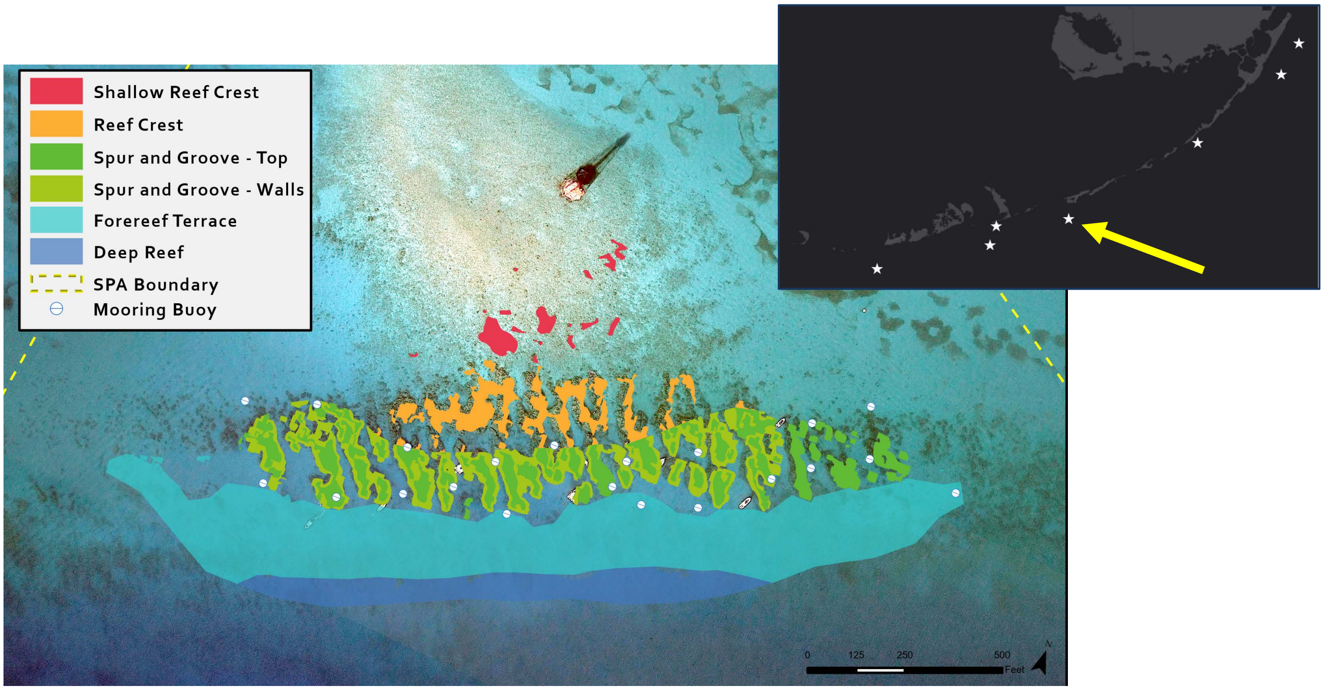
Looe Key Site Totals							
Total Mapped Area (sq m)		174,214					
Restorable Area of Reef (sq m)		57,438					
Restoration Requirement (# of Mature Corals)				Other Components			
Coral Restoration Components	Phase 1	Phase 2	Total		Phase 1	Phase 2	Total
Elkhorn Coral	*15,251*	*4,284*	19,534	Sea Urchin Additions (# of Animals)	43,078	43,078	86,157
Star Coral	*16,400*	*26,935*	43,335	Caribbean King Crab Additions (# of Animals)	0	0	0
Brain Coral	*9,134*	*14,571*	23,705	Site Preparation (# of Days)	201	101	302
Pillar Coral	*607*	*634*	1,241	Monitoring (# of Days)	383	383	766
Staghorn Coral	*6,402*	*4,051*	10,453				
Other Small Stony Coral	*0*	*18,390*	18,390				
Other	*0*	*0*	0				
Totals	**47,794**	**68,864**	**116,658**				

