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Coral Reef Restoration Monitoring Guide

Methods to evaluate restoration success from local to ecosystem scales

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Coral Reef Restoration Monitoring Guide

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About this Document

The mission of the National Oceanic and Atmospheric Administration (NOAA) is for science, service, and stewardship, specifically to 1) understand and predict changes in climate, weather oceans, and coasts; 2) share that knowledge and information with others; and 3) conserve and manage coastal and marine ecosystems and resources. The National Centers for Coastal Ocean Science (NCCOS) provides federal partners and coastal managers with the information and tools they need to balance society's environmental, social, and economic goals. NCCOS is the primary coastal science arm within NOAA's National Ocean Service (NOS). NCCOS works directly with managers, industry, regulators, and scientists to deliver relevant, timely, and accurate scientific information and tools. NCCOS was funded to coordinate the development of this product in partnership with the Coral Restoration Consortium (CRC).

The CRC was established in 2017 to foster communication and collaboration among coral restoration specialists, researchers, managers, and educators. The mission of this international group is to promote collaboration and technology transfer among participants, and to facilitate scientific and practical ingenuity to demonstrate that restoration can achieve meaningful results at scales relevant to reefs in their roles of protecting coastlines, supporting fisheries, and serving as economic engines for coastal communities. The CRC is dedicated to scaling up the coral reef restoration, science, and management efforts to enable coral reef ecosystems to persist through the 21st century and beyond. As of 2020, the CRC includes more than 1,800 people globally, and as the need for active coral reef restoration continues to expand around the world, the number of CRC participants continues to increase. The CRC's Leadership team includes pre-eminent researchers, managers, and practitioners in the field of coral restoration. Core to the function of the CRC is the sharing and dissemination of knowledge in a way that transcends regional and methodological biases. The CRC has developed working groups to deliver guidance on key topics, including field and land-based restoration efforts, coral larval propagation, restoration genetics, monitoring, and resource management. In addition, new CRC working groups continue to form to address emerging topics. The core team of the CRC's Monitoring Working Group wrote this report. Members of the Monitoring Working Group and other Working Groups also contributed content. This product synthesizes the best available information at the time of publication. We recommend that the CRC Monitoring Working Group update this product as new information continues to develop.

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For more information on NOAA's National Centers for Coastal Ocean Science, please visit:
https://coastalscience.noaa.gov/

For more information on the CRC and the Monitoring Working Group, please visit:
http://crc.reefresilience.org/

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Paola Espitia

Executive Summary

As coral restoration efforts continue to increase in size and number, there is an overwhelming need to define restoration success and determine progress towards successful restoration. Meaningful, consistent, comparable, and quantitative data is required to quantify the changes that result from restoration actions. However, there may be many definitions of success depending on the program or project goal(s). Restorations can have one or many goals that can be very different (e.g., ecological, educational), and therefore, goals cannot be addressed in a "one size fits all" monitoring approach. The application of quantitative approaches to monitoring not only provides a reliable way to evaluate progress towards restoration success, but also provides means to identify problems and apply adaptive management efforts as needed.

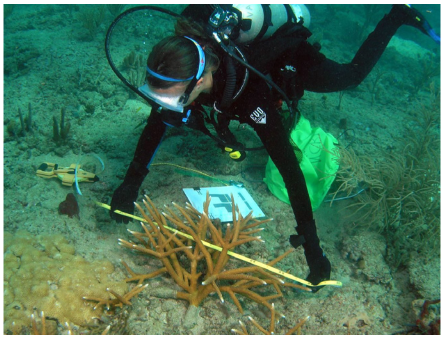
The CRC established a priority for the Restoration Monitoring Working Group to develop guidance for monitoring coral reef restorations and to determine restoration success. This "Coral Reef Restoration Monitoring Guide: Best Practices for Monitoring Coral Restorations from Local to Ecosystem Scales" was developed for practitioners and programs in any stage of their practice: from starting up a new restoration effort, to scaling up current efforts, to improving efficiency. Coral restoration practitioners can use the hypotheses- and data-driven monitoring framework presented in this Guide to make confident comparisons between projects, programs, and regions, increase the efficiency of data collection, and make informed decisions about the data necessary to describe the success of the restoration goal or objective.

Two categories of coral restoration monitoring metrics are included in this Guide: Universal Metrics and Goal-Based Performance Metrics. The four Universal Metrics, Landscape/Reef-level, Population-level, Colony-level, and Genetic and Genotypic Diversity, are suggested as basic requirements for monitoring all restoration projects, regardless of the goal of the project. These metrics provide data on restoration scale, growth, survival, and diversity, yet require minimal equipment and time. These Universal Metrics should be monitored on any restoration project regardless of the restoration scale, species, habitat, location, expertise, or budget.

Goal-Based Performance Metrics address five major coral restoration goals: Ecological Restoration, Socioeconomic, Event-driven Restoration, Climate Change Adaptation, and Research. Metrics are tailored within each goal to address key components of the goal. For example, when monitoring a restoration with an ecological goal, a practitioner should evaluate coral condition, species diversity, habitat quality, and vertebrate and invertebrate communities, and potentially others. Metrics are detailed for each goal including key points, suggested methods, reporting guidelines, and criteria to evaluate the performance towards the restoration goal and towards restoration success.

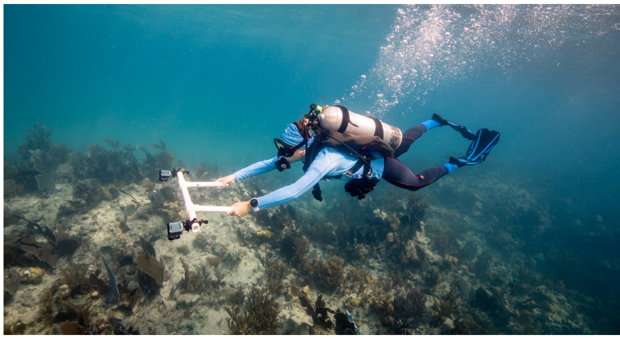
Coral reef restoration, while a quickly growing field, is still relatively new. This document is the first to provide comprehensive guidance for monitoring coral restorations to evaluate progress towards meeting restoration goals. Metrics and associated methods developed herein are based on our experiences, working group and workshop input, practitioner interviews, and current published peer reviewed literature and manuals. While every effort was made to address every situation, we recognize that as this field develops and the metrics are fully vetted, some metrics may need to be improved, modified, or deemed unnecessary. We therefore encourage the evolution of this Guide as a living document to be updated when necessary to be relevant and representative. Our experiences and the examples provided are mainly from the greater Caribbean region; however, reviews and feedback from practitioners who have worked globally indicate that the metrics developed are applicable on coral restorations in all regions.

This Guide should be used to measure and describe the progress of coral restoration projects towards meeting restoration goals. The CRC Monitoring Working Group has also developed a Coral Restoration Database and Evaluation Tool to be complementary to this Guide and used together. The Coral Restoration Database allows the input of comparable restoration projects and monitoring data. The Coral Restoration Evaluation Tool allows the practitioner to score the performance of their project, program, or region and determine what is working well and what needs improvement. The use of this Guide and feedback provided by practitioners will improve the evaluation of coral restoration success.



Nova Southeastern University Coral Reef Restoration, Assessment, and Monitoring (CRRAM) Lab

Fragments of Hope



Coral Restoration Foundation

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Acronyms

AGRRA	Atlantic and Gulf Rapid Reef Assessment
AIMS	Australian Institute of Marine Science
APT	All purpose tool
ARMS	Autonomous reef monitoring structures
BACI	Before-After-Control-Impact
BRUV	Baited remote underwater video
CPCe	Coral Point Count with Excel extensions
CRC	Coral Restoration Consortium
CRRAM	Coral Reef Restoration, Assessment, and Monitoring Lab (Nova Southeastern University)
CTD	conductivity, temperature, and depth
DGPS	Differential Global Positioning System
DNA	Deoxyribonucleic acid
GCRNM	Global Coral Reef Monitoring Network
GPS	Global Positioning System
LTMP	AIMS Long-Term Monitoring Program
MMP	Great Barrier Reef Marine Park Authority Marine Monitoring Program
NCRMP	National Coral Reef Monitoring Program
NGO	Non-governmental organization
NOAA	National Oceanic and Atmospheric Administration
PAR	Photosynthetically available radiation
RRAD	Restored reef areal dimension
RVC	Reef Visual Census
SER	Society for Ecological Restoration
SNP	Single nucleotide polymorphism
SST	Sea surface temperature

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Chapter 1
Introduction

Outlining the Need for Coral Reef Restoration

Coral reefs are important to coastal communities globally serving many cultural, commercial, and ecological purposes. They provide many key ecosystem services including provision of habitat and coastal protection as well as support to human uses including tourism and fisheries. As coral reefs continue to degrade (Gardner et al., 2003; Pandolfi et al., 2003; Wilkinson, 2008; Jackson et al., 2014), there is an increasing focus on the role of restoration in combination with threat reduction to help preserve coral reef ecosystems. As acute, stochastic events such as bleaching, disease, and storms have increased in frequency and magnitude, resulting in diminished recovery time between events (Hughes et al., 2018), restoration has been implemented as an aid to speed recovery. Restoration is also implemented to supplement natural coral populations and improve services such as increasing tourism, promoting marine education and stewardship, provisioning of alternative livelihoods, and improving fish abundance through enhanced habitat. These examples demonstrate the multi-faceted role that reef restoration plays in conservation, and why many organizations have turned to it to improve and preserve reef ecosystems.

Coral Reef Restoration and Monitoring Programs

Restoration has been implemented for many decades in terrestrial and wetland ecosystems and a few marine habitats (Aronson et al., 2010; Blignaut et al., 2013). Although coral transplantation has been ongoing since the early 1900s (Wood-Jones, 1907; Vaughan, 1911; Mayor, 1924; Edmonson, 1929), it was initially for research purposes (e.g., coral growth and environmental impacts). It was not until the late 1960s that coral transplantation became an integral part of coral reef restoration practices, albeit still at a relatively small scale and in localized areas (Maragos, 1974; Shinn, 1976; Birkeland et al., 1979; Bouchon et al., 1981; Alcala et al., 1982; Auberson, 1982; Harriott and Fisk, 1988). As the health of coral reef ecosystems continues to be threatened by environmental and anthropogenic impacts, the need for population enhancement as a means for restoring and rehabilitating coral reefs is gaining public awareness (Clark and Edwards, 1995; Kaly, 1995; Rinkevich, 1995; Young et al., 2012; Boström-Einarsson et al., 2018). More recently, funding and capacity for programs afford scientists and practitioners the resources to scale up their efforts to reduce threats and restore reefs while generating networks of communication and collaboration with the community.

Introduction

Three major waves of coral reef restoration efforts have occurred in recent history (Figure 1). The first wave began from the late 1960s when the degradation of coral reefs became more apparent, widespread, and frequent, and legislation to protect marine species and habitats was introduced around the world (Rinkevich, 1995; Edwards and Clark, 1999). At this time, restoration was very localized and in response to impacts such as ship groundings, damaging fishing practices, storms, and tourism damage (Edwards and Clark, 1999). In parallel, was the growth of passive restoration through deployment of artificial reefs (Bohnsack and Sutherland, 1985).

In the early 2000s, the second coral reef restoration wave focused on efforts to counteract local stressors (e.g., overfishing, damage from hurricanes, invasive species) and contribute to species-specific recovery. This effort incorporated artificial structures of various shapes and types to serve as a platform for coral nurseries. Around this time, restoration efforts began to include the removal of predators and competitors from benthic habitat as well as the addition of outplants from in situ and ex situ nurseries.

The third coral reef restoration wave began around 2016 and has focused on increasing efficiencies and scale, emerging tools, and technology such as micro-fragmentation, larval propagation, genetic banking, and assisted evolution. This period has also seen an expansion in the commercialization of artificial reef and coral restoration development for tourism globally with little oversight (Meyers, 2016, 2018; Moore, 2018). In order to successfully scale up to ecosystem level restoration, there is a need to quantify restoration success at multiple temporal and spatial scales as well as document lessons learned along the way.

Coral restoration monitoring has not yet fully evolved to a level commensurate with the growth of restoration outplantings. The most commonly used monitoring techniques that are currently in practice focus solely on coral colony level metrics, which lack the ability to capture ecosystem-level benefits of large-scale coral restoration projects (Abelson, 2006; Bayraktarov et al., 2016; Boström-Einarsson et al., 2018; Bayraktarov et al., 2019). As the gap in being able to report success of restoration at an ecosystem level has become more evident, the application of broader scale coral reef monitoring metrics (e.g., benthic community characteristics, shoreline protection, and socioeconomic benefits) and new and advanced technology, including remote sensing and large area imaging (e.g., photomosaics), are beginning to be discussed and more widely applied (Ferse, 2008; Yap, 2009; Fadli et al., 2012; Gintert et al., 2012; Griffin et al., 2016; Miller et al., 2016a; Montoya-Maya et al., 2016; Opel et al., 2017; Foo and Asner, 2019). As such, the CRC Monitoring Working Group seeks to bridge this communication gap with three products for the coral restoration monitoring community: 1) a guide with the best available science and management practices for monitoring the success of coral reef restorations, 2) a spatial database of coral restorations and monitoring data, and 3) an evaluation tool to measure the success of a restoration program.

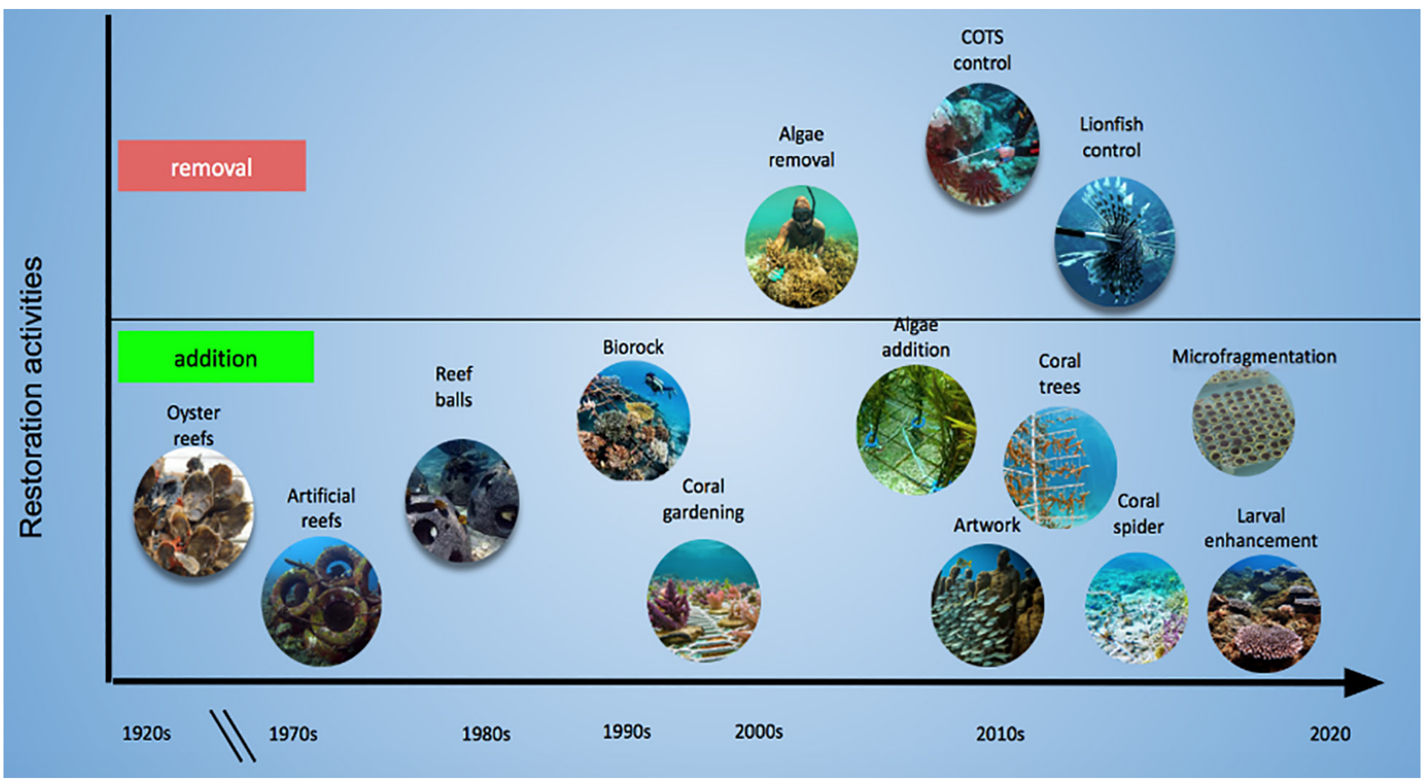

Figure 1. The history of reef restoration. Source: Adam Smith and Ian Mcleod (The Conversation).

Purpose of this Guide

The Coral Restoration Consortium (CRC) was established in 2017 to facilitate knowledge transfer between coral restoration practitioners, managers, and scientists. The CRC identified multiple knowledge gaps in many critical aspects of coral restoration, including the need for best management practices and how to define restoration success. Therefore, the CRC established multiple working groups, each with individual priorities to address current gaps. CRC guides are intended to provide current best management practices for a range of capacities and to continue to evolve, remain current, and reflect the best available science, tools, and technology.

These coral reef restoration monitoring guidelines were developed using existing guidelines for monitoring the success of restoration in other marine habitats such as oyster reefs and marshes (Coen and Luckenbach, 2000; Thayer et al., 2003; Thayer et al., 2005). As these other guidelines have demonstrated, effective protocols provide the framework for sound scientific monitoring of restoration efforts. Well designed and implemented protocols will detect early warning signs that restoration efforts are not meeting goals and help determine what modifications may need to be implemented for course correction. In addition, standardized protocols and evaluation metrics aid in coordination amongst practitioners and facilitate consistent and successful restoration. They not only assess the function of the restored area itself, but also allow for consistent comparisons of restoration effectiveness between projects on varying geographic scales (e.g., across islands, basins, regions).

Target Audience

This Guide is intended to be a reference for restoration practitioners, managers, and scientists. In an effort to accommodate a wide range of experience and resources, multiple methods are described for collecting monitoring data for multiple metrics. Monitoring metrics are categorized by restoration goals so that monitoring can be tailored to each program's needs. In addition, the document identifies several Universal Metrics that should be monitored at all restoration sites to be able to compare restoration sites in various geographic locations and with differing restoration goals. Although the methods are described from a primarily Caribbean perspective, the metrics themselves are applicable to all coral reef locations.

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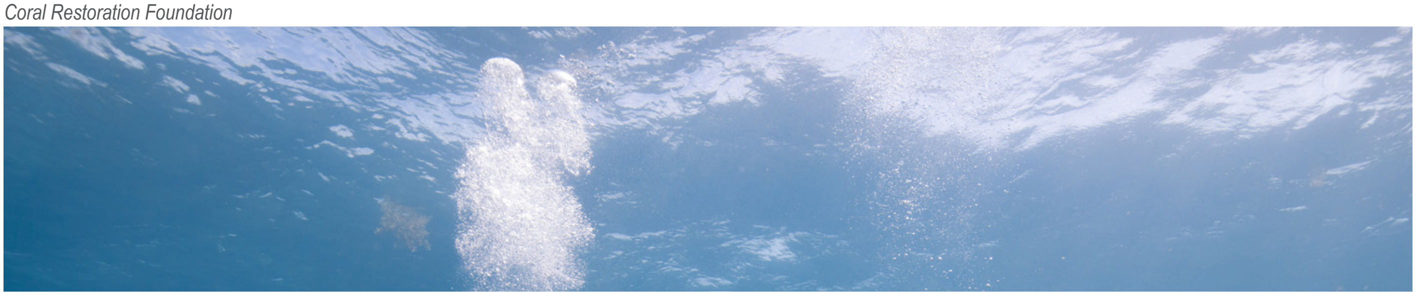

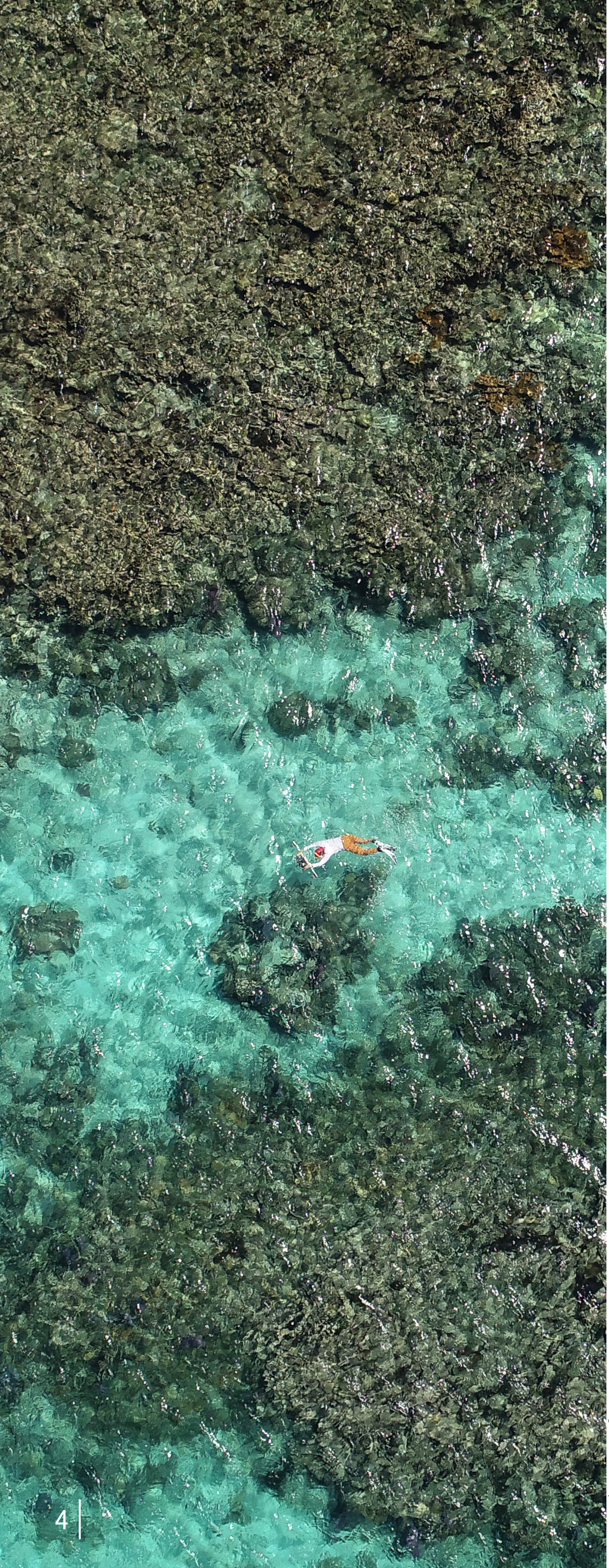

Fragments of Hope

Chapter 2

Guide for Coral Reef Restoration Monitoring

Using this Guide

The Guide is organized as follows: an introduction to the need and purpose of the guide, definition of goals for successful restoration, development of a monitoring plan, assessment of the performance of a restoration project, presentation of Universal Metrics for coral reef restoration monitoring, definition of universal environmental metrics, and development of Goal-Based Performance Metrics. The Universal Metrics are recommended to be collected by all researchers and practitioners, as they are comparatively easy to collect and inexpensive to fund, whereas the Goal-Based Performance Metrics will vary by the goals and objectives of a restoration program (e.g., coral abundance, genetic and species diversity, improving habitat quality). The guidance provided in this Guide is not all encompassing and should not be used as the only resource for monitoring restoration. We made every attempt possible to include the most relevant and needed monitoring guidelines for measuring restoration success, but it is not possible to include or recommend every type or level of data that could be collected. We expect and hope that practitioners use this as a starting point and collect data beyond what is outlined in this document to further inform the restoration community and future versions of this document.

