CORAL RESTORATION FOUNDATION

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# Lessons learned for increased scalability for *in situ* coral restoration efforts

AUTHORS:
Jessica S. Levy[1], Kayla J. Ripple[2], and R. S. Winters[1]
[1]Coral Restoration Foundation, Key Largo, FL 33037
[2]Association of Zoos and Aquariums, Silver Springs, MD

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## BACKGROUND: THE PROBLEM OF DECLINING REEFS

The health and abundance of coral reefs has been marked by stark decline dating from as early as the 1970s. Reefs were once dominated by two main reef-building coral species (*Acropora cervicornis* and *A. palmata*) that were fast growing and provided complex habitat for marine fish and other invertebrates. In Florida, coral reefs have experienced up to a 98% loss in the populations of *Acropora* coral. This decline can be attributed to multiple compounding factors including overfishing, poor water quality, extreme water temperatures, and the loss of herbivores. As these threats continue – and potentially worsen – there is a clear need for innovative methods to help abate stressors on coral reefs. Active coral restoration (or population enhancement) has emerged as the primary method to manage the loss of coral reef habitat and potentially reverse population decline for specific geographic regions. While there are many restoration organizations using diverse techniques, coral restoration practices remain relatively new, understudied, and poised to benefit from focused attention to improve scalability.

For active coral restoration to be impactful at a large scale, restoration techniques must increase the capacity to produce, outplant, and track corals through the restoration process. The field of coral restoration will continue to evolve as techniques improve and collective insight is shared amongst managers, restoration practitioners, and researchers. It is the purpose of this white paper to share the lessons learned and techniques developed by the Coral Restoration Foundation as we scaled our nursery and outplanting efforts tenfold over three years in order to engage restoration practice at ecologically meaningful scales.

## STEP 1: INCREASING CAPACITY FOR SCALABLE CORAL RESTORATION PROGRAMS

In October 2013, Coral Restoration Foundation (CRF) was awarded a three-year $700,000 grant for coral reef restoration by the NOAA Restoration Center, Office of Habitat Conservation (award number NA13NMF4630144). Supported in part by this grant, CRF was able to develop both the techniques and the infrastructure needed to support coral restoration efforts on an order of magnitude higher than that of previous projects. Herein, we highlight the most significant lessons learned in order to assist other restoration groups in their expansion of techniques for scalable *Acropora* restoration projects. Our goal is to share what we have learned in order to promote the enhancement and success of large-scale coral restoration efforts.

Endeavors supported:

1) Widespread restoration efforts throughout the Florida Keys for two important threatened coral species: *Acropora cervicornis* (staghorn coral) and *Acropora palmata* (elkhorn coral).
2) Development of *in situ* nursery techniques for growing three other species of coral listed on the Endangered Species Act (ESA): *Orbicella faveolata* (mountainous star coral), *Orbicella annularis* (lobed star coral), and *Dendrogyra cylindrus* (pillar coral).

Results obtained:

1) CRF not only met but exceeded the project's three-year restoration goals for outplant numbers of both staghorn and elkhorn (Table 1).

Table 1: Funding year and output of restoration efforts under grant # NA13NMF4630144.

| Funding Year | Species | Funded | Actual | # Sites |
|---|---|---|---|---|
| **Oct. 2013-Sept. 2014** | *A. cervicornis* | 2,900 | 3,181 | 9 |
| | *A. palmata* | 500 | 583 | 5 |
| **Oct. 2014-Sept. 2015** | *A. cervicornis* | 3,025 | 3,240 | 7 |
| | *A. palmata* | 900 | 900 | 6 |
| **Oct. 2015-Sept. 2016** | *A. cervicornis* | 3,875 | 6,098 | 13 |
| | *A. palmata* | 2,700 | 6,098 | 11 |

2) CRF was successful in pioneering new methodologies for growing stony coral, promoting genetic diversity, and refining outplanting techniques for *Orbicella faveolata* (mountainous star coral), *O. annularis* (lobed star coral), and *Dendrogyra cylindrus* (pillar coral), three other coral species listed as threatened under the Endangered Species Act.