Newfound Harbor



Newfound Harbor Site Totals							
Total Mapped Area (sq m)		**15,317**					
Restorable Area of Reef (sq m)		**5,361**					
Restoration Requirement (# of Mature Corals)				**Other Components**			
Coral Restoration Components	**Phase 1**	**Phase 2**	**Total**		**Phase 1**	**Phase 2**	**Total**
Elkhorn Coral	*0*	*0*	0	Sea Urchin Additions (# of Animals)	6,842	6,842	13,685
Star Coral	*2,967*	*6,245*	9,212	Caribbean King Crab Additions (# of Animals)	4,223	4,223	8,447
Brain Coral	*1,243*	*1,945*	3,188	Site Preparation (# of Days)	35	18	53
Pillar Coral	*0*	*0*	0	Monitoring (# of Days)	56	56	113
Staghorn Coral	*389*	*105*	494				
Other Small Stony Coral	*0*	*1,134*	1,134				
Other	*0*	*0*	0				
Totals	**4,599**	**9,429**	**14,028**				

Sombrero Reef



Sombrero Site Totals							
Total Mapped Area (sq m)		61,781					
Restorable Area of Reef (sq m)		13,461					
Restoration Requirement (# of Mature Corals)				**Other Components**			
Coral Restoration Components	**Phase 1**	**Phase 2**	**Total**		**Phase 1**	**Phase 2**	**Total**
Elkhorn Coral	*4,593*	*903*	5,496	Sea Urchin Additions (# of Animals)	10,096	10,096	20,192
Star Coral	*2,912*	*4,249*	7,161	Caribbean King Crab Additions (# of Animals)	0	0	0
Brain Coral	*1,654*	*2,658*	4,313	Site Preparation (# of Days)	79	40	119
Pillar Coral	*137*	*143*	280	Monitoring (# of Days)	90	90	179
Staghorn Coral	*2,546*	*1,000*	3,545				
Other Small Stony Coral	*0*	*4,314*	4,314				
Other	*0*	*0*	0				
Totals	**11,842**	**13,267**	**25,109**				

Appendix III. Cost Estimate Narrative

It is not expected that Mission: Iconic Reefs will be funded through one, or even a few, means. Rather, it's likely that a mix of existing and new private and public sector funds will be combined to execute this effort. However, since this restoration strategy looks at the total requirements necessary to achieve the goals, it's important to also present a high level budget estimate so would-be funders can evaluate their potential for involvement.

There were several overarching principles that guided the scoping of this effort.

- Budget estimates based on actual experience with large scale restoration projects in the Florida Keys. Estimates however factor in additional economies of scale and process improvements that result in additional savings of 30-40% that can be expected when executing a mission of this scale.
- All costs are based on a ten year project life and a 5% annual increase in expenses each year.
- Restoration practitioners, NOAA, and other partners are actively working on efforts to further increase efficiency beyond what is reflected in the already aggressive budget estimates included here. Partners executing this project are committed to rapidly operationalizing new techniques with the hope of incrementally reducing costs and using those savings to execute the project faster and work at more sides.

Costs were looked at across the major areas of work associated with Mission: Iconic Reefs.

Site Preparation

- During the field verification portion of the planning each zone within each site was visited. In addition to other information, one of the data points collected was the presence of nuisance and invasive species that would need to be removed prior to planting of corals or placement of grazers.
- A score of 1-5 was generated for each zone that considered the level of effort necessary to remove nuisance and invasive species and prepare a site for restoration. For each zone score (1-5), we estimated the square meters of site that could be addressed with a single day of work by a 4 person dive team.
- A score of 1 was considered "Minimal" and it was estimated that a 4 person dive team could prepare 500 sq meters per day, while a score of 5 was considered "Significant" where the same team could only prepare 100 sq meters per day.
- The fully inclusive average cost for a site preparation team is estimated at **$3,527 per day**.