The metrics in this guide were developed and are implemented by practitioners, researchers, and managers whose work has primarily focused on Greater Caribbean and Atlantic coral reef restoration; therefore, examples have a regional focus. However, these restoration metrics were developed from globally applied coral reef monitoring techniques and should be applicable to all geographic locations. Furthermore, metrics were designed to accommodate a range of funding and capacity while maintaining consistency in monitoring methods and data collection and reporting.

Defining Restoration

Past definitions of ecological restoration typically include phrases related to returning a damaged ecosystem to a “formal, normal, unimpaired, or pre-disturbed state or condition” (National Research Council 1992; Cunningham et al., 1998; Calow, 1998; Interagency Workgroup on Wetland Restoration, 2003). Other definitions, such as “the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems” (Jackson et al., 1995), link the need for ecological restoration to anthropogenic stressors causing the original damage or decline of the ecosystem. However, others have included the reestablishment of both structure and function of the habitat or entire ecosystem within their definitions (Estuaries Restoration Act 2000; Turner and Streever, 2002). Furthermore, the Society for Ecological Restoration (SER) defines ecological restoration as “the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed” (SER, 2004), which highlights the need for restoration to help an ecosystem which would not otherwise recover without human intervention. With severe declines in global coral cover and abundance over the past several decades, ecological restoration has become essential to preserve marine resources, rebuild vital reef habitat, and improve coral reef structure and function.

For coral reef restoration, both passive and active strategies have been employed to improve conditions and restore coral populations (Edwards and Gomez, 2007; Rinkevich, 2014). Passive restoration strategies include management actions that protect essential habitat, allow for natural recovery, and improved ecological functioning. These strategies may include creating marine protected areas that promote increased herbivory or mitigating land-based run-off and pollution that affect water quality. However, passive restoration measures alone have often failed to be successful in restoring functioning coral reef communities (Rinkevich, 2005,2008). Therefore, researchers and managers have turned to active reef restoration to both mitigate decline and enhance potential recovery of damaged or depleted coral populations (Guzman, 1991; Rinkevich, 2005; Edwards and Gomez, 2007; Young et al., 2012). Active coral restoration focuses on increasing coral reef health, abundance, or biodiversity and includes direct interventions that aim to speed up natural recovery, such as physical repairs to damaged habitat or direct transplantation of keystone species (Edwards and Gomez, 2007). Ecological restoration for coral reefs should include both passive and active methods to promote the natural recruitment and survival of species of concern, return of ecosystem structure and function, and improvement of abiotic processes that shape the community.

Restoration of viable coral populations requires a multi-pronged approach with strategies that are science-based and informed by the local ecology. For example, coral transplantation, the act of moving and securing coral fragments on reef substrata (Vaughan, 1911), is the most widely used coral restoration strategy (Epstein et al., 2003; Rinkevich, 2005), and transplantation-based restoration projects have burgeoned around the world over the last 30 years (Rinkevich, 2014). However, it is widely acknowledged that replanting corals will not stop global drivers of coral loss, such as climate change or ocean acidification, highlighting that coral transplantation on its own may not be an effective management strategy (Yap and Molina, 2003; Edwards and Gomez, 2007).

Population enhancement is an active restoration approach that specifically addresses degraded coral populations and is the most used approach around the world (Young et al., 2012). Population enhancement includes rearing corals in either in or ex situ nurseries to create a sustainable stock of corals for use in outplanting to denuded or degraded reefs. Depending on local or federal permit requirements, source corals for nurseries may be corals or fragments of opportunity (i.e., corals that would otherwise not survive local conditions), small cores or branches collected from a larger colony (collected in a way to prevent damage to the remaining parent colony [Lirman and Schopmeyer, 2016]), or whole colonies that can be subdivided through fragmentation to create additional ramets. Propagation should focus on maintaining or expanding the genetic diversity of a region in order to potentially build and maintain coral resilience to threats such as climate change. Outplanting should occur at sites where the habitat is suitable for additional natural recruitment and high survival of outplants (see full list of requirements in the CRC Guide to Field-Based Coral Reef Restoration [Goergen et al., In Review]) and other interventions to improve the habitat may be necessary.

No single restoration approach suits all locations, regions, and environmental conditions. Propagation and restoration activities should therefore be included within adaptive management actions that operate across a wide range of scales and timing to increase the likelihood of success (Jackson et al., 1995). With the shorter-term successes of propagation and transplantation programs over the past decade, coral reef restoration has expanded to explore and include other novel restoration techniques such as seeding reefs with sexually propagated coral larvae (Chamberland et al., 2017) microfragmenting coral colonies to substantially increase the number of ramets from a single colony (Forsman et al., 2015), outplanting arrays of corals to fuse together and “reskin” the substrate (Page et al., 2018), utilizing stress-hardened corals for outplanting to increase resilience (National Academies of Sciences, 2019), and assisted migration or gene-flow (Hagedorn et al., 2018; National Academies of Sciences, 2019).

Phanor Montoya-Maya

Goals of Restoration

Restoration goals can vary between geographic area, program, and project. Around the world, many restoration programs aim to restore not only their corals, but also to boost education and outreach regarding environmental issues, increase recreational or commercial fish populations, create new jobs, or even provide coastal protection to vulnerable communities (Bayraktarov et al., 2019). Such socio-cultural and economic issues are essential components of coral restoration effectiveness because of the potential to increase livelihood opportunities, build capacity in local communities, and assist with controlling human-based drivers of coral loss, as well as enhancing the long-term sustainability of restoration efforts (Brewer et al., 2012; Hein et al., 2017). Therefore, the effectiveness and success of coral restoration is strongly linked to community support and involvement (Ammar, 2009; Schrack et al., 2012; Hernández-Delgado et al., 2014).

Based on literature and current restoration practices we have identified the following goals as the most common or predominantly identified by restoration practitioners as a goal of their program:

Ecological (Ecosystem) Restoration (Chapter 7)
Socioeconomic (Chapter 8)
Event-Driven Restoration (Chapter 9)
Climate Change Adaptation (Chapter 10)
Research (Chapter 11)

Defining Successful Restoration

The success of restoration may look vastly different for each restoration project or program and depend on restoration goals. Success for some may be successfully attaching corals, whereas for others it may be successfully reducing the amount of beach erosion by restoring a nearby reef. Both of these examples should be identified as successful if the goals of the restoration program were met with clearly defined project endpoints (Palmer et al., 1997). These two examples prove that it would be nearly impossible to have a "one size fits all" approach to defining successful coral reef restoration. Furthermore, there is not an all-encompassing set of metrics to measure the success of all goals of restoration. This is why we have herein described: 1) a set of Universal Metrics to be collected at any coral restoration project, regardless of the defined goal, in order to provide a basic comparison of success amongst projects, and 2) Goal-Based Performance Metrics tailored to the five predominant restoration goals defined in the previous section.

Currently, most restoration programs define restoration success or answer the question of "Is the restoration working" by utilizing only colony survival and growth, regardless of the defined goals. While this is appropriate for determining attachment success and short term survival, many of the defined goals, Ecological Restoration, for example, need to be assessed using additional factors to accurately define the success of a program (Ruiz-Jaen and Aide, 2005; Bayraktarov et al., 2016). For example, branching corals, in particular *Acropora cervicornis*, which is the most commonly used species in Caribbean coral restoration, are known to frequently fragment or become dislodged by natural occurrences ending up relocated 10's of meters from the location it was outplanted (Lirman, 2000; Goergen and Gilliam, 2018). By using common reef survey methods to define success, such as fate tracking of outplanted colonies (monitoring the place they were outplanted), dislodged colonies are recorded as dead or missing when they may be elsewhere at the site. This results in underestimating the impact and success of the project because appropriate methods were not in place. Thus, expanding our view of the spatial extent of the area used to define coral restoration success is a necessary next step in effective restoration monitoring.

As the field of restoration expands to large-scale restoration efforts (Young et al., 2012; Boström-Einarsson et al., 2018), the definition of restoration success will become more dynamic as broader goals can be made and larger achievements can be met. Therefore, we provide a baseline for defining success for each restoration goal, in recognition that these are likely to grow and change as the field progresses.

Reef Renewal Bonaire

Success of an Ecological Restoration

The success of ecological restoration should be measured by how much ecological function is created or achieved after restoration efforts. The ultimate goal of restoration is to create a self-sustaining ecosystem that is resilient against stressors and environmental changes without further assistance (Society for Ecological Restoration International Science and Policy Working Group, 2004). In 2004, SER developed a list of nine attributes as a basis for when restoration has been accomplished, noting that not all attributes need to be fully met in order to demonstrate restoration, but should show a trend towards the intended goals or reference. Briefly the nine attributes of the restored sites are as follows: 1) similar species assemblage as the reference ecosystem and provides community structure, 2) indigenous species are used to the greatest extent, 3) all functional groups for continued development and stability are represented (or have the potential to colonize), 4) environment is capable of sustaining reproductive populations, 5) ecological function is normal for its developmental stage, 6) integrated into surrounding ecosystems, 7) threats to health and integrity have been addressed, 8) resilient to periodic stress, and 9) self-sustaining at similar levels as the reference site and has the potential to persist indefinitely (Society for Ecological Restoration International Science and Policy Working Group, 2004).

Success of a Socioeconomic Restoration

Most monitoring for coral reef restoration efforts focus on ecological success (e.g., growth, survival). Considerably less attention has been given to the social, economic, and cultural dimensions of restoration efforts that directly benefit local stakeholders and communities through the creation of jobs and skilled restoration workforces, increased community involvement and awareness, reinvigoration of cultural practices, and creation of 'blue infrastructure' (i.e., restoring ecosystem services that benefit coastal communities; Kittinger et al., 2013; Meyers, 2016; Claus, 2017). Such sociocultural and economic components of coral restoration success are essential because of their potential to increase sustainable livelihood opportunities, build capacity in local communities, and enhance the long-term sustainability of restoration efforts (Hein et al., 2017). Conversely, mismanagement of restoration projects can achieve exclusively social or economic benefit with little regard for local ecological impacts or incentivize unsustainable degrees of touristic development (West, 2008; Meyers, 2018; Moore, 2018). Therefore, approaches are needed to identify economically and ecologically viable methods to inform restoration efforts and promote stewardship and capacity building with local stakeholders.

Success of an Event-Driven Restoration

There are a variety of environmental or anthropogenic events that could drive the need for restoration such as a disease outbreak, bleaching mortality, storm related impact, ship grounding, or planned coastal construction. Ideally, the success of restoration following these events will be measured by how much coral, associated biodiversity, and ecosystem function could be saved or restored. For many of these events, restoration is an unplanned or emergency response effort to save what remains. It may be impossible to know what was there prior to impact, but where possible, assessments should be made to evaluate surrounding unimpacted areas to use as a baseline to gauge restoration efforts against.

Success of Climate Change Adaptation

While not always the primary driver, most restoration actions have direct or indirect impacts of helping local reefs better withstand the effects of climate change. Some of the concrete goals of mitigating climate change are improving reef resilience, stress hardening, successful assisted evolution, and coastal protection. These goals can be met through a variety of actions, such as physically planting corals on degraded reefs or careful and purposeful selective genetic crossing of coral genotypes.

For example, a restoration program may choose to incorporate several genotypes into an annual spawning program. The coral genotypes selected for this program can be either selected to target specific genetic crosses, or simply random, thus providing a large variety of genetic diversity in the offspring. As many species in the Caribbean may no longer be able to reproduce sexually on their own on an ecologically relevant scale, this genetic diversity is crucial to giving these species a chance at diversifying their genetics to best suit the conditions brought on by future climate change. With either sexual reproduction strategy, these coral species are given the chance to become better adapted to the current and changing conditions.

Success of Research-Based Restoration

There is still a big need for research-based restoration because the field is relatively new. The goals and objectives of research being conducted should be driven by need and data gaps. Successful, meaningful, and appropriately designed research will advance the field and increase coral reef restoration efficiency. The success of a restoration project that is research focused will be defined by the research objectives and goals.


Hiri Coral Team

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Chapter 3

Developing a Monitoring Plan

The first step to developing a plan for restoration monitoring is to clearly define the goals and objectives of the specific project that align with the program's capacity and restoration abilities. This should be completed in the project design phase (prior to outplanting) in order to appropriately design the restoration project, collect baseline data, choose monitoring metrics, and develop a timeline for monitoring. For any restoration effort to be deemed successful, a project must have the ability to manipulate an ecosystem to achieve the desired goal as well as determine if the manipulation has produced the desired outcome (Keddy, 2000). It is critical that the data are collected in a standard way, properly analyzed, and provide useful information to assess restoration success across local, regional, and ecosystem-level scales (Thayer et al., 2005).

Restoration Monitoring

There are many ways to define ecological restoration monitoring, yet, all are consistent in the need for standardized, systematic methodologies that generate the most meaningful and informative data. Meeker et al. (1996) defines ecological monitoring as repetitive measurements or observations to track change in condition. Others talk about the systematic observation of parameters (i.e., response variables) related to a specific problem tracked over time (Nichols, 1979), the consistent data collection through standard methods across time and sites (Washington et al., 2000), and data collection that indicates progress toward target criteria and established goals (Interagency Workgroup on Wetland Restoration, 2003).

Coral restoration monitoring uses many of the same methods as traditional coral reef benthic monitoring (e.g., individual colony tracking, total linear extension, percent cover), as both share the common goal to measure the change in reef condition through time at spatial scales from corals to ecosystems. However, restoration monitoring has some key differences. In order to accurately assess the success of restoration, monitoring needs to specifically target not only the corals used in restoration (i.e., outplants), but also ecosystem responses to restoration (e.g., long-term changes in coral populations, percent cover, fish and invertebrate communities). Although ecosystem restoration requires data to be collected surrounding and beyond the restored coral, data must still be collected on the restored coral reefs in order to corroborate the results with the restoration.

Depending on the goals of a restoration project, the development of sequential, multi-step objectives may be necessary to achieve the desired result (Palmer et al., 1997). For example, a project goal may be to restore ecosystem function; therefore, following the collection of baseline data and after a program has first established that corals are surviving and thriving, a program would begin by monitoring community structure components (i.e., fish and invertebrates), then identify linkages between community structure and the restoration to determine if ecosystem function has been successfully restored. This Guide offers direction on monitoring restoration for various scales (start-up to scaled-up), goals, and objectives as well as offers guidance if optimally successful restoration is not observed.

Choosing What Metrics to Sample

Here, we offer two categories of metrics: Universal Metrics and Goal-Based Performance Metrics. We suggest Universal Metrics (Chapters 5 and 6) as a minimal monitoring effort that should be applied to every coral reef restoration project, regardless of goals or objectives. The assessment of these metrics provides a basic overview of the status, size, and condition of a restoration project over time and allows for direct comparison with other projects. These metrics range from broad scale, community-level measurements to small-scale, individual measurements. For a more detailed overview of the status of a restoration program, we provide Goal-Based Performance Metrics (Chapters 7–11), which can be used for ecosystem-level restoration goals such as:

- **Ecological Restoration**
- **Socioeconomic**
- **Event-Driven Restoration**
- **Climate Change Adaptation**
- **Research**

The Universal Metrics and Goal-Based Performance Metrics detailed within this Guide should be considered the minimum level of data to be collected to achieve the respective goals and objectives. Based on the data obtained from monitoring, the restoration team may need to consider adaptive management strategies if the overall health of the restored area is not improving as expected. To detect changes in the restoration over time, metrics should be collected over the long-term. However, the frequency and duration of monitoring may vary depending on the metrics included in the monitoring design and application. By outlining the monitoring data that is desired or needed, practitioners and managers can plan for including long term monitoring within their funding and budget needs. Furthermore, monitoring design, both metrics and frequency, should be sure to address all applicable regulatory requirements.

Importance of Baseline Data and Reference Sites

Coral reef restoration goals typically include the re-creation of an ecologically functioning habitat; assessment of progress towards that goal requires a comparison between pre- and post-restoration as well as to control or reference sites that have not been restored. Baseline data provide information on the condition of the site before restoration (i.e., the pre-treatment condition), which is useful for comparison and detection of trends in change through time. Restoration monitoring activities and metrics should reflect this objective. As such, it is important to include analytical techniques to measure the effects of environmental impacts in sampling designs, taking into account the large spatial and temporal variability that occurs naturally in undisturbed habitats (Chapman, 1999). We strongly recommend that all restoration projects collect baseline data prior to any restoration. To capture the impact of restoration, a site survey must be completed prior to restoration occurring, recording at a minimum, the presence and abundance of the species being used for restoration (See suggestions in the Outplant Site Selection section of the Guide to Field-Based Coral Reef Restoration [Goergen et al., in review]).

Current baseline data should include pre-restoration surveys at restoration sites. In addition, surveys should be conducted at control sites and/or reference sites. In restoration monitoring, control and reference sites are not the same thing (Figure 2, Chapman, 1999). Surveys prior to restoration (i.e., pre-restoration survey) establish the condition of the site before any additional actions, and the objective is to quantify change through time. If a pre-restoration survey is not an option due to project constraints, a control site survey could be used as a proxy. Control sites may also be used in addition to baseline surveys. Control sites are sites in similar condition to the restoration site prior to restoration, but are left undisturbed in order to measure changes in the restored site. Control sites alone, however, are not sufficient to assess restoration success, for they merely provide a comparison to show whether the restored sites have changed. Reference

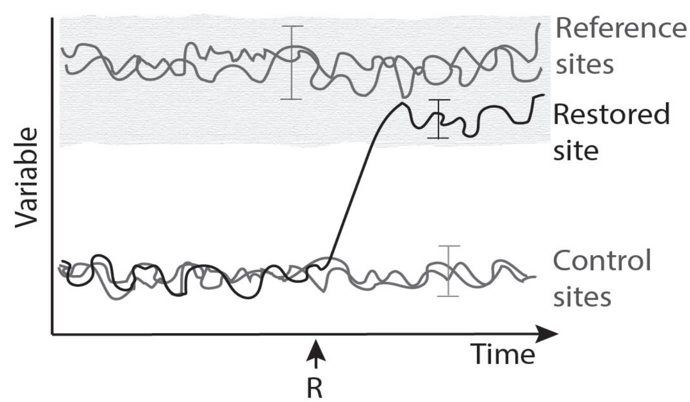


Figure 2. Control and reference sites are needed to assess the success of restoration. *R* indicates when restoration began. Measures in the restored and multiple control sites before and after the time of the impact should be compared to measures in reference sites which provide measures of expected conditions for restoration to be considered successful. Figure and caption adapted from Chapman (1999).

sites or "natural areas" provide an example of what restoration success should look like (i.e., what the restoration project would like to achieve; Thompson et al., 1995; Galatowitsch and van der Valk, 1996; Simenstad and Thom, 1996). The reference site should resemble what the project is striving to achieve through restoration, this may not always be restoring to historical levels (i.e., a lush *Acropora* thickets found in the 1960s in the Caribbean), but to an intermediate or more modern day reefscape (i.e., clusters of large *Acropora* colonies). It is important that a restoration program define a reference prior to restoration. Further, for coral reef restoration, it is not always possible to monitor a reference site within close proximity to the restored site or at all due to the highly degraded status of the system. In this case, sites as close to the composition of the target reference or long-term monitoring or historical datasets for similar habitat types should be used as a reference. When the restored site resembles the reference site, it can likely be concluded that restoration was successful (Figure 2). Reference surveys should include all metrics that are being collected at the restoration site. Monitoring control and/or reference sites should occur at the same time, frequency, and duration as restoration site monitoring.