3) CRF developed an improved systematic tracking system for genetic variants, nursery stock, and outplants, facilitating increased scalability and allowing future data analyses that may identify the variables associated with outplant success.

Application of this operational infrastructure has allowed us to further expand our nursery and outplant efforts by tenfold over initial project plans.

Resources including data structure, protocols, data systems, and so forth are available to restoration practitioners via the Coral Restoration Foundation website:
*www.coralrestoration.org/white-papers*

## STEP 2: INCREASING INFRASTRUCTURE TO SUPPORT ACROPORA RECOVERY

1.0 <u>Data Management and Project Tracking Systems</u>
With increased capacity and active restoration comes a need to increase consistency, develop standards, improve data tracking, and share data within CRF and between collaborators. These needs informed the development of data structures in order to ensure that databases would support future, scalable growth. To aid our restoration colleagues in the development of their databases, we have created a coral restoration database development workbook to be released in 2018.

| Issue | Challenge | Impact | Recommended Implementation |
|---|---|---|---|
| Genet naming | Variations in naming conventions of collected putative genets by different groups at different times | Difficulty reconciling information between groups, information collected at different times, inventorying available (or lost) genets, and inability to consistently track genets through the collection-nursery-outplant cycle | CRF developed a standardized protocol for naming putative genetics that allows tracking of unique genets through all restoration efforts and in all data systems, regardless of species, collector, or collection location. |

| Issue | Challenge | Impact | Recommended Implementation |
|---|---|---|---|
| Project management clarity | Staff change during the funding period | Project management was shared between multiple persons, making goal setting and fulfillment challenging | CRF assigned a project manager at the start of a project and clearly outlined the desired outcomes. The outcomes desired from the project were used to create data-tracking databases and dashboards. These databases should be maintained as a single, shared file structure where information is available in real-time and accessible to all parties. This provides a system for clean and easy data transfer should project management change hands in the middle of a project. All the necessary information is in a single master location accessible in real-time and available to all parties. |
| Record keeping | Diverse metrics were required for grant reporting. The internal record system was not standardized prior to this grant implementation. | Records kept in different locations or from different sources made it time-consuming and challenging to summarize metrics. | CRF created a master database system for reporting and standardized reporting systems so that there is one source of information for each metric at the project start. *Database materials will be published in a CRF workbook to be released in 2018. |
| Data collection standards and protocols (nursery and outplanting) | Nursery and outplant data collection were not standardized. | Observations and data collected were subjective to divers who collected information. | CRF developed a standardized data collection system and a systematic training protocol to educate users, and revised our methods for processing data received. These efforts are complemented with a master database system to track the information. |

| Issue | Challenge | Impact | Recommended Implementation |
|---|---|---|---|
| Short-term goal tracking | Lack of a systematic way to track daily work hindered long-term planning and adherence to project timelines. | Difficulty of planning long-term and understanding the needs of nursery and outplant operations, both now and in the future | CRF implemented a dashboard to schedule and track the progress of our nursery and outplant efforts. The dashboard is synced with our master data systems, providing real-time transparency to all users. |

## 2.0 Nursery Operations

*In situ* nursery systems have emerged as a valuable tool supporting restoration goals, most prominently the ability to protect the population's genetic diversity and to produce fragments *en masse* for large-scale, ecosystem-level impact. At CRF, nearly 300 genotypes from 6 different coral species have been collected and are in curation, and over 40,000 coral colonies have been outplanted across 20+ restoration sites throughout the Florida Keys Reef Tract.

As our nursery program evolved over the past decade, so too did our coral growth techniques, which enabled us to increase efficiency in coral propagation and nursery maintenance. This became apparent in our propagation of staghorn coral (*A. cervicornis*) when coral growth surpassed our ability to outplant using current outplant methods. Initially, each genetically unique strain of coral (a putative genotype) was maintained on its own coral tree. As production rates increased, such a one-genet-one-tree system made harvesting of coral material for outplanting challenging, since large amounts of live material matured synchronously regardless of expected usage. Maintaining genetic diversity of corals used for restoration is essential to the success of all restoration projects, as different genotypes behave and respond differently to various stressors. Some genotypes may have a stronger tolerance to increased temperatures, greater disease resistance, or greater growth rates. Additionally, successful sexual reproduction is related to the level of genetic variability across genotypes for fertilization during spawning. The goal of any restoration intervention effort is to achieve natural sexual reproduction in order promote self-recovery. Thus, genetic diversity is key to promoting reef resilience, especially under changing ocean conditions.