Coral Restoration

- Restoration of individual corals back to the reef is one of the major components of this mission and the primary metric by which restoration requirements were generated.
- In order to develop an estimate of costs for this component of the effort we looked at our previous experience with each of the six major species groups that will be restored as part of the project. Each species has differing rates of growth, different husbandry requirements, and turn over in the nursery at very different rates. As such the cost for restoring one species can vary considerably from another, but as they each play very different roles on the reef it is important that they are all included as part of the package.
- Costs range from near $100 a coral for the elkhorn and staghorn corals that grow quickly and can be raised exclusive in ocean based coral farms; while slower growing species such as star and brain coral that need to raised partially in shoreside laboratories have costs that exceed $500 per coral.
- Overall the weighted average cost per coral restored is **$259**.
- Costs of restoring an individual coral cover the full life cycle of that unit from sourcing, grow-out, all the way to outplanting.

Grazers

- The return of grazers (long-spined sea urchins and Caribbean king crabs) to the reef is necessary to help return the reef from an algae dominated environment to a coral dominated environment.
- However, the use of grazers in reef restoration is still in its infancy and much needs to be done to both advance their propagation and survival in addition to testing their effectiveness.
- As this plan lays out a 20 year vision for the restoration of these sites, it was necessary to make some considerations for development activities, such as the restoration of grazers, and project the requirements associated with the effort, even though the action is less ready than other project components.
- Even though there is a requirement listed for grazers, there is no intention to implement at that scale until appropriateness and effectiveness can be fully evaluated.
- The costs for this component were developed in consultation with experts in *ex situ* culture of marine organisms. The cost of facility build-out, operations, and maintenance were considered assuming new facility on existing property. The costs and production were considered over an 8 year operational period.
- Urchins are the most substantial portion of this effort, and therefore, were the basis of the overall grazer cost estimate.
- Considering build-out and annual production, costs were estimated at **$35 per grazer addition** (urchin or crab).

Site Maintenance

- One of the major lessons learned of restoration work to date in the Florida Keys is that restoration is not a set and forget activity. When a terrestrial site is developed, whether it be into a restoration project, a park, or a golf course, it comes with a team that culls invasive species, takes out the trash, and generally keeps the site in an optimal condition.
- 2-3 site maintenance teams will be established across the region and will spend every possible field day at their designated reef sites. Those teams will work alongside a volunteer workforce using the same models that have been used effectively for decades at terrestrial parks.
- Site maintenance teams will include 2 divers and, in general, are assumed to be able to visit and conduct minor interventions and maintenance of 1,000 sq. m. per day.
- Site maintenance teams will conduct maintenance at least once per month at each site.
- Cost is **$2,502 per day**.

Monitoring

- Monitoring to track successes and failures in order to inform mid-course corrections and adaptive management is critical to the long term success of any restoration effort.
- 20% of each zone within each site will receive comprehensive monitoring. Permanent plots will be established and performance will be tracked against the restoration targets.
- Monitoring teams will include 4 divers. Each team is expected to be able to evaluate 6 plots per day.
- Over the course of 10 years, it is estimated that 20 dedicated monitoring events will be needed. This will allow for events 2-3 times per year during the initial establishment phase, annual monitoring during the outplanting years, and post-disturbance monitoring after major storms or other disturbances.
- Site maintenance teams will also conduct site wide roving diver surveys during their work to provide insight into the performance of other areas of the site that are outside of the permanent monitoring plots.
- Cost is **$4,652 per day**.

Adaptive Management and Disaster Recovery

- As with any project there is a need for the ability to respond to unanticipated and unplanned events. Therefore, a contingency fund is necessary to protect the restoration investment.
- **10% of the subtotal** of all other costs.

Cost Estimate Details

All costs are based on 180 field days per year and are fully inclusive of:

- Divers, Surface Support, and a Vessel Captain

- In-water, Shoreside, and Lab Facilities
- Shoreside Personnel
- Diving Equipment and Facilities
- Vessels, Fuel, and Maintenance
- Administration and Project management.

Phase 1A / 1B

- Phase 1 is split into two phases. Phase 1A is focuses on elkhorn coral restoration in the appropriate zones, which occur at five of the seven Iconic Reef sites. Phase 1B balances the reef with other coral species and grazers.
- Costs are apportioned based on the # of corals in 1A vs 1B.