The popular BACI (Before-After-Control-Impact) experimental design can be used to make comparisons between restoration sites, control sites, and reference sites to evaluate restoration success (Green, 1979; Underwood, 1994; Falk et al., 2006). The BACI design requires the monitoring of a control and/or reference site and the site to be restored prior to the restoration occurring, and then continuing to monitor each of these sites post-restoration, preferably long-term (Figure 3). The experimental design of a project will affect the data, analyses, and the way that success of restoration can be described. Therefore, proper planning prior to project deployment is essential (Falk et al., 2006; Opel et al., 2017; Mahlum et al., 2018).

The formulation of a reference ecosystem involves analysis of the composition (species), structure (complexity and configuration of species) and functionality (underlying abiotic and biophysical processes and community dynamics of organisms) of the ecosystem to be restored on the site (McDonald et al., 2016). As a reference, the Evaluation Tool (Appendix 2) outlines metrics of success for a restored site. Sites with very high success scores (1 = successful for a particular metric) should resemble a good representative reference site (e.g., natural area).

Choosing an Appropriate Sampling Design

Sample design is driven primarily by project objectives and logistical constraints. A random sampling design can reduce sampling bias (e.g., to sample areas with the most corals or fish). A project with the objective to collect a spatially representative sample typically implements a randomized design. Sampling designs that incorporate randomization are generally considered more statistically defensible than non-random sampling because all sites within a study area have an equal chance of being visited, and the resulting sample is more representative (Krebs, 1999). However, a sampling program with the objective to monitor the status of a population through time within a system, may be able to justify a fixed sampling design (Elzinga, 1998; Smith et al., 2016). Sampling units also must be spaced far enough apart so that they are considered independent to avoid pseudoreplication (Hurlbert, 1984; Hargrove and Pickering, 1992; Davies and Gray, 2015).

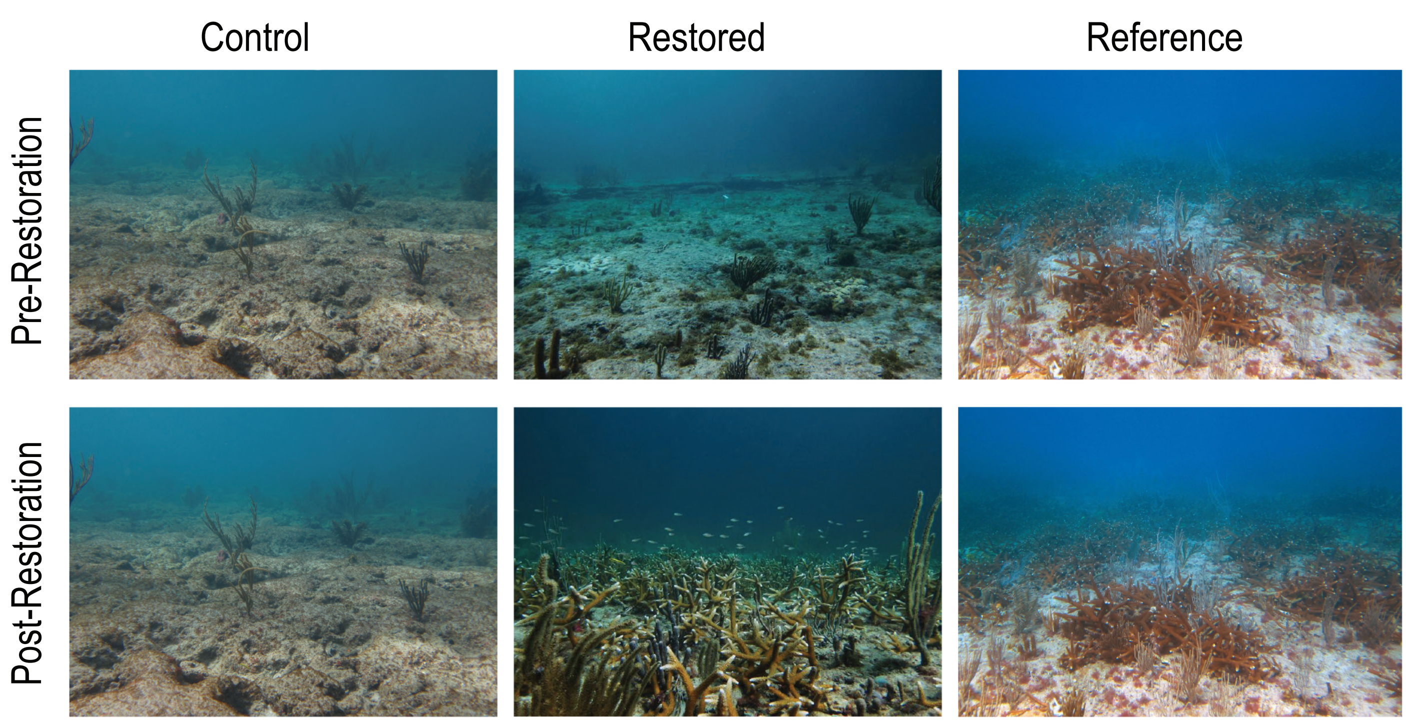
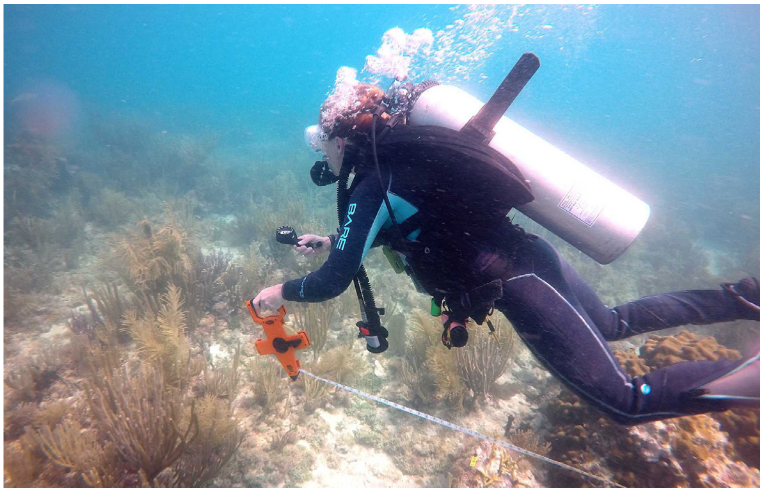


Figure 3. Photo representation of an example of a BACI (Before-After-Control-Impact) design and the differences between a control and reference site. Image credit: Nova Southeastern University Coral Reef Restoration, Assessment, and Monitoring (CRRAM) Lab.

There are a number of ways that sample design can be incorporated into a monitoring protocol. Some examples of design include haphazard sampling, simple random sampling, stratified random sampling, systematic sampling, two-stage sampling, restricted random sampling, and cluster sampling (Elzinga, 1998; Thayer et al., 2005; Baggett et al., 2014). A table created by Elzinga (1998, Table 7.2) outlines uses, advantages, and disadvantages of many of these methods and is a reference for the development of a project monitoring plan. The simplest methods may be a haphazard or simple random sampling approach (Figure 4). However, for a restoration project, it may be necessary to deploy a more systematic approach (e.g., systematic, cluster, two-stage, restricted random or stratified sampling) to ensure that restored corals are being monitored in numbers that are sufficient enough for data analyses to be both statistically and ecologically meaningful. This concept is illustrated in Figure 4, where a simple random sampling design misses a majority of the corals used for restoration; however, a change in survey design to a restricted random sampling includes delineated outplanted areas where random sampling is deployed only in those outplanted areas. This would be an appropriate method to survey colony demographics; however, if studying a different metric, such as change in coral cover, the simple random design or others may be more appropriate to capture change inside and outside of an outplanted plot, especially for transient species (e.g., *Acropora* species). Therefore, it is best to determine the method appropriate for the outplanting design during the development of the monitoring protocol.

The final component to consider in sample design is whether sample units will be permanent or temporary, which will also affect the interpretation and construction of statistical tests. By completely re-randomizing for each sampling event, units will be temporary and samples are considered independent of each other. If randomly chosen units are sampled at time one and re-sampled at time two, the units are considered permanent and the samplings are dependent. Permanent units are more efficient in detecting changes between sampling periods, especially if you expect to see high variability between units and high degree of correlation between sampling. To detect changes, such as change in cover and conditions, with temporary units, a larger number of units would need to be used (Elzinga, 1998). Permanent units require precision when installing and resampling, can be more costly to install (time, tags, pins, and markers), require maintenance and authorization (permit), and can require more time in order to find each unit during sampling events. Furthermore, permanent units do not capture changes outside the permanent area (e.g., movement of fragmented species). For some applications (disease), it may be beneficial to use a combination of both temporary and permanent units (Kohl et al., 2015).



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Determining Sample Size

Sample size (e.g., number of transects, plots, area, quads) will be determined by the goals and design of the restoration project and/or to meet permitting regulations. There is no one correct sample size or area, so long as the sampled population statistically represents the complete set of units about which inferences will be made (i.e., the target population; Elzinga, 1998). A sample size for measuring change in abundance may not be the same as change in fish diversity and abundance and should therefore be calculated for each metric sampled. An a priori power analysis or other appropriate statistical test can be performed for each metric to indicate the ideal sample size necessary to detect change (Fairweather, 1991).

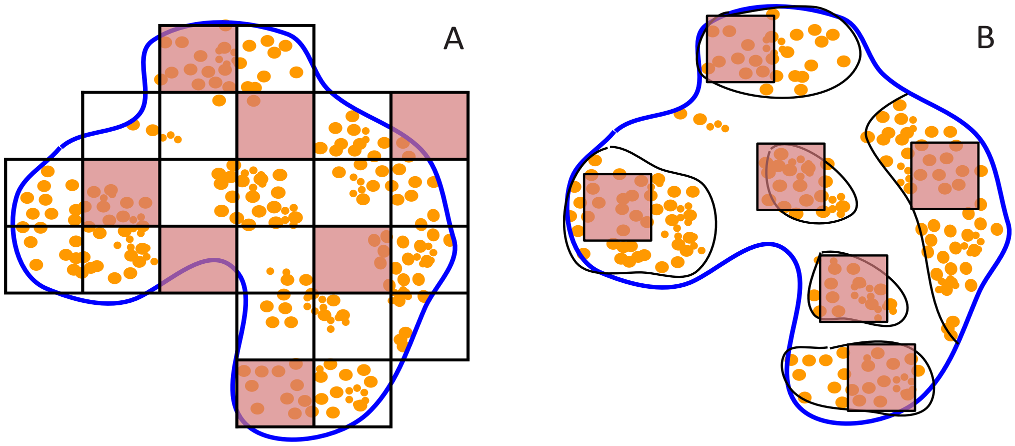

Figure 4. Example designs of (A) simple randomized sampling and (B) restricted random sampling. Random sampling, due to the outplanting design, does not adequately capture the restored corals, therefore the areas for sampling can be restricted to the outplanted areas and then random sampling plots can be chosen within these restricted areas.

The most efficient sampling unit size and shape generally depend on the variable that is measured and the spatial distribution of the sampling area, with the ideal design yielding the greatest statistical precision (Elzinga, 1998). Very few restored coral populations are randomly distributed, but rather are aggregated or clumped. This difference in relative density between clumped and a more spaced out distribution will also be a factor in determining how large of an area to sample and how many places within that area need to be sampled to ensure an appropriate representative sample is taken. Many statistical programs and online resources can be used for determining sample size.

Timeframe/Length of Monitoring

The initial steps in any restoration project are to: 1) clearly articulate the goals for each site and treatment, and 2) develop a timeline for monitoring the success of restoration activities, within the context that the timeframe of monitoring should be biologically/ecologically meaningful for the change anticipated (Figure 5). For example, a 50% increase in the density of boulder corals within 2–5 years is unlikely, although is very likely for fast growing ephemeral coral species in ideal conditions. Once the actions are identified that will improve the condition of the resource, monitoring should begin either before or immediately following alterations to the baseline status of the area. Mid- and long-term monitoring are also essential to understand ecological change over time and determine the effectiveness of restoration activities and management decisions.

Short-, mid-, and long-term monitoring efforts require consistent, standardized data collection with a system that includes quality assurance and data management that is replicable among other sites and programs (Le et al., 2012). The timeframe to monitor for the desired results or change induced by restoration will vary by species, i.e., a change in reef complexity will be measurable within a few years for a fast growing branching species, whereas for massive species a change may not be measurable for decades. These differences in change determined by the species used for restoration are also applicable to the timeframe of observing ecological success.

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Short-term monitoring (one year or less) should be considered ***implementation monitoring***, or “how well was the initial phase of restoration designed and executed” (i.e., site selection and outplanting). This early phase of monitoring should assess the general effectiveness of outplanting methods, establish consistent parameters, evaluate initial before-and-after changes to the restoration area, and identify target values for the restored area. Site selection criteria should play a big role in determining the restoration, and therefore the short-term success of the restoration project.

Mid-term monitoring (1–5 years) should be considered ***effectiveness monitoring***, or “how well did treatment design match the desired goals, and how successful is the project based on those goals” (i.e., positive outplant growth and performance-based goals). At this phase, it should be clear if the chosen site allowed the outplants to grow and thrive. Metrics that indicate success include outplants that exhibit high survivorship (i.e., positive change in abundance of each species), a high percent of live tissue per coral, low tissue loss from bleaching, low prevalence of disease, low abundance and impacts of coral predators, limited competition by algae and other competitors, and low levels of physical damage (breakage/dislodgement).

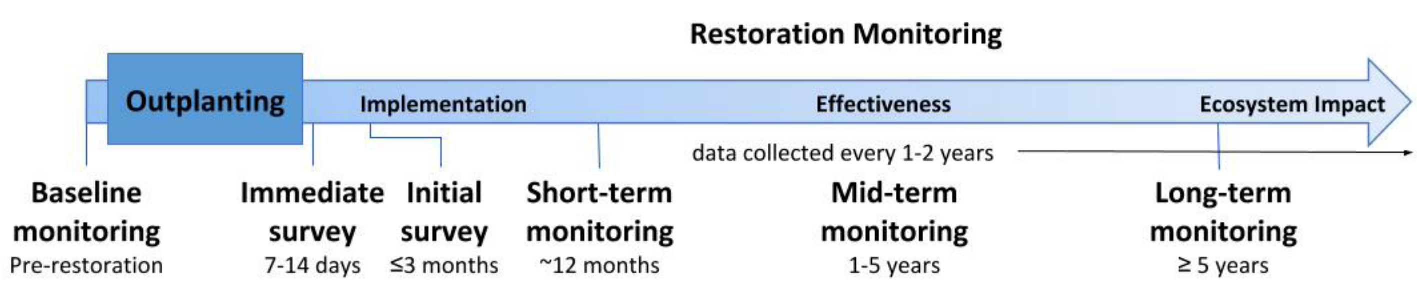
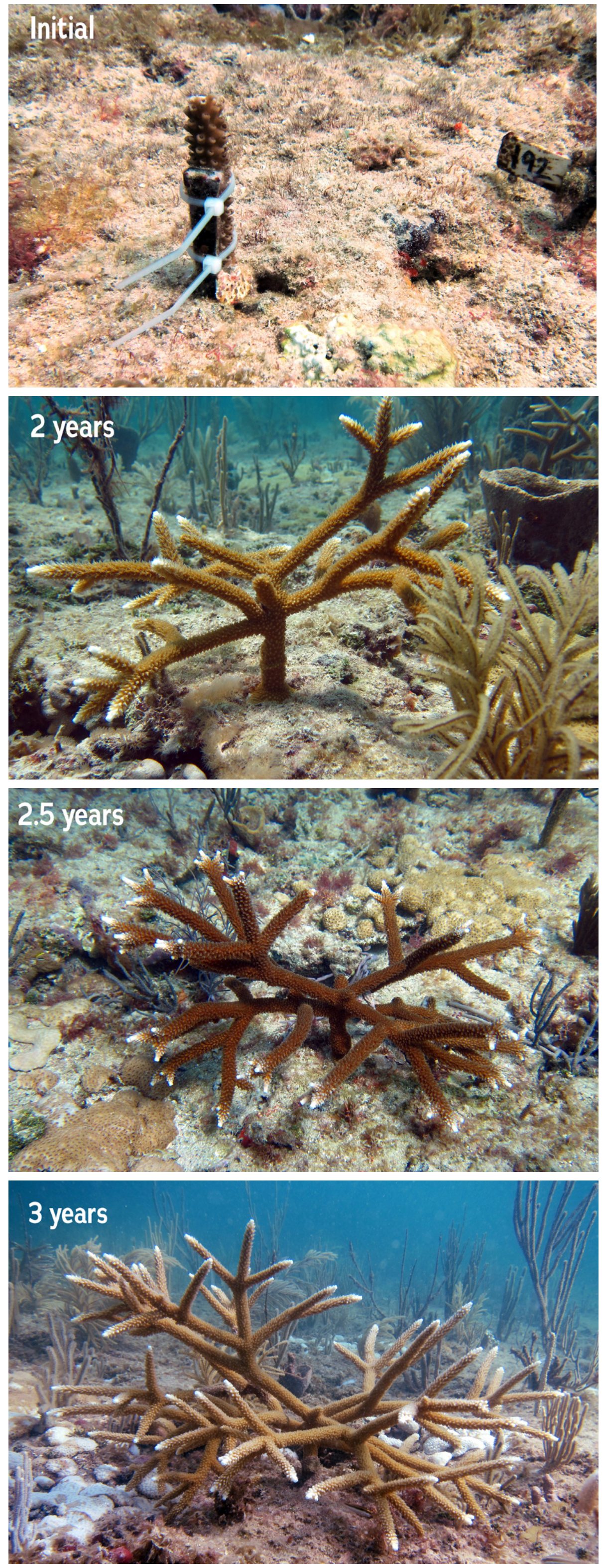


Figure 5. Timeline for monitoring restoration after outplanting. Additional monitoring is recommended in response to specific events such as disease, bleaching, and cyclones.

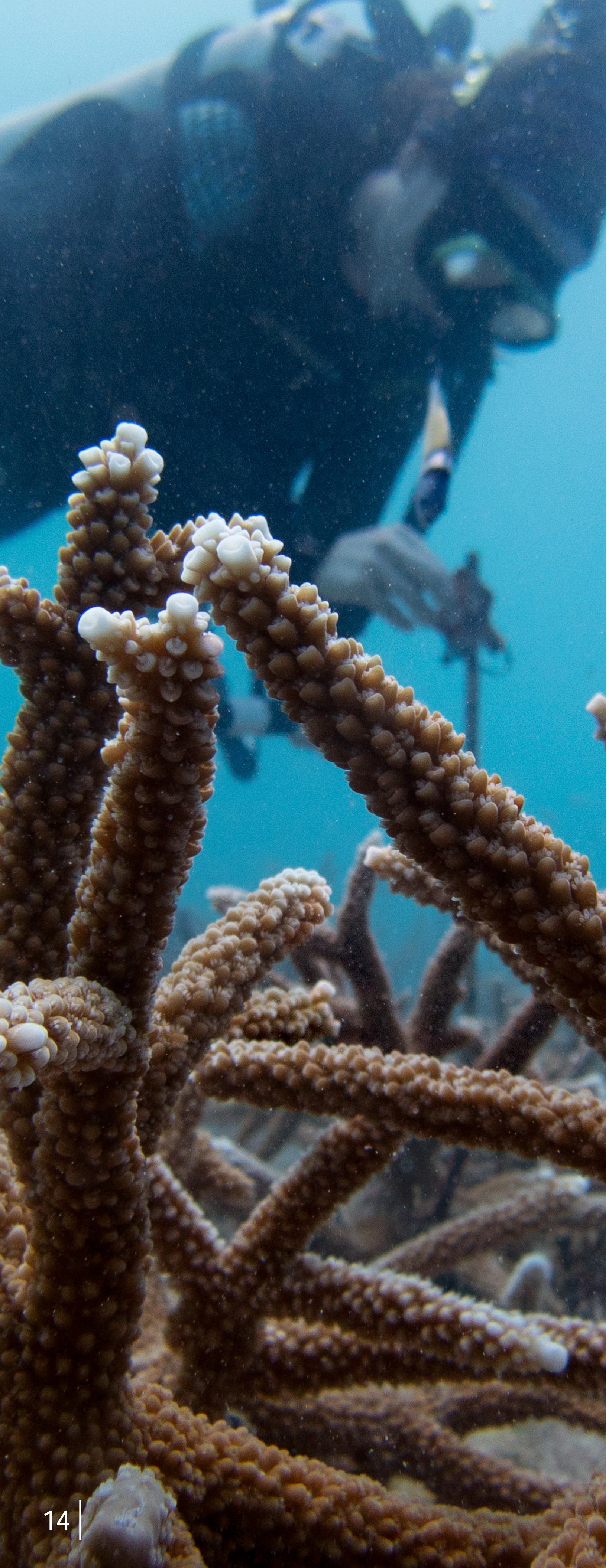
Long-term monitoring (5+ years) should collect information on the restored area once the outplants have had time to settle, grow, and have an impact on the overall reefscape based on their abundance and complexity. Long-term monitoring should include data collection on the ***impact of the restoration activities to the broader ecosystem***. Success criteria include, but are not limited to outplants that exhibit sexual reproduction (gamete production) upon reaching the size/age of sexual maturity, increase reef height/rugosity of site, improve ecological value of reef (e.g., provide habitat for fish and other reef vertebrates), and exhibit high survivorship and abundance after five years or more following outplanting.

Monitoring frequency can vary due to differences in ecosystems, geographies, habitat/reef type, environmental conditions, outplanting frequency, and potentially the growth rate or other factors for the restored species in question (i.e., disease or spawning events), but it is important to have a multi-year, long-term plan in place regardless of these variables. Other examples of monitoring frequency in ecosystems include: 3 months and every 1–2 years for up to 6 years in oyster restoration (Baggett et al., 2014), annually for 3 years (Schmitt and Duke, 2016) or 6 years (Upadhyay et al., 2015) in mangroves, and annually for more than 3 years for seagrass (Bell et al., 2008), and within 3 years of reforestation for establishment success, but over 10 years (up to 50–100 years) for full rainforest ecosystem recovery to be determined (Le et al., 2012).