To achieve a balance between maintaining genetic diversity and managing the growth of genotypes, we modified our nursery design, focusing on the "role" that a particular genotype played in our overall restoration effort. These roles include: 1) stock for active restoration efforts, grown to be outplanted; 2) the curation of genetic diversity across many genotypes, regardless of whether a particular genotype was being used in an active restoration project; and 3) the maintenance of sexually mature spawning stock. Previously, coral production and genotype preservation were not differentiated. This led to multiple genotypes being grown in numbers that far exceeded our operational capacity to outplant. At CRF, the Tavernier Nursery houses over 400 trees and has been restructured to contain a staghorn production area, an elkhorn production area, and a genetic preservation area, or "gene bank". The gene bank houses representative samples of all known genotypes collected across each species. Maintaining a small stock for every genotype collected was imperative, considering that we know anecdotally many of these genotypes are no longer found in wild populations.

Significant effort was invested in refining growth methods for *A. palmata* as well as developing new methods for growing additional coral species, including *Orbicella* spp. and *D. cylindrus*. Just as genetic diversity is critical in enhancing coral populations, species diversity is critical in supporting reef communities. Boulder corals play an essential, stabilizing role for coral reefs, yet their inclusion in restoration efforts is underrepresented (traditional propagation methods for fast-growing, branching *Acropora* corals are not effective for slower growing, mounding corals).

Unlike the Acroporids where fragmentation can take place *in situ*, boulder coral "heads" cannot be fragmented without being taken into a land-based laboratory where power tools can be applied. We have developed a technique to "core" parent colonies to produce an initial time-zero population, which can then be fragmented in our nursery, similar to the Acroporid fragmentation process, to produce subsequent clones. A parent colony is brought to land once and fragmented (or cored) using a diamond-blade circular drill bit. These fragments (or cores) are then epoxied onto the flat surface of small credit-card like cards that document all genetic information for each colony (Figure 1). The coral cards are moved into the nursery, where they are suspended on modified coral-tree structures (Figure 2) that allow the growing corals to be faced upwards, toward the sunlight. In the nursery, the boulder coral grows tissue down onto its epoxy base, then outward in a thin, sheet-like layer along the card's surface. Because the coral skeleton is still thin at this phase, the tissue can be cut with diagonal cutters to produce subsequent generations of fragments. These fragments can either be attached to new cards and suspended in the nursery, or attached to structures, like cement disks or plugs, to prepare them for outplanting.

| Issue | Challenge | Impact | Recommended Implementation |
|---|---|---|---|
| Excess stock of staghorn corals | Coral production surpassed outplant capacity. | Coral stock was overgrown, which could produce overcrowded conditions leading to disease outbreaks and susceptibility to breakage.<br><br>Additionally, outplanting was driven by stock availability (i.e. removal of excess stock) rather than a systematic approach to mixing genotypes for individual projects. | Develop a nursery structure that differentiates coral stock based on its functional role within the restoration program, be that restoration-based production, maintenance of genetic diversity, research and development, or spawning. Not every genotype collected needs to be fragmented and grown in large numbers for outplanting efforts. *Data sheets and affiliated materials will be published in a CRF workbook to be released in 2018. |
| Techniques for *A. palmata* production | Scalable production of elkhorn coral was difficult in comparison to that of staghorn due to slower growth rates of the elkhorn species. | Growth of *A. palmata* from fragmentation to outplant-ready sizes is slower than for *A. cervicornis*. Increased maintenance is required to propagate large numbers. | Unlike staghorn, where each fragment will ultimately be outplanted, the husbandry of elkhorn coral must be different to maximize efficacy. A "starter" elkhorn is hung on in-water trees using thicker monofilament line than is used for staghorn. These starter colonies are allowed to grow and branch to a larger size then staghorn. For outplanting, fragments are harvested by cutting the new growth of the starter colony, while the original starter core remains in place and is allowed to continue growing. |