Table 1. Summary cost per unit for each budget category.

Site Prep (Day)	$3,527
Cost p/Coral	$259
Monitoring (Day)	$4,652
Maintenance (Day)	$2,502
Grazers	$36
Adaptive Mgt (% of subtotal)	10%

Table 2. Summary statistics for corals and grazers added by reef site.

		Phase 1 A/B ACTION: Add rapid-growing corals DURATION: 5-7 Years of Work 10-YR GOAL: ~15% cover			**Phase 2** ACTION: Add slower-growing corals DURATION: 10-12 Years of Work 20-YR GOAL: ~25% cover	
Region	Reef	Restorable Area (sq m)	# of Corals Planted	# of Grazers Added	# of Corals Planted	# of Grazers Added
Upper Keys	Carysfort Reef	125,890	112,228	94,982	93,026	94,982
	Horseshoe Reef	12,223	16,139	5,696	19,556	5,696
Middle Keys	Cheeca Rocks	12,414	12,209	15,517	21,783	15,517
	Sombrero Reef	13,461	11,842	10,096	13,267	10,096
Lower Keys	Looe Key Reef	57,438	47,794	43,078	68,864	43,078
	Newfound Harbor	8,447	4,599	11,066	9,429	11,066
	Eastern Dry Rocks	36,337	30,667	21,633	35,917	21,633
	Subtotal	266,209	235,479	202,068	261,842	202,068

Table 3. Summary statistics for site preparation and monitoring by reef site.

			Phase 1 A/B ACTION: Add rapid-growing corals DURATION: 5-7 Years of Work 10-YR GOAL: ~15% cover		Phase 2 ACTION: Add slower-growing corals DURATION: 10-12 Years of Work 20-YR GOAL: ~25% cover	
Region	Reef	Restorable Area (sq m)	Site Preparation (Days)	Site Monitoring (Days)	Site Preparation (Days)	Site Monitoring (Days)
Upper Keys	Carysfort Reef	125,890	407	839	203	839
	Horseshoe Reef	12,223	34	81	17	81
Middle Keys	Cheeca Rocks	12,414	31	83	16	83
	Sombrero Reef	13,461	79	90	40	90
Lower Keys	Looe Key Reef	57,438	201	383	101	383
	Newfound Harbor	8,447	35	56	18	56
	Eastern Dry Rocks	36,337	302	242	151	242
	Subtotal	266,209	1,089	1,775	544	1,775

Table 4. Budget for Phase 1 by reef site and budget category.

Phase 1

ACTION: Add rapid-growing corals
DURATION: 5-7 Years of Work
10-YR GOAL: ~15% cover

Region	Reef	Site Preparation	Coral Restoration	Grazer Additions	Monitoring	Maintenance	Adaptive Mgt.	Total
Upper Keys	Carysfort Reef	$1,434,002	$29,101,940	$3,419,340	$3,904,254	$3,779,707	$4,163,924	$45,803,168
	Horseshoe Reef	$119,533	$4,185,003	$205,057	$379,075	$366,983	$525,565	$5,781,215
Middle Keys	Cheeca Rocks	$109,459	$3,165,963	$558,623	$384,995	$372,713	$459,175	$5,050,929
	Sombrero Reef	$280,068	$3,070,743	$363,454	$417,479	$404,161	$453,591	$4,989,497
Lower Keys	Looe Key Reef	$710,247	$12,393,494	$1,550,820	$1,781,336	$1,724,511	$1,816,041	$19,976,449
	Newfound Harbor	$123,738	$1,192,572	$398,366	$261,967	$253,611	$223,025	$2,453,280
	Eastern Dry Rocks	$1,063,795	$7,952,343	$778,794	$1,126,933	$1,090,984	$1,201,285	$13,214,134
	Subtotal	**$3,840,843**	**$61,062,060**	**$7,274,454**	**$8,256,040**	**$7,992,670**	**$8,842,607**	**$97,268,672**

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