Liz Goergen

Prior to following the monitoring metrics outlined in this Guide, we recommend two surveys in close proximity to outplanting, a pre-restoration baseline survey and a rapid visual assessment within two weeks of outplanting (immediate site survey), to capture any potential transport, handling, or predation issues. Both surveys can identify immediate problems leading to early course corrections. Monitoring of coral reef restoration, for the monitoring metrics presented within this guide, should occur within 3 months of outplanting (initial survey), approximately 12 months following outplanting (short-term), and every 1–2 years thereafter (mid- to long-term) in order to assess the drivers of success and alter methods if necessary to ensure positive growth and stability of the restored areas (Figure 5). Programs that are outplanting continuously to the same area or site should complete an initial survey following each outplanting event (or those within a couple of months of each other), events could then be further grouped for subsequent annual surveys; this will be based on the programs capacity. It is also important to consider natural and anthropogenic-induced events when developing a monitoring timeframe, and include provisions to reevaluate coral survivorship as soon as possible after a major disturbance. Seasonal (e.g., coral spawning, bleaching), acute (disease and storms), as well as planned (e.g., coastal construction) events can all affect the frequency, feasibility, and outcome of monitoring activities.



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Chapter 4

Assessing the Performance of a Restoration Project

Evaluation of the success of a restoration program requires monitoring metrics that quantify change to address the goals that were identified for the program (Figure 6). With evaluation of the appropriate metrics from the start of the restoration (or even before the restoration begins), program failures and/or successes can easily be identified and addressed quickly if, or when, they are necessary. The assessment of the performance of a restoration project may look different for each program or even for different projects within a program due to difference in the goals and objectives.

Within this guide, we propose two categories of metrics to Guide in assessing the performance of a restoration project (Figure 7). The first is the Universal Metrics (Chapter 5), which are designed to describe restoration size, composition, and status in a basic way that is comparable and useful amongst practitioners, scientists, and managers. These Universal Metrics are intended to provide a framework of data that all practitioners can collect, regardless of their expertise and resources, in a standardized and meaningful way. Such a standardized approach allows comparison between restoration sites: what was restored, how much was restored, and how have restored sites have fared through time.

The second set of metrics focuses on the goal of the restoration program known herein as Goal-Based Performance Metrics. Currently, the primary goal identified by practitioners through interviews is to achieve Ecological Restoration, therefore this Guide focuses on the development of metrics to assess the performance of this goal (Chapter 7). Additional restoration goals were identified (Chapters 8–11), however, as most of these goals are still in the infancy in the field of restoration assessment, only a few metrics were developed in this document, but are likely to be developed in more detail in the near future.

The proposed methods, described in the following chapters, are metric specific and designed such that data collected can be analyzed to understand the effect of restoration. Although the methods included here are not novel, this Guide brings together applicable options for assessing restoration projects in an effort to collect comparable data throughout the field of coral restoration. If the suggested performance criteria for the respective metric are not met, practitioners should evaluate adaptive management strategies. A monitoring feedback loop such as this will allow us, as a restoration community, to identify failure and success specific to a restoration component.

To further strengthen the assessment of a restoration project and allow for additional analysis, we also advise that site assessments should be replicated at control/reference sites, plots, or areas nearby that have not been restored. This additional data collection will allow for comparison to sites that never received outplanting to evaluate restoration success. Guidance on selecting control/reference sites is provided in Chapter 3.

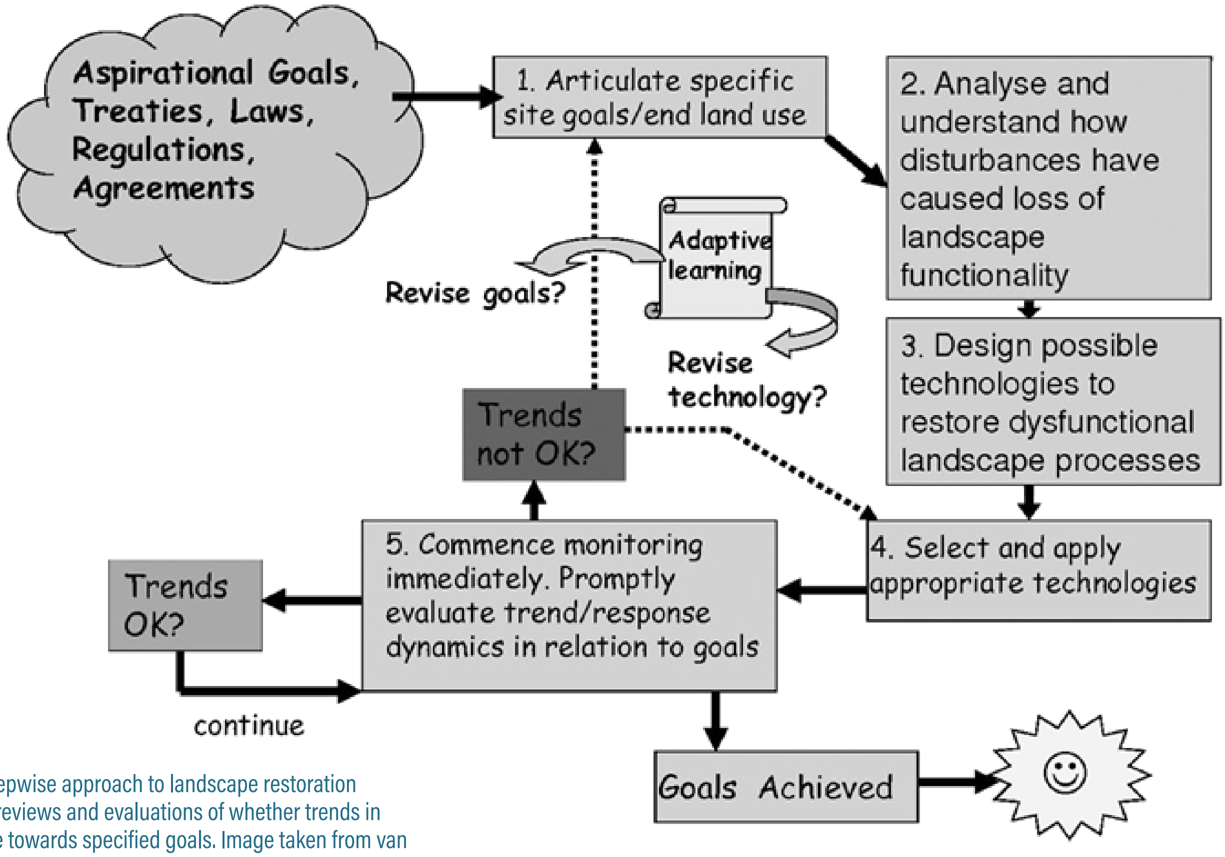

Figure 6. A stepwise approach to landscape restoration with regular reviews and evaluations of whether trends in indicators are towards specified goals. Image taken from van Andel and Aronson (2012). © 2012 Blackwell Publishing Ltd.

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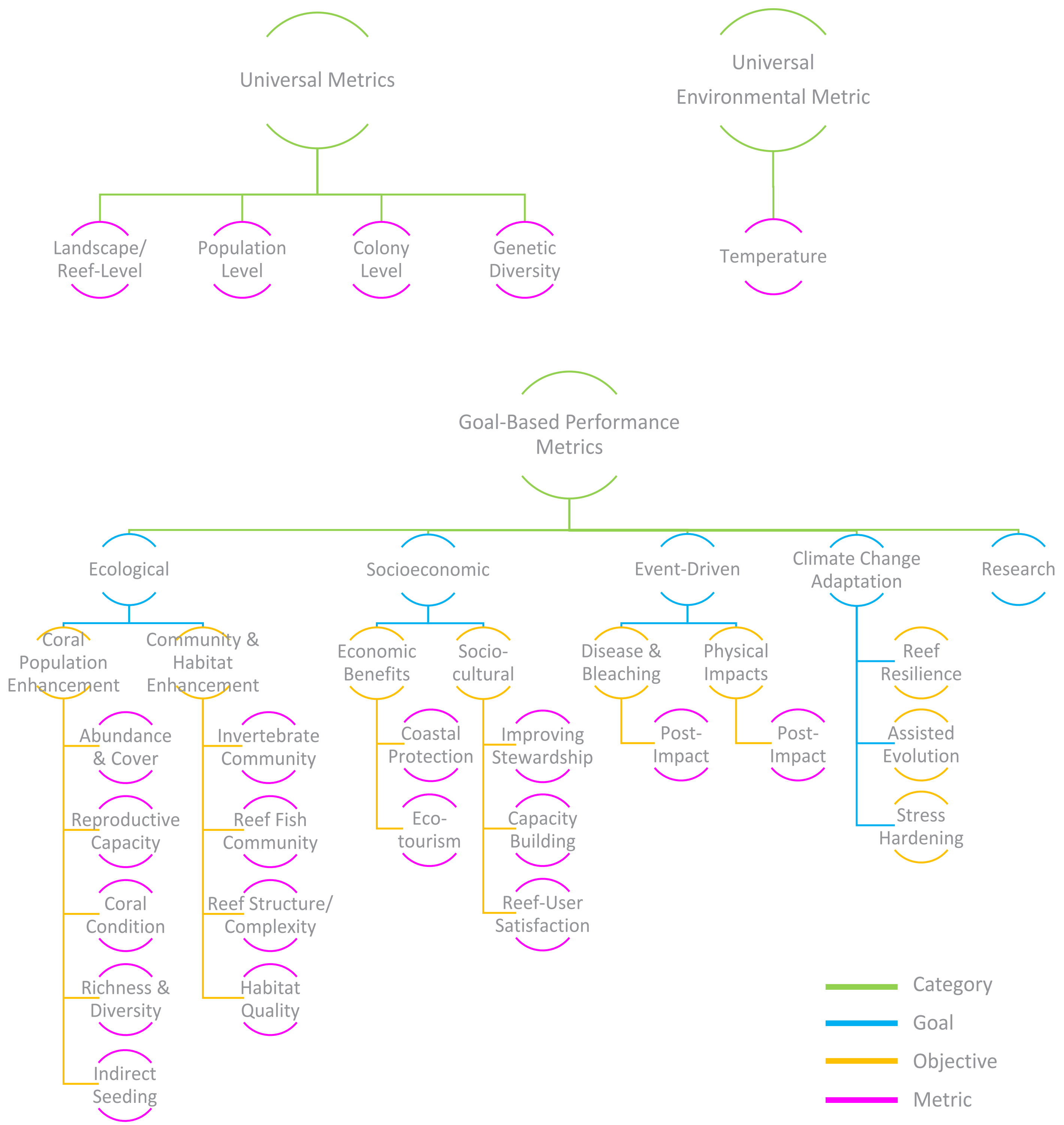

Figure 7. Summary of recommended approaches for monitoring coral reef restoration.

Basic Performance Criteria

The success of a restoration program depends on progress towards meeting the defined goals and objectives of projects and programs. There is therefore a need to compare across sites and treatments in a standardized way, over time and among programs, in order to generate meaningful results. Universal Metrics have been identified as basic monitoring criteria that can and should be collected at every restoration site, immediately, within three months, and on an annual basis there after (Figure 5), even with limited resources (Baggett et al., 2014). These metrics are not designed to cover all aspects of restoration monitoring and should be supplemented by the Goal-based Performance Metrics (Chapters 7–11) for program-specific needs.

The four Universal Metrics and one Universal Environmental Metric in Table 1 below are designed to describe restoration size, composition, and status in a basic way that is comparable and useful amongst practitioners, scientists, and managers. The Metric Output shows the type of information that is collected based on the Universal Metric in question. Combined, these metrics will describe the status of restoration over the broad ecosystem (Landscape-level) as well as on a smaller scale (Colony-level).

Restoration Goal-Based Performance Metrics

This section of the Guide outlines guidance for restoration monitoring with project-specific goals in mind. In addition to data for the Universal Metrics (Chapters 5 and 6), restoration monitoring for project-specific goals may also be conducted to evaluate restoration success using defined Goal-Based Performance Metrics. Not all monitoring metrics are useful for different types of restoration projects (i.e., determining differences in growth between genotypes is not relevant to restoration projects focused on community outreach). Monitoring select Goal-Based Performance Metrics (Chapters 7–11) together with Universal Metrics, will offer information on what and how to determine success for the following restoration goals: 1) Ecological Restoration (e.g., coral population and community and habitat enhancement), 2) Socioeconomic (e.g., coastal protection, tourism, education), 3) Event-Driven Restoration (e.g., disease/bleaching, physical impacts — planned and unplanned), 4) Climate Change Adaptation (e.g., improve resilience, assisted evolution), and 5) Research (Table 2).

Goal-Based Performance Metrics are designed to detect change due to restoration from one time period to the next. Prior to choosing which metrics will be deployed at the restoration site, practitioners should first clearly define a null hypothesis and then choose the methods appropriate for answering the defined hypothesis. A null hypothesis is usually written that no change has occurred in the parameter of interest. For example, fish abundance will not change following outplanting of corals to the restoration site is a null hypothesis. By employing a chosen set of metrics to answer this question, the data obtained can be statistically analyzed to test if the null hypothesis is true.

These chapters should be used as a resource to identify and test metrics that will answer project-specific questions. Not all questions can be answered at all restoration sites, so stay within your restoration means (restoration site design, species used, season of study) and abilities (project-timeframe, practitioner skill-set) to detect changes resulting from restoration activities over time. Coral disease events, for example, typically occur during or following the summer months, therefore testing a hypothesis relating to the impact of disease on restoration during a winter time-period will not accurately assess the hypothesis.

The proposed restoration Goal-Based Performance Metrics are most valuable if included as part of a controlled restoration experiment, in which various outplanting treatments are replicated and compared to control plots where no restoration has been conducted (Bayraktarov et al., 2016). Another option is to utilize the BACI design (Eberhardt, 1976; Green, 1979) by conducting initial surveys of the area to be restored for comparison to data collected immediately after restoration or during long-term monitoring.

Table 1. Summary of Universal Metrics and Metric Outputs.

Universal Metric	Metric Output
Landscape/Reef-level Metrics: Restored Reef Areal Dimension (RRAD)	The area encompassed by outplants and the area across which outplanted corals may spread
Population-level Metrics	Restored coral size, abundance, distribution, and survival. Additionally, cover and density can be estimated when combined with the areas from above
Colony-level Metrics	Mean, distribution, and prevalence of colony partial mortality and colony survival.
Genetic and Genotypic Diversity	Number of genotypes per species
Water Temperature	Monthly minimum, maximum, and mean temperature

Table 2. Summary of Goal-Based Performance Metrics and the Metric Outputs.

Goal	Objective	Metric	Output
Ecological Restoration	Coral Population Enhancement	Abundance and Cover	Change in abundance and cover of restored corals
		Reproductive Capacity	Observation and documentation of timing, genotypic variability, and percent of restored corals reproducing sexually
		Coral Condition	Presence/absence, prevalence, and percent tissue lost due to disease, predation, bleaching or physical impacts on restored corals
		Species Richness and Diversity	Species richness, diversity, and evenness of corals at a restoration site
		Indirect Seeding of Sexual Recruits	Substrate retention, settler survival, and yield
	Community and Habitat Enhancement	Invertebrate Community	Abundance, density, presence/absence, species richness, diversity, and evenness of invertebrates at a restoration site
		Reef Fish Community	Abundance, size, presence/absence, species richness, diversity, and evenness of fish at a restoration site
		Reef Structure and Complexity	Mean height of corals and reef structure at a restoration site
		Habitat Quality	Habitat quality (water quality, benthic cover, coral recruitment, turbidity, and sedimentation) following restoration
Socio-economic	Economics	Coastal Protection	Risk to coastal communities from coastal inundation and erosion
		Responsible Ecotourism Opportunities	Diver participation and training programs to support restoration, development of restoration programs to economically benefit community and reduce dive pressure on natural reefs
	Socio-cultural	Cultivating Stewardship Through Education and Outreach	Promote environmental awareness of coral reefs and restoration
		Capacity Building	Capacity for volunteers and citizen scientists to contribute effectively to restoration
		Reef-User Satisfaction	Awareness of restoration and the benefits provided to the reef
Event-Driven Restoration	Disease and Bleaching	Post-Impact Survey	Prevalence of colonies impacted Description of diseases present Determination if restoration is feasible
	Physical Impacts	Post-Impact Survey	Quantification of impacts to corals and reefs Determination if restoration is feasible
Climate Change Adaptation	Improve Reef Resilience	Various; Undefined	Identification of corals which have tolerance to certain stressors
	Assisted Evolution	Various; Undefined	Percent success rate of assisted gene flow or migration
	Stress Hardening	Various; Undefined	Percent of corals manipulated that show increased tolerance
Research	Based on research question(s)		

Adaptive Management Strategies

Adaptive management is a process in which novel management tactics are introduced into a system that requires change. Adaptive management is an approach which allows for management and course-correction in the event that a restoration program is unsuccessful in meeting its goals (Murray and Marmorek, 2003). This is a structured, iterative decision making process that requires system monitoring to understand the extent to which the newly introduced tactic is successful (Holling, 1978). Adaptive management approaches can be used to not only change and improve a system, but also to learn about a system.

Figure 8 illustrates the adaptive management process, whereby monitoring and evaluation after restoration leads to potential adjustments to restoration design in order to generate optimal results. Goals and objectives outlined in this Guide offer criteria to assess during the "do" and "learn" phases of this process that will inform practitioners if adjustments should be made and where they might need to be made in the process. In conjunction with this guide, the CRC is creating a Guide to Field-Based Coral Reef Restoration (Goergen et al., In Review), which provides guidance for the "plan" phase and select adaptive management strategies.

Utilizing this strategy gives the practitioner the knowledge and power to improve the likelihood of success at a restoration site. This process relies heavily on frequent monitoring, as this allows the practitioner to identify, evaluate, and modify a program that is producing sub-optimal results. Adaptive management requires coming up with effective and realistic alternative measures, which should be considered for implementation if a program does not meet goal-based standards. Deviations from expected results may be considered justification for potential mid-course corrections. Further, the benefits of following the process of adaptive management can identify specific areas of shortcomings or failures, which will aid in improving the success and efficiency of coral reef restoration (Figure 9).

Specific adaptive management strategies are not described in detail in this Guide because developing each of the possible strategies is out of the scope of this restoration monitoring focused document. This Guide provides the basis and minimum data to be collected on a restoration project, but it is then the responsibility of each practitioner to analyze the respective data and evaluate their program using the Evaluation Tool for Coral Restoration or other technique to identify when course correction should be

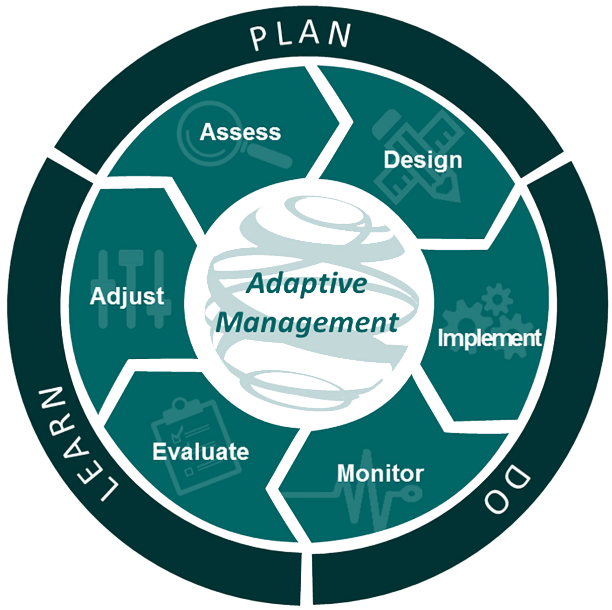

Figure 8. Diagram of the adaptive management framework. Image credit: ESSA Technologies Ltd.