| Issue | Challenge | Impact | Recommended Implementation |
|---|---|---|---|
| A lack of techniques for *in situ* production of *Orbicella* spp. | Traditional *in situ* and *ex situ* nursery techniques require modification and adaptation for slower growing, non-branching, corals. | Standard propagation methods are not suited for growth of mounding coral species; maximization of efficiency while keeping production methods and equipment as similar as possible for different coral types is desired | CRF is developing techniques for open-ocean nursery production of these corals to produce multiple generations of mounding coral species. Present work is geared towards the production of multiple generations of many genotypes using labeled plastic cards printed using Zebra Technologies and suspended from modified coral tree structures. |

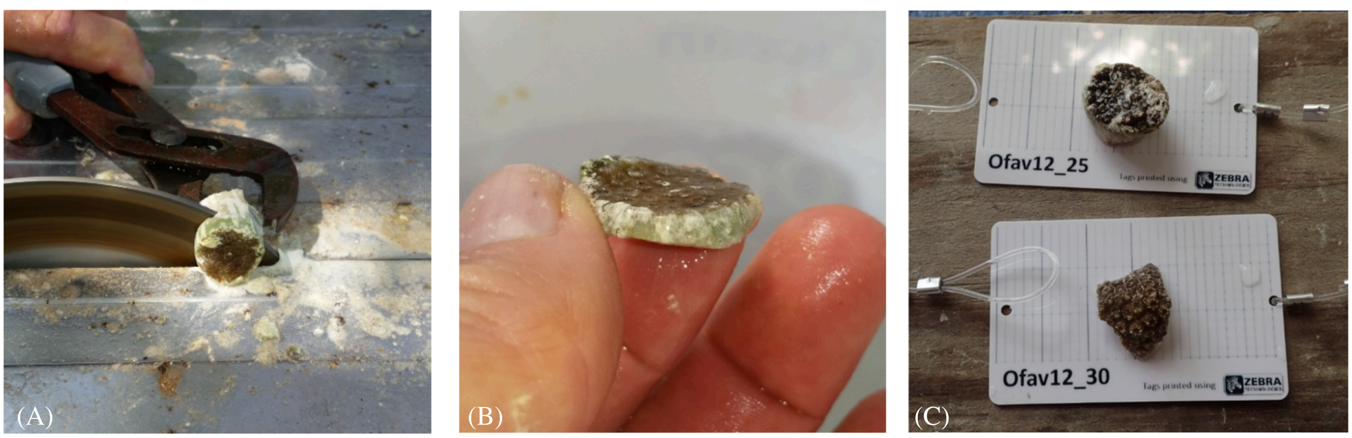


Figure 1: (A) Land-based process of coring the parent colony. *Orbicella* spp. is being trimmed off the initial coral plug. (B) Finished coral plug with excess skeleton removed. (C) Mounted coral plugs prior to planting in nursery. Photo credit: Coral Restoration Foundation.