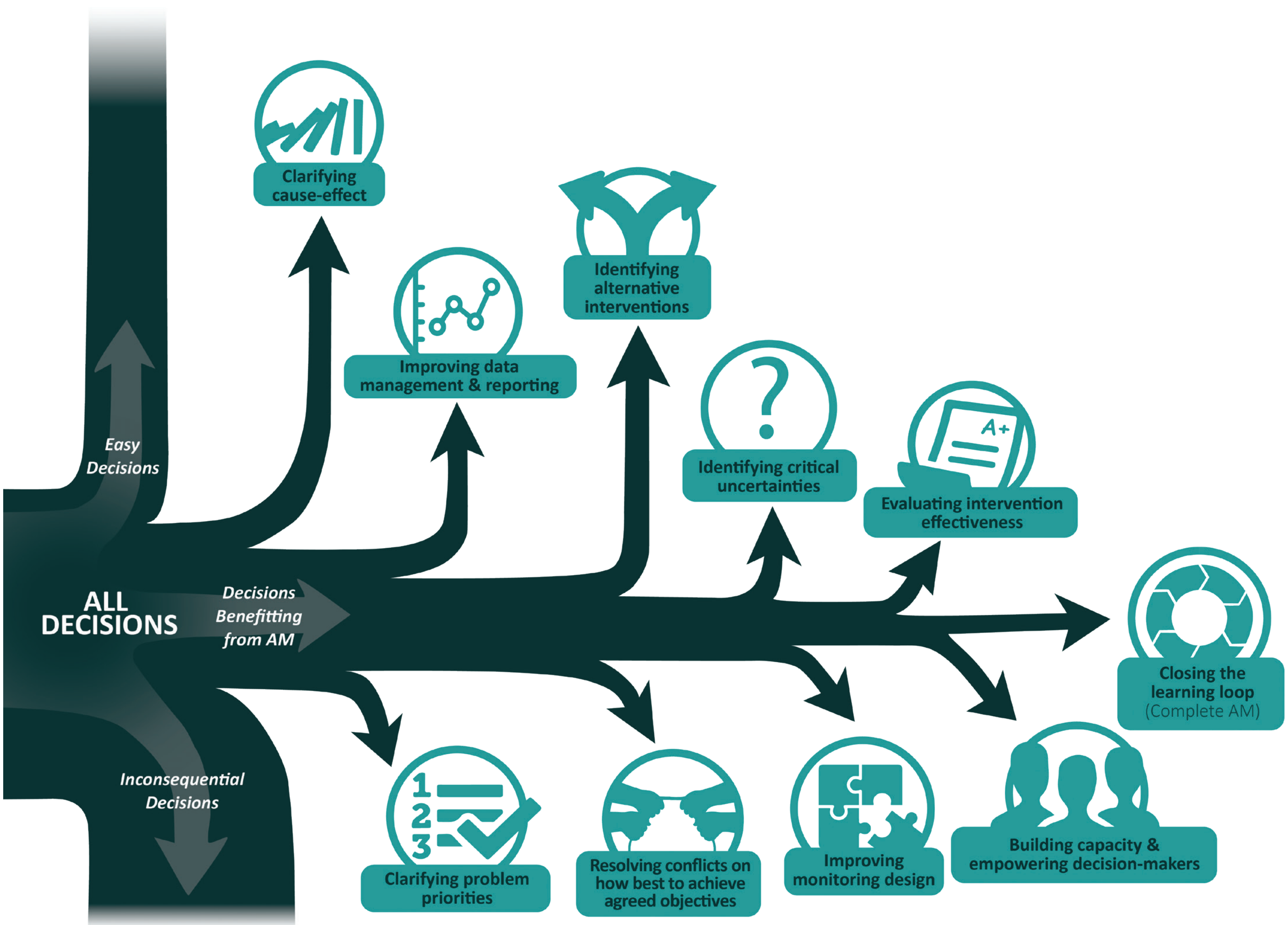

Figure 9. Example of decisions benefiting from adaptive management. Image credit: ESSA Technologies Ltd.

implemented and potential adaptive management strategies. The strategies of adaptive management vary greatly depending on the issue at hand, and each requires different levels of skill and resources to implement. The ability to implement changes mid-way through a restoration project will likely require open communication with project stakeholders, such as the practitioner's local permitting and funding agencies. Adaptive management does not mean that a practitioner needs to start over or reinvent-the-wheel in terms of the restoration project; rather, it suggests adjustments to techniques and methodologies (e.g., using nails to outplant corals instead of epoxy, Guide to Field-Based Coral Reef Restoration [Goergen et al., in review]) based on areas in which the program is struggling. Many of these can be identified through criteria identified in this Guide and the Evaluation Tool for Coral Restoration.

One of the purposes and advantages of frequent restoration monitoring is the ability to document and recognize changes before the conclusion of a restoration project. Should resources be available and a practitioner choose not to employ adaptive management strategies, there is a risk that coral health and the surrounding habitat quality will be compromised. Adaptive management relies on the principle of learning on the fly, which results in a level of uncertainty. This technique can be politically or socially unpalatable as, sometimes, the course of action calls for implementing a short-term suboptimal management option to gain knowledge and improve future decision-making (McDonald-Madden et al., 2010). While this may appear to be in direct contrast with "best practice" strategies, adaptive management strategies are essential to better understanding underperforming systems.

Coral Restoration Consortium's Coral Restoration Database

The CRC identified a need to identify coral nursery and restoration projects to make connections and demonstrate the cumulative impact of individual efforts. The resulting product is a geospatial Coral Restoration Database (Appendix 1) developed by the CRC's Monitoring Working Group. Nursery and outplant input datasheets were developed to collect the information requested by researchers, practitioners, and managers. The database can be used to report the universal monitoring metrics identified in this document and to summarize information for examination using the Restoration Evaluation Tool (Appendix 2). An interactive map of coral nursery and outplant locations and corresponding site information can be found online (Appendix 3; Figure 10). The database will be located online for ease of uploading and querying data.

Evaluation Tool for Coral Restoration

The Restoration Evaluation Tool (Appendix 2) is an adaptation of the original Reef Restoration Program Evaluation Tool developed for restoration activities in the Dominican Republic (Lirman et al., 2017). This product addresses the increasing need to develop uniform, consistent guidelines to provide feedback on the status of restoration efforts that are initiated with differing levels of expertise and a wide range of programmatic goals (e.g., restoration, education, enhanced livelihoods). This tool follows the recovery goals, objectives and criteria outlined in the Recovery Plan for

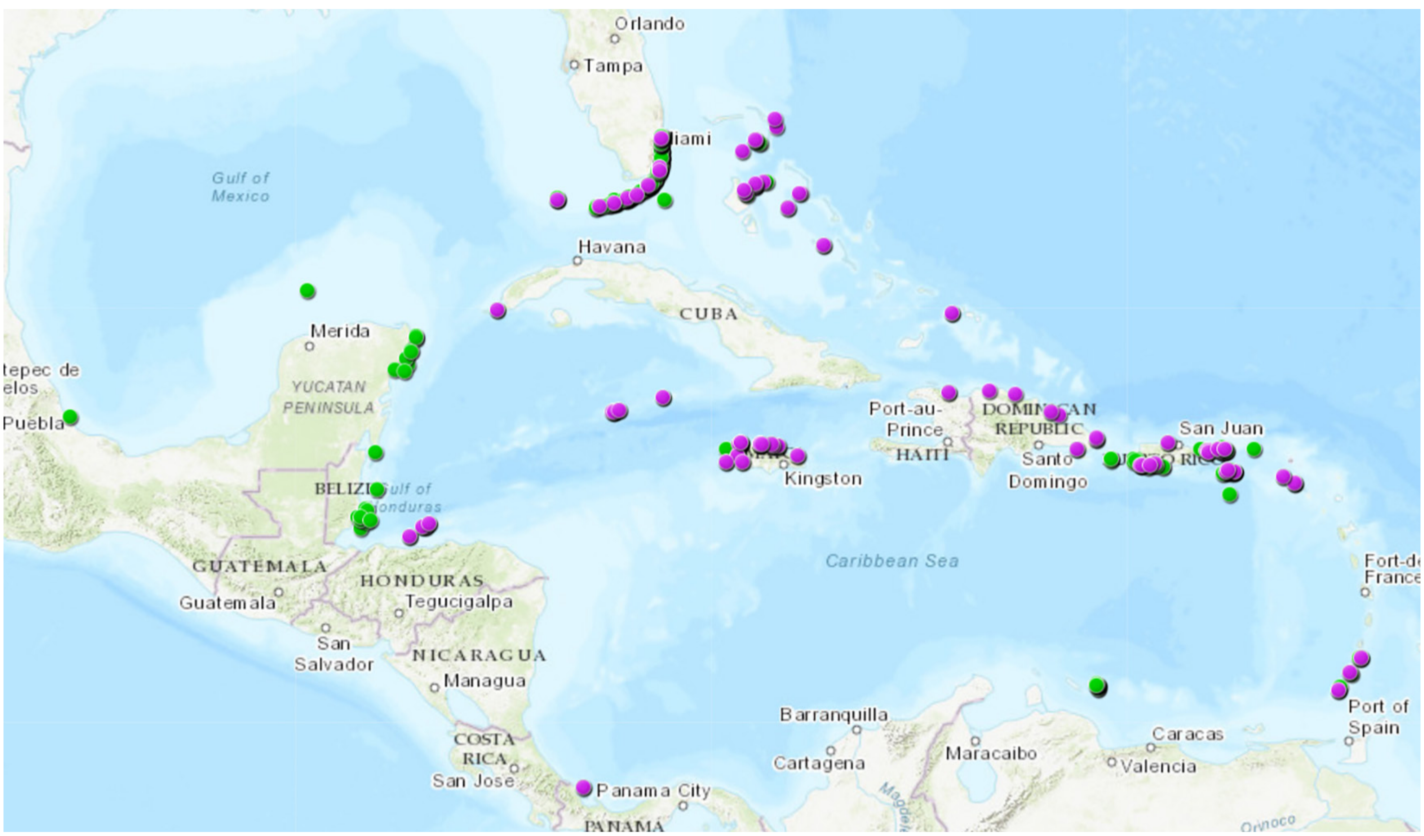

Figure 10. Preliminary map of Caribbean coral nursery sites (pink) and restoration sites (green).

Coral Restoration Consortium

Elkhorn and Staghorn Corals (NOAA National Marine Fisheries Service, 2015), which may also be applied to additional species which are now listed within the U.S. Endangered Species Act or have recently suffered dramatic losses in abundance and cover due to severe bleaching and disease events.

The simple assessment tool captures status information of a wide range of potential project components and goals, including key steps such as coral collection, nursery deployment and maintenance, coral monitoring, stakeholder involvement, funding sources, data sharing, education and outreach, and project sustainability. The metrics outlined in this tool are designed to evaluate overall program success as a summary of success criteria, or "restoration benchmarks", while also identifying metrics which may require adaptive management to improve performance (Schopmeyer et al., 2017). Metrics outlined within this evaluation tool focus on best management practices or results from restoration-based research conducted by experts in the field of coral propagation and outplanting (see Appendix 2 for references).

Restoration benchmarks are visualized here as a "stoplight" (i.e., green, yellow, red), where nursery, outplanting, and program metrics are scored using a binary system (yes or n/a), then the scores are tallied and color coded based on potential max score (Figure 11). The resulting color/score indicates restoration success based on survivorship, productivity, genetic diversity, and overall condition of coral outplants based on recommended monitoring metrics outlined in this guide and other CRC Working Group guidance (Field-Based and Genetics). Scores represented by shades of green are greater than 75% of the mean and those metrics are considered successful. Scores represented by yellow to orange are 50-75% of the mean and indicate that some changes may be needed to improve the success of those metrics. Finally, scores represented by red are less than 50% of the mean and highlight areas where adaptive management is necessary to fulfill project, program, or regional needs (e.g., population enhancement, research, mitigation, education, stakeholder livelihood, and community engagement). For example, if outplant survival is low (<50% of the mean of other outplant sites and represented on the Programmatic Evaluation Tool as "red"), monitoring efforts may be able to determine that outplant mortality is caused by predation by corallivores. Therefore, a program may decide to conduct predator removal at the outplant site or even abandon the restoration site and move outplanting efforts to a different site with lower predator prevalence. As another example, if a project receives a low score based on the genotypic diversity of outplants, then a project can increase propagation of additional genotypes, find additional locations for new collections which may increase genotypic diversity, or consult with partner projects to exchange novel nursery corals (all permit pending).

The intent of this tool is to evaluate each restoration metric to promote the design of adaptive strategies to improve performance and encourage communication between restoration partners (either locally, regionally, or globally) to increase success. The stoplight indicator framework allows self-critique of methodologies, techniques, and protocols. This evaluation of the current status

	project 1	project 2	project 3	project 4	project 5	project 6	% of projects
Nursery Score	100	67	56	89	100	44	76
Outplanting Score	83	75	50	83	92	42	67
Total Project Score	92	71	53	86	96	43	71

Figure 11. Example values for nursery and outplanting score to generate a "total project score" (left) and "stoplight" scale (right) to show "no action required" (green), "some action required" (yellow-orange), and "warning, changes must occur" (red).

Tanya Ramseyer/FWC

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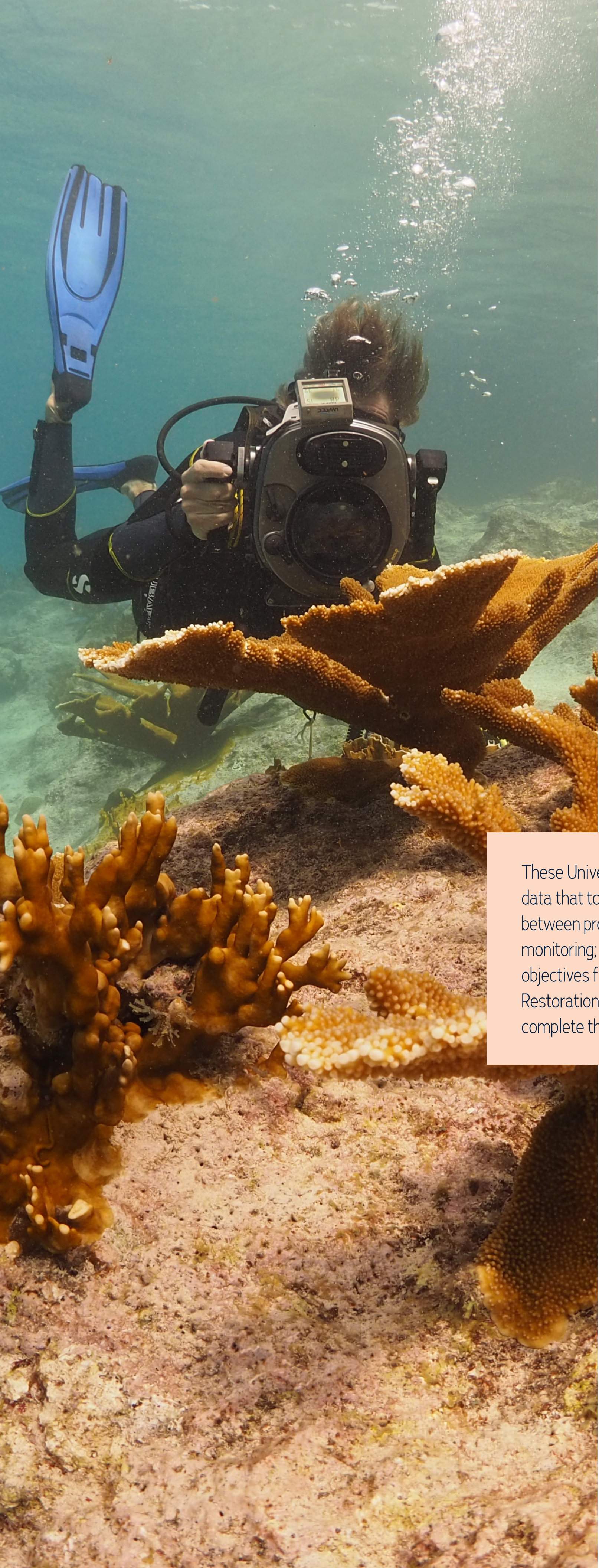
of restoration techniques outlines the positive attributes of productive projects and programs and promotes the development of successful strategies. Therefore, this approach will advance the development of science-based benchmarks to achieve population-based recovery for coral reefs.

Within the evaluation tool, criteria are divided into sections relevant to the specific restoration. Criterion may be relevant at the project, program, or regional scale or based on the specific goals of the project (e.g., species enhancement, education and outreach, Event-Driven Restoration). Projects are defined as an individual coral field nursery or outplanting event (multiple outplanting events may occur at one outplant site, but may be considered and monitored as separate projects). Projects may also be scored and compared within or between programs/regions. Project-level success is largely based on the utilization of best management practices, overall coral survival and growth, and maintaining genetic and genotypic diversity of local coral populations. Programs are considered individual restoration partners or practitioners completing nursery or outplanting projects. Program-level success is largely based on programmatic stability, spatial and temporal capabilities, and long-term potential. Regions may be considered counties, states, shelf units, countries (dependent on size), or any area where multiple projects and/or programs are conducting restoration (both nurseries and outplanting). Regional evaluations incorporate the scoring of multiple partners who are collaboratively restoring reefs within the same area/region. Regional criteria are largely based on spatial coverage and functional capacity, communication and collaboration between partners, management agencies, and other stakeholders, and the potential for long-term strategies.

The Role of Science in Restoration

Habitat restoration is increasing in public awareness and political respectability due to advancements in science and subsequent science. In order to be influential, scientific ideas and experience must be offered in a timely manner and welcomed as a useful component of restoration, with the most desirable outcome being a review of all relevant ideas and best available science during the decision-making process (Turner, 2005). Integrating science into the big picture or broader program goals is done most effectively when formal mechanisms exist for incorporating science into programs and policy (Van Cleve et al., 2006).

Effective science can be generated in a number of ways, including input from peer review, collaboration and multidisciplinary partners, using case studies, pilot studies, and baseline information to create conceptual models, and determining performance measures and program-specific goals early in the planning stage. Effective use of the science reflects an important focus in program evaluation and the assumption that the ineffective scientific methods in restoration can be diagnosed and corrected via systematic lessons learned studies (e.g., Day et al., 2004; Van Cleve, 2004). These elements combined have implications for adaptive management and highlight the importance of both content and process in restoration planning and implementation (Van Cleve et al., 2006). Furthermore, this method of checks and balances provides guidance to address missing links in a program or process and determine what is realistically possible and scientifically achievable under the constraints of capacity and funding.



Reef Renewal Bonaire

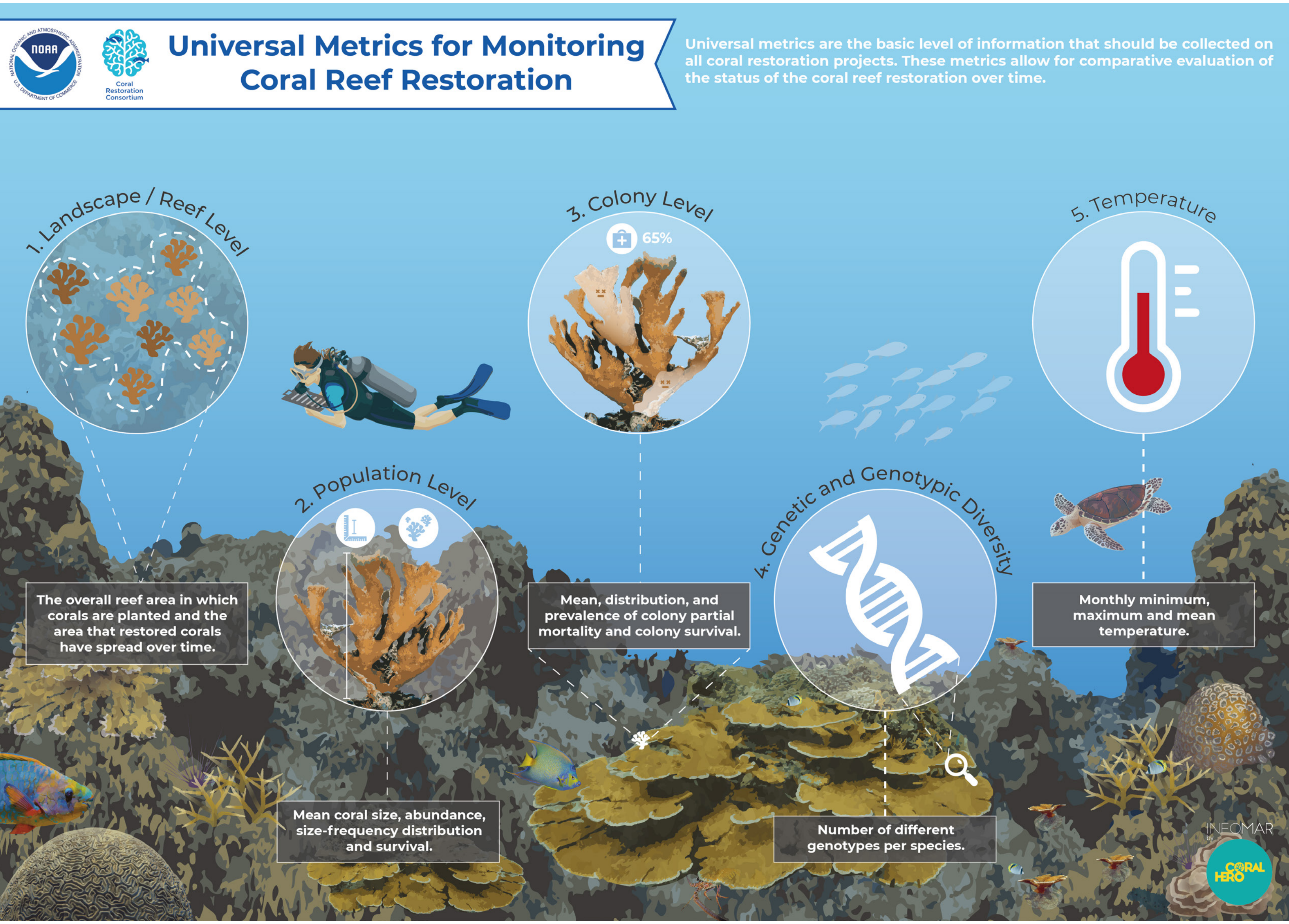
Chapter 5

Universal Metrics for Coral Reef Restoration

Restoration projects often have different goals, and “success” of a restoration site is dependent on whether or not the defined goal was achieved. However, there is a need to describe restoration sites that have differing goals, methods, and designs in a more standardized way to be able to make comparisons among sites. These Universal Metrics for coral reef restoration are designed to describe restoration size, composition, and status in a basic way that is comparable and useful amongst practitioners, scientists, and managers. Four Universal Metrics: 1) Landscape/Reef-level Metric: Restored Reef Areal Dimension, 2) Population-level Metrics, 3) Coral-level Metrics, and 4) Genetic and Genotypic Diversity are identified as metrics that should be collected at every restoration site on an annual basis (Table 1). The intended purpose for these Universal Metrics is to provide a framework of data that all practitioners can collect, regardless of their expertise and resources, in a standardized and meaningful way to allow comparison of restoration sites (what and how much was restored and how have restored sites fared through time).

These Universal Metrics provide a standardized framework for the collection of restoration data that together evaluate the success of restoration over time within a program or between programs. The Universal Metrics are not designed to cover all aspects of restoration monitoring; therefore, we recommend defining a coral reef restoration program's goals and objectives first (see Chapter 2), and then include additional metrics recommended in the Restoration Goal-Based Performance Metrics chapters of this document (Chapters 7–11) to complete the monitoring plan for each project or program based on specific needs.