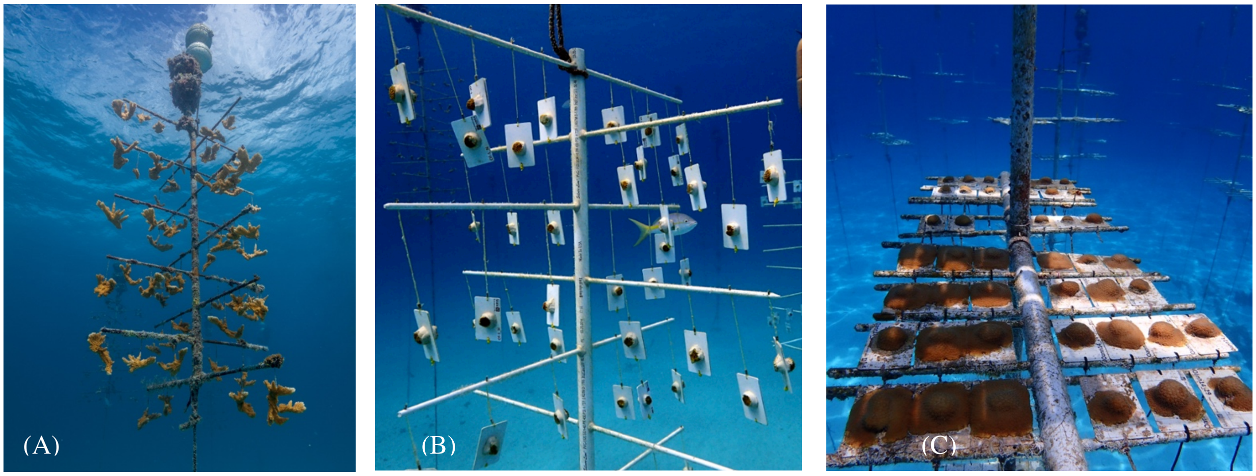


Figure 2: Image (A) is the traditional tree structure that staghorn and elkhorn (pictured) are suspended from. Initially, we suspended the boulder corals similar to that of the *Acropora* species (B). Our trees structures have evolved to now hold rows of boulder corals on platforms built into the arms of each trees (C). Photo credit: Coral Restoration Foundation.

3.0 <u>Outplant Strategy</u>

One of, if not the, largest change that CRF has made in the last few years has been to our outplant strategy. Initially, once a group of nursery corals was harvested, whomever was diving on the day of outplanting would decide on outplant location and composition of the coral cluster. For a small organization trying to maximize its impact, this was a time-saving approach. However, we quickly realized that this influenced the short-term success of outplants: survivorship was correlated with factors of the reef site, micro-environment, and cluster composition, factors which themselves were the result of experience. Additionally, this uncoordinated placement of clusters complicated the creation of site maps and subsequent monitoring. We realized that having a coordinated, planned outplanting strategy implemented by experienced divers increased efficiency and survivorship, and focused our efforts on restoring specific areas to ecologically meaningful degrees. Lead divers were able to better select the most promising micro-environment on a predetermined restoration site and systematically lay out coral clusters. In addition to the benefits already mentioned, this improved mapping of the site and allowed us to leverage the effort of more inexperienced divers for attachment, thus increasing total output. Due to this increased efficiency and ordered structure, the outplanting efforts were accomplished much faster than with previous methods. Additionally, we transitioned from placing identification tags directly on the substrate to securing small unique tags directly to the coral itself. This enabled us to better track each unique cluster over time and was captured in our data systems.

Outplanting efforts were also reconceptualized to promote genetic diversity at degraded reef sites. During a single outplant event, multiple putative genotypes were placed in the same reef area with the goals of: (1) promoting resilience in restored populations, and (2) promoting successful sexual recruitment during spawning events. As already stated, in previous years the genotypes used for outplanting were driven by existing nursery stock, meaning that when trees were overstocked they would become the priority for outplanting. Because of these nursery limitations, we were unable to choose specific genotypes for a restoration project, and sites contained different, random mixes of genotypes. Therefore, our capacity to differentiate between site suitability and genetic performance was impaired. Gene by environment interactions are crucial to understanding the genetic influence on outplant survivorship, and ultimately can be used to enhance the success of restoration efforts through better site and genotype selection.

Improvements made to our outplant methodology provided the platform that guides our current restoration program. Our current restoration work is designed to align with several of the population-based recovery metrics outlined in NOAA's *Acropora* Recovery Plan. Outplant efforts continue to be rooted in promoting genetic diversity and population enhancement. For example, outplant efforts now use 50 distinct genotypes of both *A. cervicornis* and *A. palmata*, selected to maximize genetic variability of available curated stock, in a concentrated effort across eight reefs in the Florida Reef Tract. The diversity standards for outplants are based on genetic sequencing at two levels of resolution (hi-res ddRAD sequencing and low-res mtDNA) rather than putative information, allowing for the identification of unique genotypes.

| Issue | Challenge | Impact | Recommended Implementation |
|---|---|---|---|
| Outplant tags | PVC tags were not suitable for long term use *in situ*. Algae and fire coral would hide or encrust tags, making them illegible or unreadable. | It was difficult to track individual coral clusters over time for monitoring. | Printing tags with laser printing technology (e.g. Zebra brand printers), allows us to track all cluster information over extended periods of time. To decrease loss of tags, several tags should be included in a single cluster for redundancy in the event that one tag is lost or corals fragment *in situ*. |

| Issue | Challenge | Impact | Recommended Implementation |
|---|---|---|---|
| Unique cluster naming system | Coral clusters lacked a unique naming convention. | Individual clusters of the same genotype could not be previously distinguished on the same reef or different reefs. | We developed a system for uniquely naming outplanted clusters. Each cluster name (a combination of genotype and cluster identifiers) is unique and found only once, regardless of outplant site. This allows individual clusters and their performance to be efficiently monitored over time. |
| Transport stress | Need to minimize transport stress between nursery harvest locations and outplant sites. | Greater transport stress negatively influenced coral health prior to reaching an outplant site. Transport stress affected survivorship. | Limit transport stress by increasing aeration, decreasing transport density, and decreasing transport times. |
| Selecting spots for outplanting | Micro-environment selection for outplanting was subjective and not consistent across reef sites. We discovered that diver experience was correlated with differences in various parameters during outplanting that could influence survivorship. | Cluster placement was not always in optimal areas on a reef and was highly variable based on divers. This made it difficult to determine what caused success or mortality at restoration sites. Additionally, this resulted in inconsistencies in mapping outplant sites, leading to difficulty in subsequent monitoring. | Placement and mapping procedures were systemized by the development of outplanting protocols and consistent training of trip leaders on how to lay out coral clusters for restoration. Clusters were placed in rows based on genotype to prevent scattering and to simplify site-map making for subsequent monitoring. |

| Issue | Challenge | Impact | Recommended Implementation |
|---|---|---|---|
| Under-representation of genetic diversity on reef sites | Ensure genetic diversity at restoration sites. | Corals utilized for restoration projects were determined by which trees needed to be thinned out within the nursery. This limited our ability to outplant specific genets in order to increase genetic diversity on a reef site. | Modification of the nursery design coupled with pre-selection of our desired genotypes allowed us to systematically ensure that each reef site received a diverse selection of coral genotypes. |
| Outplant capacity is the rate limiting factor for restoration | There is a limited capacity to move corals to reef sites quickly and efficiency. | At the operational level, traditional outplant methods require one diver to secure one coral at a time. This scale is too small to achieve large scale goals for reef recovery. | New techniques, methods, and strategies need to be developed in the field of coral restoration as a whole in order to be able to truly upscale restoration efforts for greater chance at recovery success. |

## 4.0 Monitoring

The monitoring program at CRF seeks to understand factors that influence the health, condition, and long-term survivorship of outplanted corals at restoration sites. Recognizing monitoring efforts as part of the restoration process is a critical first step. Secondly, appointing one person to manage training, scheduling, and implementation can streamline monitoring. This makes the process more manageable, particularly when resources (e.g. available boats) must be shared between different activities (i.e. nursery maintenance, outplanting, and monitoring). Prior to our establishment of a formal monitoring program, efforts were conducted only when extra staff capacity and field resources were available.

Inconsistent tagging methods and outplant location records made it difficult to locate clusters over time, prohibiting assessments for habitat suitability or genetic performance. To solve this problem, we developed a unique tagging system for each coral cluster placed on the reef, which allows us to track the same cluster over time. Similarly, the refinement of our site map protocol enabled us to accurately record cluster location, enabling staff members to locate the clusters regardless of prior familiarity with the site or time between visits.