The data collected for Universal Metrics #1–3 can be combined to provide an overall description of the restoration site. Metric # 1 defines the boundary of the area(s) in which data are collected for # 2 and #3. Universal Metric #2 describes the size of restored corals, and #3 provides additional details of the health and quality of restored corals by estimating partial mortality. By combining these three metrics, changes in restoration sites can be evaluated over time in terms of area, colony size, abundance, density, coral health, percent cover, and reproductive potential (based on coral size).



Within this chapter, four Universal Metrics are provided to evaluate coral restoration efforts in a concise and comparable manner (Table 1). The field of coral reef restoration is continually evolving, and it is likely that the proposed metrics may need to be dynamically updated with the evolving field. **To further strengthen the usefulness of the Universal Metrics and allow for additional analysis, we also advise that if time, budget, and program capacity allows, Universal Metrics #2 and #3 should be replicated at control/reference sites, plots, or areas nearby your restoration site that are not being restored.** This additional data collection will allow for comparison to sites that never received outplanting to evaluate restoration success. Guidance on selecting control/reference sites can be found in Chapter 3.

For each metric, we provide the following guidance for data collection: a rationale, definition of terms, diagrams, suggested methods, reporting, sampling frequency, and performance criteria (See Summary of Universal Metrics). In addition, this Guide connects to two additional products developed by the Coral Restoration Consortium's Monitoring Working Group: 1) CRC Coral Restoration Database (Appendix 3), and 2) An Evaluation Tool for Coral Restoration (modified from Lirman et al., 2017). All three of these products have continuity in the reporting and evaluation; for example, each data type within the Universal Metrics is related to the Database (Appendix 1), and the Evaluation Tool (Appendix 2) connects these data collections to programmatic success (see the end of this chapter for a product integration summary). The continuity between these products makes for straightforward data reporting, program evaluation and comparison, and data sharing and collaboration.

Universal Metric #1: Landscape/Reef-level Metrics: Restored Reef Areal Dimension

Restored Reef Areal Dimension (RRAD) is a quick approximation of the overall reef area in which corals are planted and the area that restored corals have spread over time. **This metric is valuable as it provides guidance for reporting standardized project size and area of restored reef to gauge the overall impact and success of a restoration project.** The objective is to capture the growth/spread/persistence of the restored area, which is particularly important for branching species such as *Acropora* species that are known to frequently break and re-attach across a site and are difficult to track at the individual colony level. For massive species, the RRAD may not change as quickly as for branching species, but maintaining adequate abundance within the Ecological Footprint over time is paramount to restoration success. In addition, to capture the impact of restoration, a site survey must be completed prior to restoration occurring, recording at a minimum, the presence and abundance of the species being used for restoration (See suggestions in the Outplant Site Selection section of the Guide to Field-Based Coral Reef Restoration [Goergen et al., in review]). RRAD is determined by two components: Outplant Plot and Ecological Footprint.

Outplant Plot is the approximate area (summed) of reef on which corals were outplanted. This is the area where active restoration (physically planting corals) was completed. Within a restoration site, there may be multiple plots depending on your project's design (Figure 12). Individual Outplant Plots are defined as groupings of restored corals that have a spacing of around 2 meters or less between corals. If groupings of corals are separated by well over 2 m, they should be considered separate Outplant Plots and need to be measured individually. There may also be instances where the Outplant Plot area is equal to the Ecological Footprint (see Singular example in Figure 12). Outplant Plot area is only collected during the initial restoration, providing an initial baseline of planted area.

Ecological Footprint is the maximum areal extent of reef which encompasses all Outplant Plots using the shortest contiguous boundary. This area could be very similar or the same to the Outplant Plot during the initial survey depending on your restoration design (Figure 12). Separate Ecological Footprints should be measured if the distance between Outplant Plots is greater than 10 m or they are separated by a physical barrier that is not suitable habitat (e.g., a sand channel between two spurs or patch reefs; Figure 13). Small sand patches atop a reef can be included in the footprint. Subsequent surveys should include all living colonies attached or loose, both in their outplanted location or new location due to fragmentation/dislodgement (fragmented coral; Figure 12). Fragmented corals, assumed to originate from the outplanting, should be included in the footprint if they are within 10 meters of another colony (outplanted or fragmented). Over time the Ecological Footprint may shift, grow, or shrink depending on the survival or propagation of restored corals. Following high-energy events, the restored area may change significantly. In some cases, corals may have moved completely from the previously mapped area; if this is the case, a survey of the surrounding reef area is warranted. Further, the change of RRAD over time, if georeferenced, may indicate direction of typical site energy as seen by the direction of coral movement.

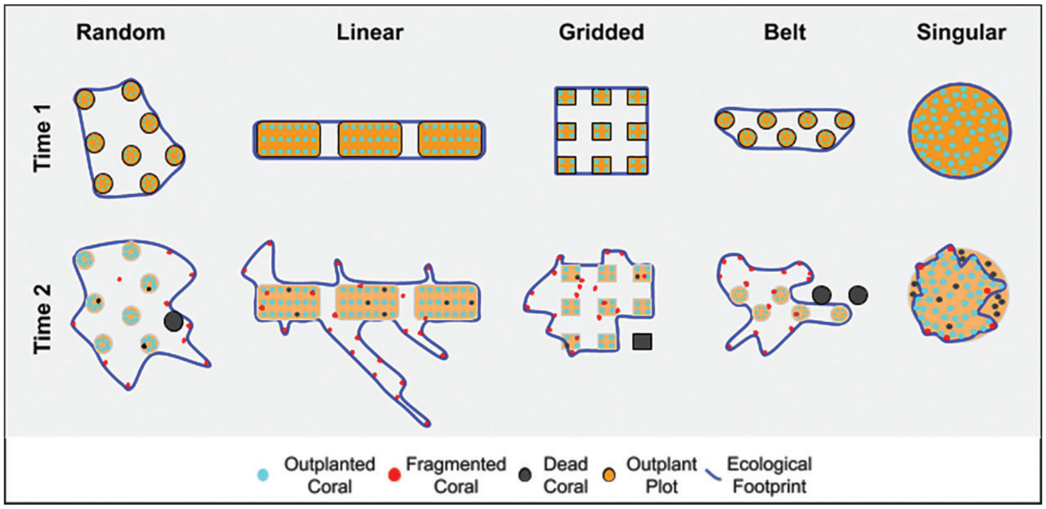


Figure 12. Examples of Outplant Plot (orange area) and Ecological Footprint (blue boundary) on various restoration project designs (random, linear, gridded, belt, and singular). Time 1 is representative of the time of outplanting or shortly thereafter (within a month). Time 2 is representative of a future sampling event (annual or following a disturbance), orange Outplant Plots are lightened just for reference to Time 1 diagrams, but are not measured in Time 2.

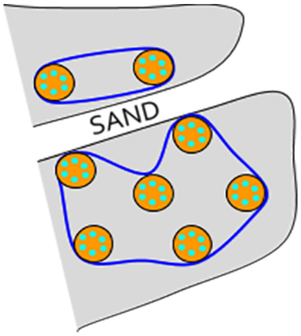


Figure 13. Example of measuring the Ecological Footprint on a spur and groove-like reef

As sites change over time, the number of Ecological Footprints may change. For example, if your original restoration design consisted of multiple Outplant Plots separated by more than 20 m, you would initially have multiple Footprints. If the restored corals fragment and spread across the site to fill in the distance between restored corals, the number of Footprints at a site would be reduced although the total footprint of the restored area may increase (Figure 14).

Required Units: Surface area (m^2) by each component of RRAD, note the accuracy of the measuring device and the method used.

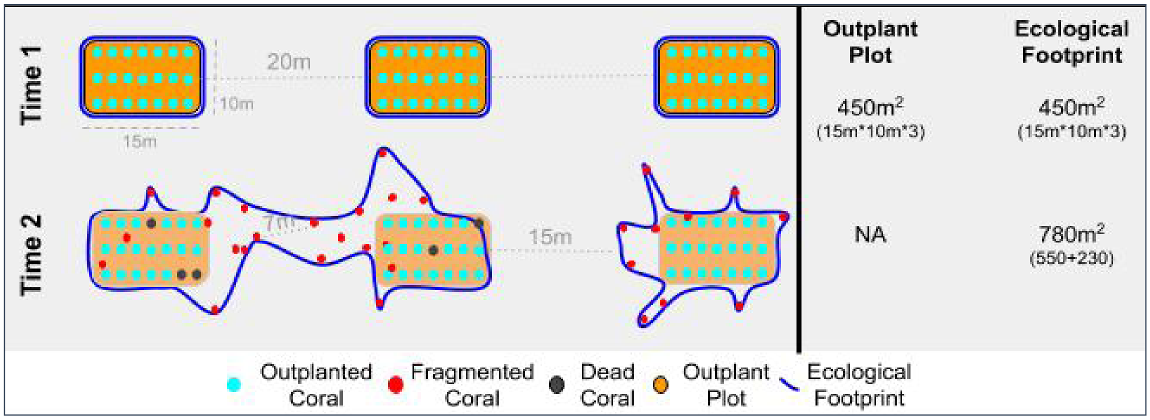


Figure 14. Example of the change in number of Ecological Footprints as restoration corals fragment and spread across the site filling in the gap between outplant corals.

Possible Methods

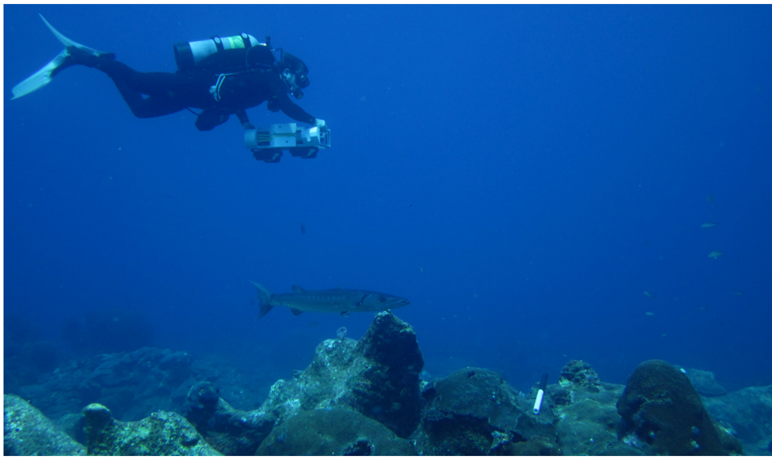
The following are methods that could be used to collect both the Outplant Plot Area and Ecological Footprint. These suggestions are not exhaustive, but are to be used as examples or guidance. It is advised that the same method be used over time within a program to ensure data comparability. If a program decides to change the method, the old and new method should both be used during the transition monitoring event for comparability. The methods laid out below are basic guidance and modifications may need to be made depending on your programs restoration design or local conditions. Individual programs should define, prior to monitoring, the methods that will be used, how the boundary will be swum, what shape will be used if using length and width, and at what distance colonies should be included (herein 10 m is suggested, but this should be adapted to your program needs). The purposes of collecting RRAD are to compare at a broad scale the size of restoration projects and the changes of those projects over time (i.e., not an analysis of a few meter difference in area, but the change from 10s to 100s of meters). To aid in consistent repetitive monitoring, a map of the previously mapped areas could be brought with underwater or deploying temporary markers surrounding outplant colonies so the mapper can easily see the colonies which should be included in the area. Whichever technique is selected, it is important to identify the method and accuracy of the equipment used when reporting your RRAD.

In situ tracing

Utilizing a handheld global positioning system (GPS), a surface swimmer (snorkeler or diver) traces the Ecological Footprint by marking waypoints over restored corals in an attempt to mark the boundary of the area of restored corals. Collected waypoints can then be exported into geographic information mapping software such as ArcGIS®, QGIS, or Google Earth® to create a polygon in which all the restored corals are located and an area can be calculated — Outplant Plot and/or Ecological Footprint.

This method is best for field conditions with calm seas and with water clarity that allow for the surface swimmer to easily identify restored corals form the surface. To increase accuracy, temporary markers may be deployed on the substrate next to the restored corals to provide guidance for the swimmer. This may be necessary for restoration projects that utilize smaller corals or are restoring deeper sites. Examples from the literature (Devine et al., 2005; Lirman et al., 2010; Walker et al., 2012; Miller et al., 2016a) outline use of this method in depth.

Accuracy of Equipment: *Depends on GPS instrument specifications (wide area augmentation system [WAAS], differential global positioning system [DGPS]) and visibility, but <3 m 95% accuracy is typical.*



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Maximum Length and Width

Using a flexible survey tape, divers or snorkelers will measure the greatest length and width of the area where restored corals are located. The measurement of the area could be completed using multiple measurements if the area is large or is heavily misrepresented using only one set of length and width measurements (Figure 15).

Accuracy of Equipment*: Length and width measurements should be reported to the nearest 0.5 m. Best judgment should be used when determining which shape (square, rectangle, circle, ellipse, etc.) is used to estimate the project footprint.*

Mapping software

Aerial imagery such as in Google Earth®, ArcGIS®, or QGIS can be used for RRAD. Based on local field knowledge, the perimeter of the Ecological Footprint can be traced to create a polygon. Area can be calculated from the polygon in a mapping software program.

Mosaics

RRAD can be calculated from photomosaics of a restoration site. Underwater landscape mosaics are image-based tools for large-area (10s–1000s of m^2) coral reef mapping and monitoring. A mosaic image is a spatially explicit georeferenced composite of images of a site usually taken from an overhead perspective. Photomosaics can combine the practicality of large-scale, rapid-reef survey effort with the high power to detect change in benthic cover or colonies provided by permanent site monitoring. Imagery can be collected via divers or drones, and protocols differ between methods and groups conducting each method (Appendix 4). The Coral Restoration Consortium's Monitoring Working Group webinar on "Photomosaics as a Tool for Monitoring Coral Restoration Success" can be found online (Appendix 3).

To collect imagery for a mosaic, a restoration site is first delineated using georeferenced permanent markers on the corners or on the boundary of the proposed survey area. A mosaic survey can then be performed over the area delineated by the markers using overlapping patterns to ensure complete coverage and overlap of images. Collected images are then processed by using specific software (e.g., Agisoft) to create a mosaic image of the restoration site. After the mosaic is complete, both the Outplant Plots and Ecological Footprint can be delineated on the image, and areas calculated using spatial software such as ArcGIS® (Figure 16). Note that imagery data are large and can require significant computational capacity.

If using mosaics to survey for RRAD, include a significant buffer around the area of outplanted corals to account for future growth and areal spread of restored corals. The size of the buffer will depend on specific site conditions, habitat availability, and species used; a larger buffer should be used for species that fragment more frequently.

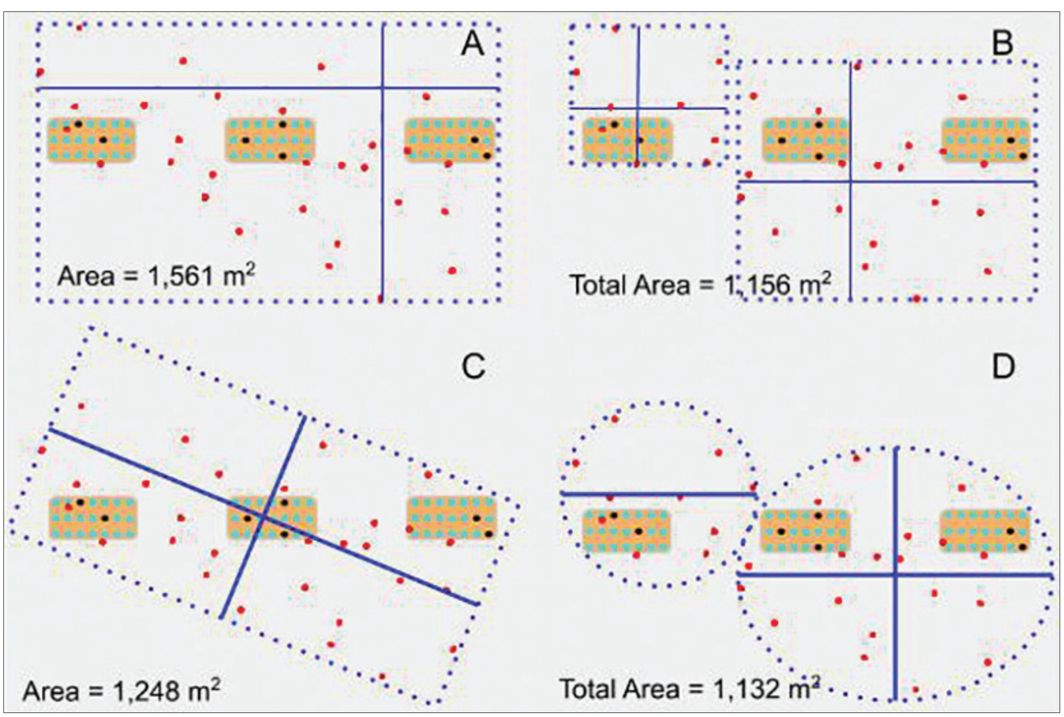

Figure 15. Options for measuring the Ecological Footprint of your restoration site using length and width measurements (A-D). Multiple areas or shapes could be used to best represent the site and distribution or the restored corals (B, D).

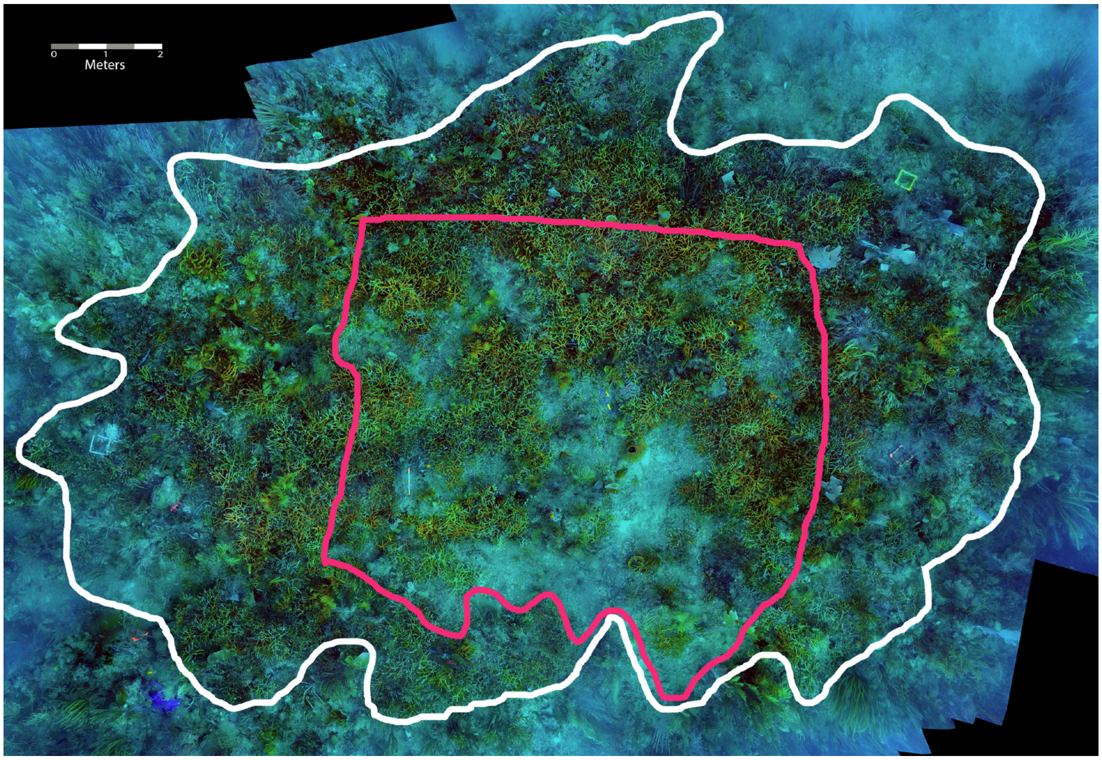

Figure 16. Example of a mosaic of a restoration site (Griffin et al., 2015; Figure 2). The red line outlines the original Outplant Plot and Ecological Footprint (2006), and the white line outlines Ecological Footprint in 2014.

Examples from the literature outline the use of this method in depth (Lirman and Fong, 2007; Gintert et al., 2012; Griffin et al., 2015; Gintert et al., 2018).

Accuracy of Equipment: *Equipment and techniques used will determine the quality and usability of the mosaic. For an equipment reference, Gintert et al. (2012) completed a comprehensive analysis of output quality using a variety of cameras and both still and video image capture techniques.*

Reporting

Outplant Plot and Ecological Footprint should each be reported as cumulative area (m^2) per restoration site. For example, if a site has numerous Outplant Plots, the reported value is a sum of the area of all Outplant Plots (Figure 14). Collected data should be reported in program-specific databases as well as uploaded into the CRC Coral Restoration Database (Appendix 1), which can be found online (Appendix 3).

Sampling Frequency

At minimum, RRAD sampling should be completed at every restoration site immediately following an outplanting event (Figure 5). Annual surveys are recommended to capture the success of restoration across time and can be used as indicators of program success or trigger the need for adaptive management strategies (Figure 5). Depending on the restoration objective and if using mosaics, collection of mosaics prior to restoration efforts may be useful to show the pre-restoration condition. In addition, surveys following a disturbance could provide data on restoration disturbance impacts, further informing guidance on restoration management and site design and selection.

Performance Criteria

The Ecological Footprint should show no net decrease over time from the original Outplant Plot area for all species and should ideally increase. If a net decrease in the Ecological Footprint is observed due to outplant mortality, the cause of the decrease in area restored should be ascertained in order to evaluate whether adaptive management strategies are necessary.

Evaluation Tool Criteria Alignment (Appendix 2): Universal Metric #1 aligns with two criteria:

1. Restored Reef Areal Dimension (or RRAD) is measured at each restoration site. If measurements were recorded a project will receive a score of 1 (Evaluation Tool Outplanting Criteria #5).
2. Restored footprint or area shows no net decrease over time from original project area. If restored footprint or area stays the same or increases from the original project area a project will receive a score of 1 (Evaluation Tool Outplanting Criteria #6).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).

Universal Metric #2:

Population-level Metrics

Population-level Metrics describe the restored population through mean coral size, abundance, size-frequency distribution, and when combined with RRAD (area of restored reef) practitioners can roughly estimate percent of the restored reef that is covered in coral (percent coral cover) and calculate the density of restored colonies per m^2. **Mean coral size is used as a broad look at the restored population, whereas the distribution of corals amongst size classes can provide insight into population maturity and contribution to habitat complexity. The change over time in the distribution of corals within size classes also provides information about coral growth and health** (Hughes, 1984; Hughes and Connell, 1987; Bak and Meesters, 1998; Brito-Millán et al., 2019), although some caution should be taken as size does not always equate to age and growth (Hughes and Jackson, 1980). Change in abundance is also a good measure of coral survival or retention. Restoration projects using more than one species should collect these data separately for each species. While change in these population-level metrics will be very slow for most massive coral species, this metric is very important for branching and fast growing species as changes can occur quickly and frequently (Lirman, 2003; Riegl and Purkis, 2009; Vardi et al., 2012; Mercado-Molina et al., 2015; Riegl et al., 2017; Goergen and Gilliam, 2018).

A **restored coral** is defined as one continuous skeletal unit, which has live tissue. Isolated tissue areas on one skeletal unit are considered part of one coral as long as the skeleton is continuous between the living tissue areas (Figure 17). Maximum coral diameter defines coral size, which includes the entire skeleton both living and dead. Note: estimated live tissue will be calculated later using Universal Metric #3.

When measuring branching corals, maximum coral diameter is the greatest length across the coral from branch tip to branch tip; branch tips can be living or dead, whichever is the maximum (Figure 17D).

These measurements are meant to be a quick estimate of coral size and do not require precise coral measurements. Coral sizes should be classified into the following bins: <5 cm; 5–10; 11–20; 21–30; 31–40; 41–50; 51–75; 76–100; >100 cm (Table 3). Corals greater than 100 cm in maximum diameter should be measured to the

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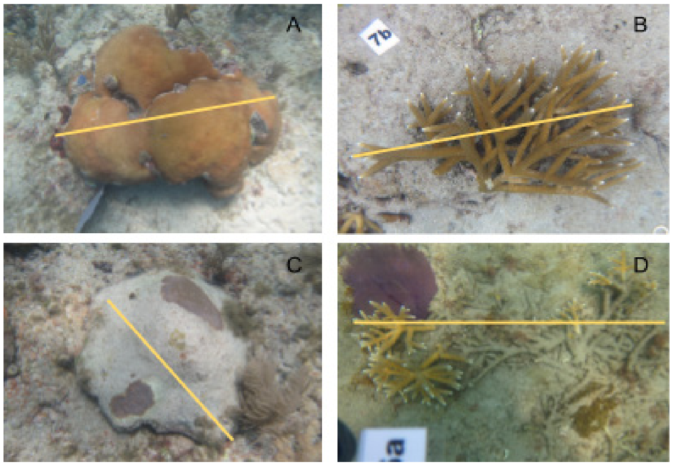


Figure 17. Maximum colony diameter (yellow line) of mounding and branching corals. Images C and D provide examples of measuring colonies with partial mortality or tissue isolates on a continuous connected skeletal unit. Image credit: Nova Southeastern University CRRAM Lab.

Table 3. Values (cm) for the central point of each size class.

Size Class	<5	5-10	11-20	21-30	31-40	41-50	51-75	76-100	>100
Central point	3	7.5	15.5	25.5	35.5	45.5	63	88	use coral size

nearest 5 cm. Programs that are using different size classes, use the center point of your size that is most comparable for entry into the database (Table 3 and example below). However, going forward we encourage you to use these size classes. If micro-fragments are used for restoration, the diameter of each micro-fragment should be measured and not the size of the substrate (i.e., old coral head) on which they were outplanted. When fusion of outplanted colonies occurs, colonies should be measured as one.

Coral Fusion

Coral fusion occurs when two or more individual corals of the same species join as one and may occur in some restorations depending on the species or techniques that were used. This is a likely situation in fast growing species that have a higher frequency of dislodgement and fragmentation; corals may fragment and roll into each other creating larger colonies. Another likely fusion scenario is when micro-fragments are used for outplanting, as these are typically planted in very close proximity to each other in the hopes that they fuse together creating a larger colony. In all cases of fusion, maximum diameter should be taken using the combined, fused colonies and not the individual parts. For example, if 10 micro-fragments were outplanted on a substrate the size class of 10 individual colonies would be reported during the initial monitoring, as the fragments grow it is likely that after a number of years the number of colonies would be reduced to a fewer number of colonies or perhaps just one colony if fusion of all fragments occurred. The observation of fusion will be reported in the database as a presence or absence by species at each restoration site. The reporting of fusion will help support the reporting of a reduction of coral abundance.

Required Units: Mean coral size by species (in cm); Abundance of coral by species (#); Percentage or number of corals per species by size class (in % or #). *Combined with Universal Metric #1: Restored Reef Areal Dimension Cover of restored coral (in % for percent cover or m^2 for area) and Density of restored coral (corals/m^2) can be determined.* It is important to identify the method used by your program when reporting your distribution data.

Possible Methods

The following are methods that could be used to collect the data for the Population-level Metrics. These suggestions are provided as examples or guidance and are not an exhaustive list. It is important to identify the method used by your program when reporting your distribution data. In addition, if using these data to describe cover and density, the method used to collect RRAD should also be reported.

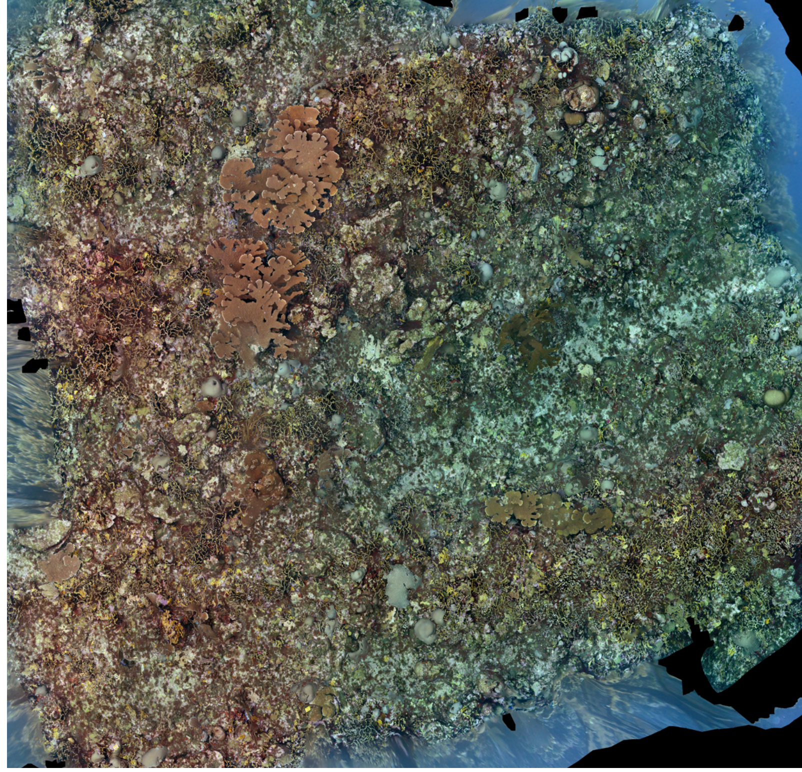
Ecological Footprint Survey

Within the area defined as the Ecological Footprint, divers will survey restored colonies. Maximum coral diameter will be estimated for each coral using a PVC measuring stick, flexible tape, or ruler. The measuring tool can be marked in 10 cm increments for rapid classification of colonies into size classes (see example datasheet in Figure 18).

Depending on the size of the Ecological Footprint, transect lines or temporary markers may be used to minimize overlap in data collection, divide the footprint to smaller sections (sub-areas within the footprint), and ensure all areas are surveyed.

Additional data collection option:

A map of the Ecological Footprint and the locations of restored corals within it over time can provide insight on site dynamics (e.g., the typical directional movement of corals across the site based on currents or waves). This can be completed by divers estimating the location of corals within the Ecological Footprint while collecting the coral size data (Figure 19). In order to ensure that surveyors avoid double counting corals, sub-sampling areas can be established by using transect tapes or temporary markers around the site. A handheld GPS could be used to mark waypoints over every coral



100 Island Challenge, Scripps Institute of Oceanography, University of California San Diego (UCSD)

within the Ecological Footprint, and waypoints can be uploaded into mapping software to create a georeferenced map of all restored corals within the Ecological Footprint (Miller et al., 2016a).

Mosaics

Population-level Metrics can be collected from photomosaics (see data collection limitations of mosaics in Appendix 4). The result of the mosaic process is a high-resolution photographic archive of all benthic organisms within the area of interest that can be used to assess coral community health at the time of the mosaic survey (Methods for obtaining a mosaic are above in Universal Metric #1 and Appendix 4). The integrated mosaic and high-resolution images can be used to improve coral species identification and health assessments. Coral colonies can be followed through time based on their geographic location within the mosaic image. Individual tagging of coral colonies is not needed using the mosaic survey method. For example, methods of obtaining coral size data from a mosaic see Appendix 4. Examples from the literature outline in depth how to use this method (Burns et al., 2015; Gintert et al., 2018; Fukunaga et al., 2019).

Surveyor:_______________ Footprint/site name:___________________
Date:_____________ Sub-Area (if necessary):_________________

	Tally in appropriate bin based on maximum coral diameter (cm)								
Species	<5	5-10	11-20	21-30	31-40	41-50	51-75	76-100	Measure corals >100 cm
ACER	/	////	///	//////	//		///	/	105,120
MCAV	///	/	/////		/	///	//	//	130,180,210

Figure 18. Example datasheet for collecting coral size-frequency distribution data.

Sub-Sampling

Depending on the size of restoration, measurements of all restored colonies may not be feasible or advised due to time constraints. In this scenario, surveys can be conducted at a subset of the colonies at each restoration site. Subsetting can be done by selecting a portion (15–20%[1]) of the Ecological Footprint to represent the condition, health, and growth of the corals at the site including all species and representative genotypes. Survey of the same subset area over time is not necessary (depending on objectives), but it is important to report that only a portion of the area was surveyed. If using the coral fate tracking method (see Universal Metric #3: Colony-level Metrics), a subset of the corals (20% or up to 50 corals[1]) can be chosen for your survey, but should be chosen prior to or during outplanting and kept consistent across the project to avoid bias and to provide an accurate estimate of survival. Methods for choosing the colonies and area can be found in Chapter 3.

[1] Proportions were chosen based on current Florida, USA permitting regulations for restoration. This proportion may need to be modified to fit a program's permitting regulations or reporting needs.

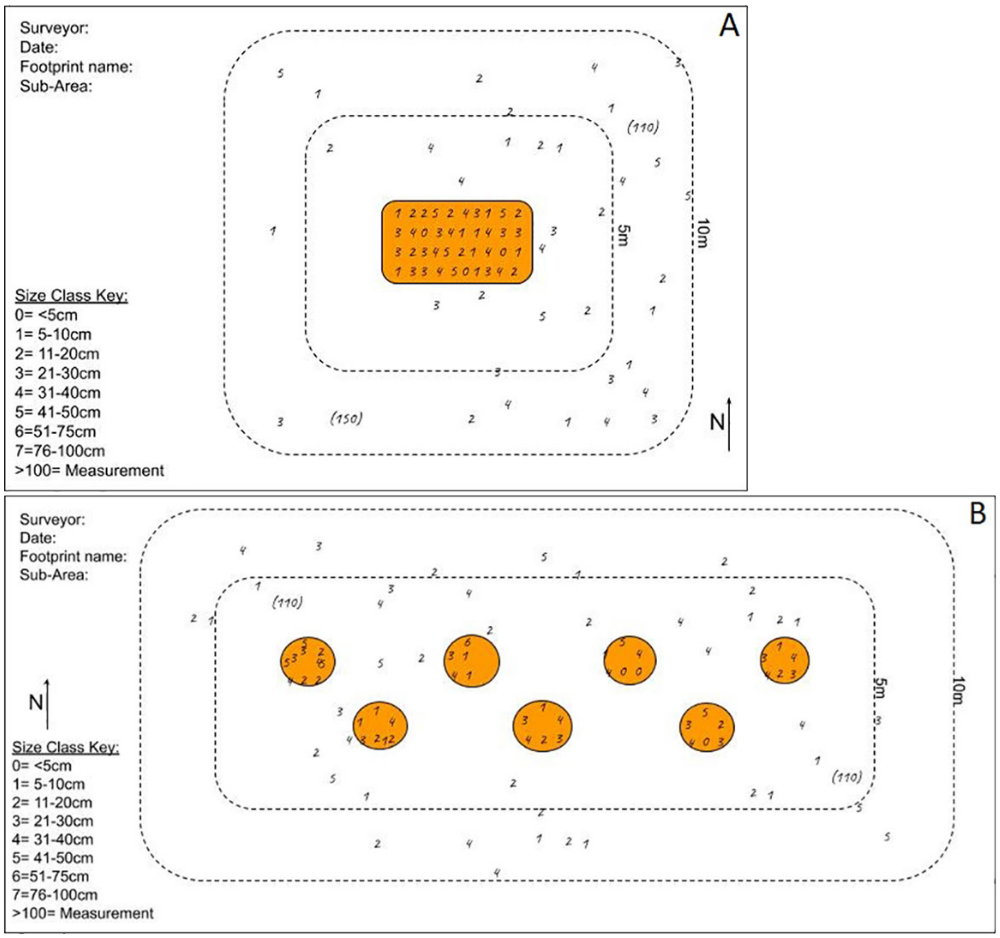
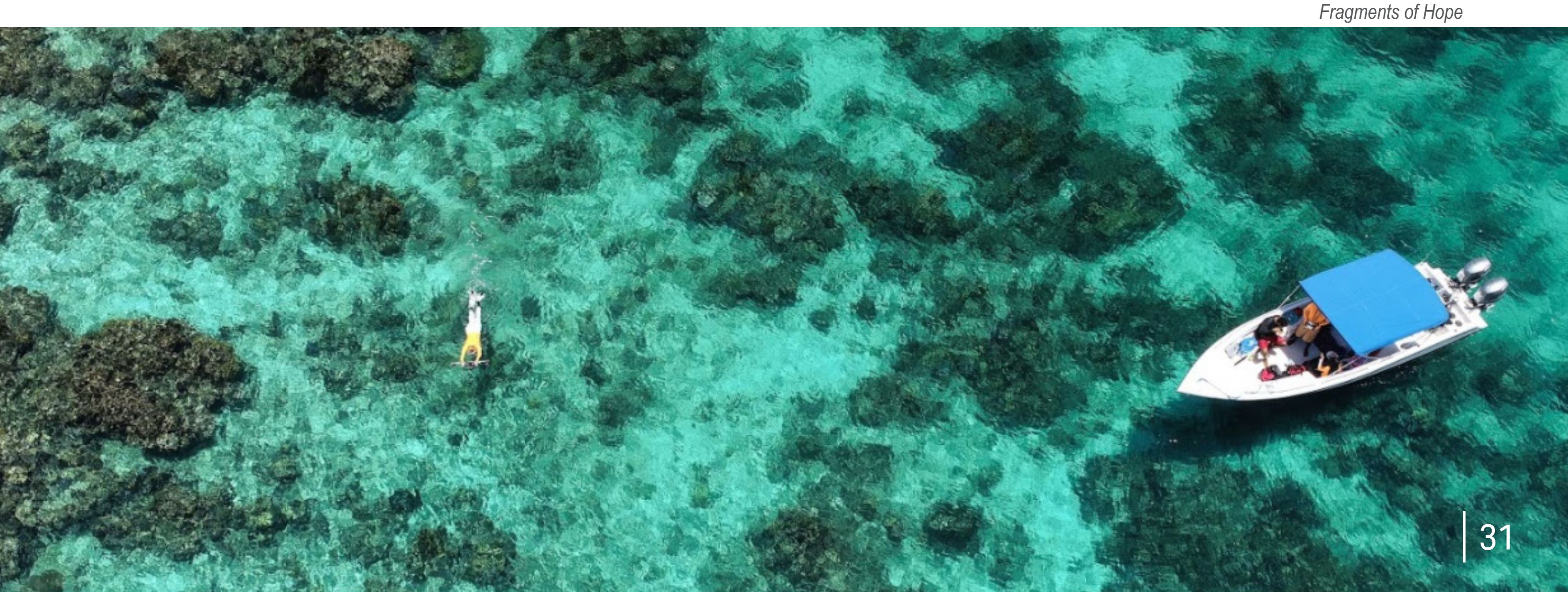


Figure 19. Example datasheets for collecting size class data while mapping restored colonies at the site for (A) linear and (B) belt outplant designs. Data in this example are collected by writing the size class of the coral using the key in its approximate location. The dotted lines on the map with distances 5 and 10 m are only used to guide the surveyor and can be modified to the practitioners needs.

Fragments of Hope



Tiffany Boisvert/FWC

Reporting

Data collected for Population-level Metrics should be reported as number of corals per designated size class by species at each site. From these data, the following analyses can be performed: mean coral size, total abundance, and coral size-frequency distribution (as a percentage or number of colonies per size-class). In combination with the area reported for the Ecological Footprint, a rough estimate of percent cover and density of restored corals can also be calculated. Collected data in the form of number of corals per size class and if data represent a subset of corals/outplants should be reported in program specific databases as well as uploaded into the CRC Coral Restoration Database (Appendix 1), which can be found online (Appendix 3). The above metrics can be automatically calculated within the CRC Coral Restoration Database for each project; however, the equations are provided below for program specific databases.

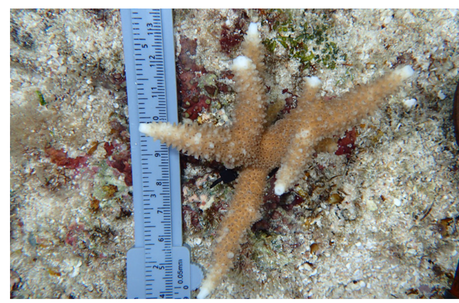
Abundance is a sum of the total number of restored corals within the Ecological Footprint. This value over time will provide a rough estimate of restored species **survival**.

Percentage of corals per size class should be calculated by dividing the number of corals in the respective size class by the total number of colonies within the Ecological Footprint or number sampled.

To determine the **mean coral size**, use the following equation:

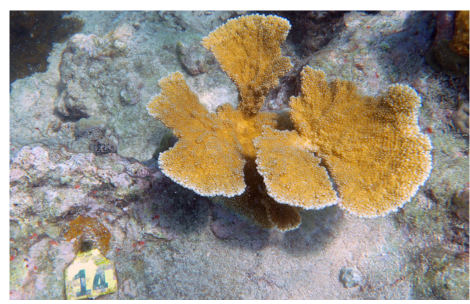
$$\bar{x} = \frac{(n_{SC1} \times 3) + (n_{SC2} \times 7.5) + (n_{SC3} \times 15.5) + (n_{SC4} \times 25.5) + \cdots + (n_{SC8} \times 88) + sc9}{\sum n_{SC1-9}}$$

Where n_{scx} is the number of colonies in the provided size class and the multiplier represents the central point of the associated size class (Table 3). For size class 9 (>100 cm), add each colony measurement in the equation.



Whitney Hoot

If data were collected using different size classes, such as 5–10, 10–25, 25–50, 50–100 cm, data should be reported using the central points of each size class and entering it in the category which is most similar in the database. For example, the central points for these sizes classes are 7.5, 17.5, 37.5, and 75, respectively. Therefore, data would be entered under 7.5, 15.5, 35.5, and either 63 or 88 (practitioner's judgment call on which would be most representative), respectively, the other size classes would remain blank.



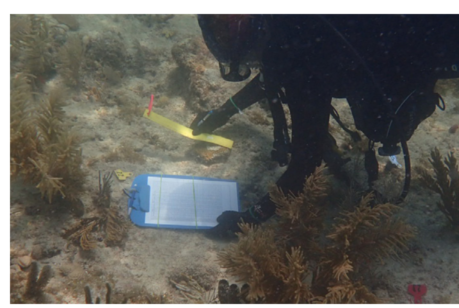
Hector Ruiz

Mean Coral Size Example:
Using the example data in Table 4 and the equation above, mean coral size is estimated as 32 cm.

$$\bar{x} = \frac{(1 \times 3) + (14 \times 7.5) + (13 \times 15.5) + (24 \times 25.5) + \cdots + (5 \times 88) + 105 + 101 + 110}{93} = 32\ cm$$

Table 4. Example data collected for coral size-frequency.

Species / Size Class (cm)	<5	5-10	11-20	21-30	31-40	41-50	51-75	76-100	>100
Acropora cervicornis	1	14	13	24	25	5	3	5	105, 101, 110



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Bonus Reporting: Combined with the Universal Metric #1: Restored Reef Areal Dimension, cover of restored coral (in % for percent cover or m^2 for area), and density of restored coral (corals/m^2) can be roughly estimated at the time of outplanting. Mosaics could also be used to estimate coral cover and density of outplanted corals (see mosaic methods sections throughout the document for guidance). When estimating % coral cover during future monitoring events, Universal Metric #3 (% live tissue) must be included to incorporate potential partial mortality that could have occurred since outplanting at Time 1. See Universal Metric #3 Reporting.