Monitoring requires manpower. Prior to increasing staff capacity, CRF had limited manpower to perform monitoring assessments. Outplanting and restoration activities should be at the center of a coral restoration group's mission. Rerouting resources for collecting information can seem difficult when there are limited resources for outplanting or nursery work. However, monitoring efforts are essential for providing information to donors and the public, and informing the development of more efficient and successful restoration practices.

The lack of a central database and inconsistent data collection points meant that we were unable to effectively compare results between reef sites. We could not compare the performance of genotypes overtime, the success of a reef site, or the survivorship of corals accurately. In order to efficiently leverage our monitoring data, we developed and consistently implemented collection protocols that align with permitting requirements of the Florida Keys National Marine Sanctuary and Florida Fish and Wildlife Conservation Commission. All data was stored in a central location. While not enough time has passed to compare site performance or coral condition (data collection is still in early stages), we have been able to assess the baseline survivorship of corals at restoration sites. This allows us to share information with researchers looking to understand various factors (e.g. genotype performance) and their contribution to overall performance.

| Issue | Challenge | Impact | Recommended Implementation |
|---|---|---|---|
| Consistency in labeling outplanted clusters across species | Within outplanted clusters, individual staghorn colonies were tagged directly (tags attached the coral itself) and elkhorn clusters were identified by nailing a tag into the substrate. | Staghorn colonies were able to be tracked as individuals, but elkhorn colonies were not. | Implement consistent, species-specific tagging methods to identify both the clusters and individual coral colonies being tracked over time. |
| Site mapping | Mapping lacked standardized protocols. | It was difficult to find clusters of corals on the reef at the time of monitoring. | CRF standardized site mapping procedures, including details of geographic features, directional cues, and distance markers, while improving training on the creation and reading of site maps. |

| Issue | Challenge | Impact | Recommended Implementation |
|---|---|---|---|
| Monitoring efforts were inconsistent and not aligned with permitting agency needs. | Monitoring information was not standardized. Permit reporting needs should match monitoring efforts. | Monitoring data collected was not consistent across outplant sites or years. | CRF standardized our data collection system, processing methods, data-collection sheets, and master tracking system. Training materials were developed to ensure standardization. |

## CONCLUSION

The last few years have signified a time of transition and growth for the Coral Restoration Foundation. During this time, we refined restoration techniques, enhanced our monitoring efforts, developed standardized data systems, and strengthened our overall operational standards. Consequently, we were able to bolster our restoration program, build a solid platform for increasing restoration capacity, collect consistent data, and track data in a database for future analysis within CRF and in collaboration with partners. The net effect was increased outplanting capacity and a more than tenfold increase in restoration activity.

Overall, the fundamental changes to our standard operating procedures came at three pivotal points.

- First, the delineation of coral nursery stock as either production or preservation. This allowed for greater capacity in our nurseries to produce outplant stock and maintain genetic diversity.

- Second, the focus on continuous, incremental improvements to efficiency in order to increase scalability. By making consistent, additive changes (e.g. maintaining the base of elkhorn colonies as nursery stock or pre-placement of outplant clusters by an experienced diver) we have become more efficient in our daily dive activities.

- Third, the development of standardized data systems and collection processes, which has been essential to supporting the influx of large amounts of diverse information from multiple sources. CRF has created new standard operating procedures (SOPs) that encompass data collection, training, and processing of SOPs across nursery, outplanting, and monitoring activities. Combined, these advancements have resulted in an infrastructure platform and systematic approach that can support increased growth and scalability.

Within the quickly developing field of coral habitat restoration, there is a consensus among managers, practitioners and researchers that restoration must be active on large scales in order to be meaningful. We hope that this document facilitates furthering restoration efforts towards the scale needed for ecosystem-scale success.

## ACKNOWLEDGEMENTS

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We look forward to continuing to share our experiences and lessons learned with the restoration community. For more information, contact Jessica Levy at 1(305) 453-7030, or via email at Jessica@coralrestoration.org.

Additional resources can be downloaded through the Coral Restoration Foundation website at: www.coralrestoration.org.

Coral Restoration Foundation • 89111 Overseas Highway, Tavernier, Florida 33070, USA • (305) 435 7050
www.coralrestoration.org