Cover Estimate Example:
Using the area from Figure 15D (1,132 m^2) and the example distribution data from above, cover can be estimated by using the approximate areas of a coral from Table 5 or if more detailed data such as length, width, and height of the colony were collected. These examples are provided as guidance, there are many other ways your program may choose to determine cover or other metric outputs herein. *A. cervicornis* is best represented as an ellipse (Huntington and Miller, 2013). Therefore, the **Total Cover**, in area, of restored corals for this example is 85,610 cm^2 (8.56 m^2) which is 0.8% cover within the Ecological Footprint.

$$Total\ Cover\ (cm^2) = (n_{SC1} \times 5) + (n_{SC2} \times 33) + (n_{SC3} \times 172) + (n_{SC4} \times 383) + \cdots + (n_{SC8} \times 4562) + SC9$$

Where n_{scx} is the number of colonies in the provided size class and the multiplier represents the area of one colony of the associated size class. For size class 9 (>100 cm), the area of each colony should be added to the equation using the formulas in Table 5.

$$Percent\ Cover = \frac{Total Cover \,/\, 10{,}000 \frac{cm^2}{m^2}}{Area\ of\ Ecological\ Footprint}$$

Density Example: Using the same data as the above example the density of restored corals in the Ecological Footprint would be 92 corals/1,132 m^2= 0.08 corals/m^2.

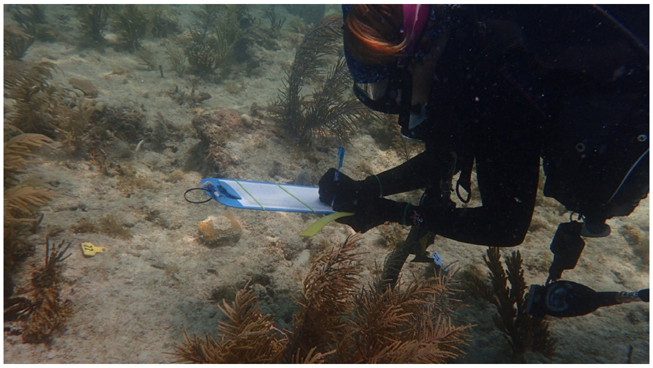
Table 5. Approximate area (cm^2) of a coral colony for the given size classes based on an ellipse or circle. Choose the shape that best represents the corals used for restoration (Huntington and Miller, 2013).

Estimated Area / Size Class	<5	5-10	11-20	21-30	31-40	41-50	51-75	76-100	>100
Based on an ellipse $A = \pi \times \frac{1}{2}d \times \frac{3}{8}d$	5	33	142	383	742	1,219	2,338	4,562	Based on coral size
Based on a circle $A = \frac{1}{4}\pi d^2$	7	44	189	511	990	1,626	3,117	6,082	Based on coral size

Sampling Frequency

Minimally, Population-level Metric sampling should be completed at every restoration site immediately following an outplanting event (Figure 5). During the initial survey, wild coral abundance and location within the Ecological Footprint should also be noted so future conclusions can be made about the impact of restoration activities. Annual sampling is recommended to capture changes in restored coral survival, population growth, and abundance (Figure 5). It is highly recommended that these data collections occur over the long-term, over 5 years. In addition, sampling following a disturbance will provide data on restoration disturbance impacts such as coral loss, movement, and change in size-class distribution (Figure 5).

Reef Renewal Bonaire



The Nature Conservancy

Whitney Hoot

Performance Criteria

The distribution of restored coral sizes should remain similar to initial distribution or show a shift towards greater frequency of larger colonies (Figure 20). A general shift towards smaller colonies in the distribution from the initial distribution, a reduction in the mean coral size or total abundance should be evaluated, and adaptive management strategies should be used if appropriate.

Evaluation Tool Criteria Alignment (Appendix 2): Universal Metric #2 aligns with two criteria:

1. Restored corals display positive net change in coral size (determined by an increase in mean colony size of shift to larger colonies in size-class frequency distribution) or no net decrease in abundance (branching species of staghorn *Acropora* only). If corals (all species) display positive net growth (increase in total linear extension, max diameter, colony area, % colonies in larger size classes) and/or no net change in abundance a project will receive a score of 1 (Evaluation Tool Outplanting Criteria #9).
2. Restored corals exhibit high coral survivorship within the first year post-outplanting. If the annual survival of restored corals (by species) is over 80%, a project will receive a score of 1 (Evaluation Tool Outplanting Criteria #12).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).

Universal Metric #3:

Colony-level Metrics

To gauge the success of restoration it is important to measure colony survival. Because corals, as clonal organisms, can experience partial mortality, we suggest collecting these data by estimating the amount of live tissue by species per restoration site. **This metric is important for evaluating growth, cover, and success of a restoration site. When combined with size-class distribution data, a rough estimate of the amount of tissue (in area-m^2) per site can be determined.**

The estimate of **live tissue per colony** should be recorded from a planar view by tallying colonies into the following rankings: 0% (dead); 1–25%; 26–50%; 51–75%; 76–99%; or 100% alive (Figure 21). It is likely that the number of dead colonies reported will be an underestimation because as colonies die, they may fragment, become dislodged, bioeroded, or become overgrown and not easily identified.

Recent mortality is also an important health characteristic to track on restored corals; however, it is not directly included as a Universal Metric because the suggested frequency of data collection for Universal Metrics is annual, which is not an adequate frequency for tracking or describing recent mortality. Therefore, we have chosen instead to use the percent of living tissue and suggest that the health of restored corals by way of recent

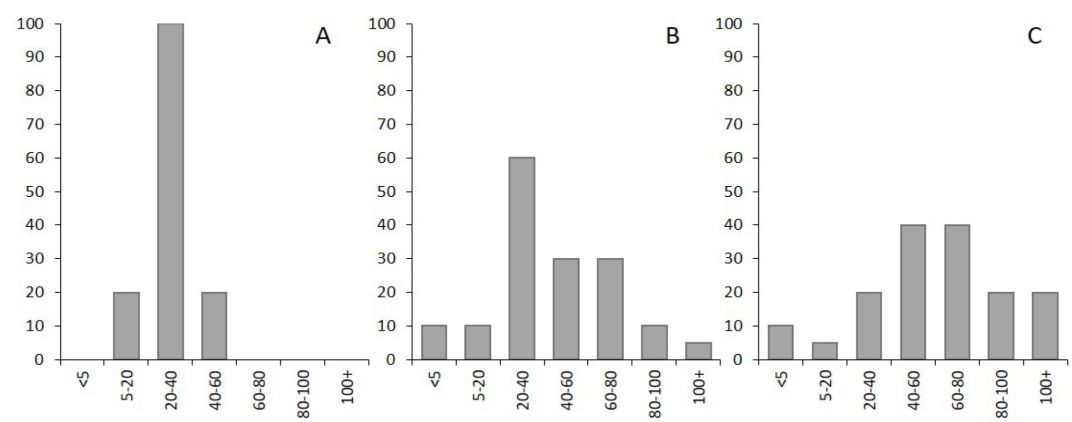


Figure 20. Example size-frequency distributions of restored corals from (A) initial, (B) 1 year , and (C) 2 year.

mortality and disease, bleaching, and predation prevalence be described using the metrics in Restoration Goal-Based Performance Metric #1.3.

Required Units: Mean percent live tissue per coral (in %); Percentage or number of corals in each ranking of mortality (in % or #).

Possible Methods

The following are methods that could be used to collect an estimate of coral partial mortality. These suggestions are not exhaustive, but are to be used as examples or guidance. Whichever technique is chosen, it is important to identify the method used when reporting your data.

Methods used for Universal Metric #2: Population-level Metrics can be applied to this metric; see above for detailed descriptions of methods:

Ecological Footprint Survey

Follow the methods outlined above in Universal Metric #2, replacing coral size with an estimate of live tissue. Figure 22 illustrates an example datasheet for data collection using this method.

Mosaics

Follow the methods described in both Universal Metrics #1 and #2 and the guidance provided in program-specific standard operating procedures found in Appendix 4.

Coral Fate Tracking

This method is best used for new programs to obtain knowledge and data on coral growth and health to evaluate the success of a site and techniques used. Individual restored/outplanted colonies can be tagged or mapped within the Outplant Plot to monitor over time, and using this method allows practitioners to track the health of individual colonies. However, this method can be extremely time consuming as a program grows. Unlike the Ecological Footprint survey, this method covers the same area and surveys the same colonies during every survey event; therefore, individual coral growth and health can be measured (rather than an estimate of the population growth). Fate tracking colonies works well for coral species that do not frequently fragment or their primary mode of reproduction is not asexual (i.e., non-Acroporid species), as it can underestimate coral survival and restoration success for those branching species. As a restoration program grows, coral fate tracking can be more time intensive than other methods due to the time needed for finding coral tags and to ensure that data on the same colonies are collected over time. For a large-scale restoration, we recommend random selection of a subset of the colonies outplanted that represent the species and genotypes outplanted to each site.

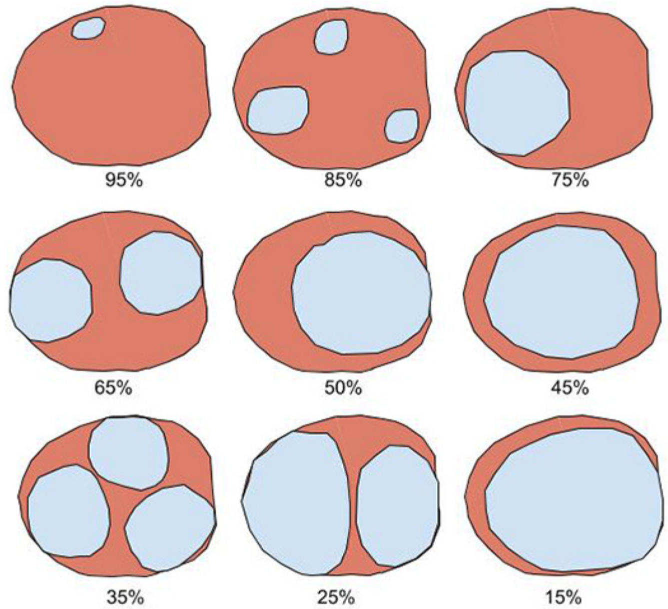


Figure 21. Examples of estimating live tissue per coral. Red represents live tissue, gray represents bare/colonized skeleton.

Sub-Sampling

Depending on the size of restoration, measurements of all restored colonies may not be feasible or advised due to time constraints. In this scenario, surveys can be conducted on a subset of the colonies at each restoration site. **Methods for choosing the colonies and area can be found in Chapter 3 and must follow the same subsetting methods chosen for Universal Metric #2.**

Surveyor:________________ Footprint/site name:___________________
Date:_____________ Sub-Area (if necessary):________________

	Tally in appropriate bin based on **Percent of Coral Alive**						
Species	Dead	1-25%	26-50%	55-75%	76-99%	100%	Notes
ACER	//	/	///	//////	/////	////	
MCAV	///		////		///	/////	

Figure 22. Example datasheet for collecting estimated live tissue data using the Ecological Footprint survey.

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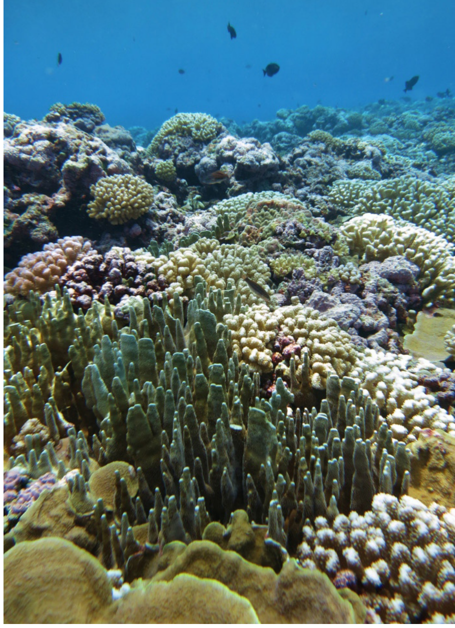

Louise Giueffi/NOAA


Reef Renewal Bonaire

Reporting

Estimated live coral tissue should be reported for each species as the number of corals in each class of live tissue at each site. These data can then be analyzed in four ways: 1) restored coral survival, 2) percentage or number of corals per class of live tissue, 3) percent of corals with partial mortality, and 4) mean percent live tissue per restored coral. In addition, in combination with Universal Metrics #1 and #2, a rough estimate of percent cover of restored corals can be calculated.

Collected data, in the form of number of corals per live tissue class and if a subset of corals/outplants was used, should be reported in program-specific databases as well as uploaded into the CRC Coral Restoration Database (Appendix 1), which can be found online (Appendix 3). The above metrics can be automatically calculated within the CRC Coral Restoration Database for each project, however, the equations are provided below for program-specific databases.

An estimate of **coral survival** can be made by dividing the total number of colonies tallied with live tissue by the total number of corals outplanted. Survival in this application is defined as the total number of colonies with any live tissue. While dead colonies can be reported, this tally may be a misrepresentation of colony survival because as colonies die they quickly become colonized and difficult to identify.

The distribution of coral partial mortality can be reported by the **number or percent of corals per live tissue class**. Percent of corals in each of the classes is found by dividing the number of corals in the respective class by the total number of colonies within the Ecological Footprint or number sampled.

Percent of corals with partial mortality (prevalence) is calculated by dividing the sum of colonies that have between 1–99% of live tissue by the total number of colonies surveyed minus dead colonies. For example, using the data from Table 6, the percent of colonies with partial mortality is 38% (35/93).

Table 6. Example data collected for coral estimated live tissue.

Species / Live Tissue Class	Dead	1-25%	26-50%	51-75%	76-99%	100%
Acropora cervicornis	3	2	3	3	27	55

To determine the **mean percent live tissue per restored coral** use the following equation:

$$\bar{x} = ((n_{\mathrm{LT1}} \times 0) + (n_{\mathrm{LT2}} \times 12.5) + (n_{\mathrm{LT3}} \times 40) + (n_{\mathrm{LT4}} \times 65) + (n_{\mathrm{LT5}} \times 87) + (n_{\mathrm{LT6}} \times 100)/\sum n_{\mathrm{LT1-6}}$$

Where n_{LTX} is the number of colonies in the provided class and the multiplier represents the central point of the associated class (Table 7). For the example data in Table 6, the calculated mean percent live tissue is 88%.

Table 7. Values (%) for the central point of each estimated live tissue class.

Live Tissue Class	Dead	1-25%	26-50%	51-75%	76-99%	100%
Central point	0	12.5	40	65	87	100

Bonus Reporting: Combined with Universal Metrics #1 and #2, cover of restored coral (in % for percent cover or m^2 for area) can be roughly estimated. For the initial monitoring event, this can be estimated by using only Universal Metric #1 and #2, as the corals are likely to be 100% alive. Because the data collected for Universal Metric #2 and #3 are not paired (coral size data and percent cover are not reported together), direct correlation between size and percent live tissue cannot be made. For example, our data does not inform us of the percent living of a 10 cm colony, only the number of colonies that are between 5–10 cm and the number of colonies with 76–99% living tissue, which may or may not be the same colonies. Therefore, percent cover reported here is a rough estimate based on means, and an explanation of this process should be given when reporting these data.

<u>Cover Estimate Example</u>: Using the area from Figure 15 (1,132 m^2) and the example size and percent live tissue distribution data below (Table 8 and Table 9), cover can be estimated by using the following equation:

$$Percent\ Cover = \frac{\left(Total\ Cover / \ 10{,}000 \frac{cm^2}{m^2}\right) \times Mean\ Percent\ Live}{Area\ of\ Ecological\ Footprint}$$

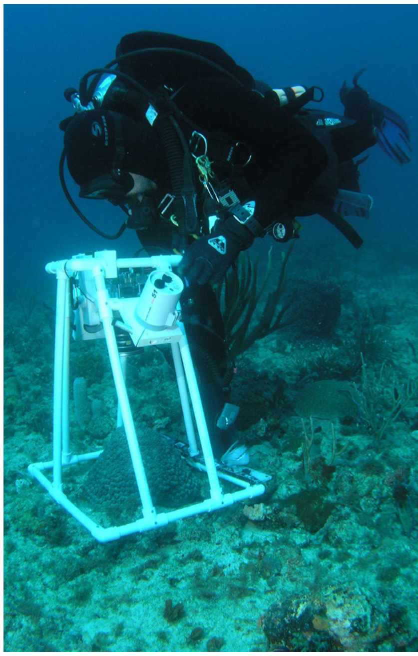
The total cover, in area of restored coral (this estimate includes dead skeleton) for the example data in Table 8 is 92,764 cm^2 (9.27 m^2). The mean percent live tissue per restored coral for the example data in Table 9 is 88%. Therefore, the estimate of percent cover of live tissue is 0.8%.

Table 8. Example data collected for coral size-frequency distribution.

Species / Size Class (cm)	<5	5-10	11-20	21-30	31-40	41-50	51-75	76-100	>100
Acropora cervicornis	3	10	16	15	40	5	1	6	100, 100, 110

Table 9. Example data collected for coral estimated live tissue.

Species/Live Tissue Class	Dead	1-25%	26-50%	51-75%	76-99%	100%
Acropora cervicornis	2	3	5	6	35	50



Nova Southeastern University CRRAM Lab

Sampling Frequency

Minimally, live tissue of restored corals should be estimated at every restoration site within two weeks and within three months following an outplanting event (immediate and initial site survey; Figure 5) which will identify if any problems exist with outplanting techniques or site characteristics that were missed during the pre-outplanting survey that may be negatively affecting the success of a restoration program. Then forward, annual estimates of live tissue are recommended to capture restored coral growth and health. It is highly recommended that this data collection occur over the long-term, for at least five years. In addition, sampling following a disturbance will provide data on restoration disturbance impacts such as change in the health of corals.

Performance Criteria

The mean percent live tissue per colony should show minimal decrease, and the number of restored corals with partial mortality should show minimal increase over time for all species. It is inevitable that coral loss (whole coral or partial coral) will occur, however if the general trend in live tissue or the distribution of coral partial mortality is towards an increase in mortality, the restoration site should be evaluated and adaptive management strategies should be evaluated to determine and reduce the cause of the loss of live tissue.

Evaluation Tool Criteria Alignment (Appendix 2): Universal Metric #3 aligns with three criteria:

1. Restored corals maintain a high percentage of live tissue per coral. If the mean live tissue per colony is greater than 80%, a project will receive a score of 1 (Evaluation Tool Outplanting Criteria #13).
2. Restored corals exhibit high coral survivorship/ abundance during years 2–5. If annual outplant survival is >65% or if >65% of colonies are present at the site a project will receive a score of 1 (Evaluation Tool Outplanting Criteria #23).
3. Outplants exhibit high coral survivorship/abundance over 5 years post-outplanting. If annual survival is >50% or if >50% of the colonies are present at the site programs will receive a score of 1 (Evaluation Tool Outplanting Criteria #24).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).

Reef Renewal Bonaire

Universal Metric #4:

Genetic and Genotypic Diversity

Genetic diversity can be defined on several levels in organisms that have sexual and asexual reproductive modes, such as corals and plants. Genotypic diversity refers to the number of genets in a population as defined via multilocus genotyping. Genets are the result of sexual reproduction. Each genet may consist of many ramets ("colonies") that were the result of asexual processes, such as fragmentation. Genetic diversity (or gene diversity) refers to the amount of variation on the level of individual genes in a population. Genetic diversity may be expressed as heterozygosity or allelic richness. Traditionally, molecular markers (such as microsatellite loci) target non-coding regions of the genome to measure genetic diversity. The data then reflects demographic processes not subject to selection, thereby satisfying assumptions of standard population genetic models that yield measures of the scale of dispersal (Baums et al., 2019).

Genotypic Diversity is a measurement of the number of unique genotypes (genets) that are used for restoration by species. **This is an important metric to gauge the potential for future species genetic diversity through sexual reproduction and to evaluate a program's contribution to genetic and genotypic diversity.** This metric can also be used as an intra-program metric to ensure genetic and genotypic diversity across and amongst restoration sites. Further, genetic diversity is an important driver of long-term facilitation of species recovery and conservation (Baums, 2008; Drury et al., 2017b; Baums et al., 2019).

Genet herein is broadly defined as the collection of ramets that represent a unique coral genotype. It is recognized that not all restoration programs have the resources to collect and have samples processed for genetic analysis therefore geographic distance can also be used to designate putative genets. Based on literature, we suggest a conservative distance between donor colonies to be at least 100 m to increase the likelihood of unique genets (Baums et al., 2005; Foster et al., 2007; Underwood et al., 2007). Ensuring some measure of distance between donor colonies will provide the best possibility of genetic diversity between sampled colonies especially when dealing with brooding versus broadcasting species, this may result in needing to sample at multiple reefs.

Genotypic Diversity is measured by recording the number and quantity of genotypes (genets) used per species at a restoration site. When possible, it is suggested that a minimum of 5 unique genets per species be planted at each restoration site (Baums, 2008; Drury et al., 2017b; Baums et al., 2019).

Within coral nurseries, it is suggested that at least 20 distinct genotypes are propagated and used for outplanting to maintain high levels of genetic diversity that originate from the standing stock (Baums, 2008; Shearer et al., 2009; Drury et al., 2017b; Baums et al., 2019). In addition, it is best to propagate genets with one or more phenotypic trait that may prove valuable in the future, such as low partial mortality, high lesion healing rate, rapid growth rate, and resilience or resistance to bleaching and/or infectious disease (Baums et al., 2019). However, effort should also be reserved for propagating underperforming genets because some genotypes may harbor genetic variants with unknown value. For outplanting, Baums et al. (2019) suggests clusters or groups of four to six genets to enable successful fertilization upon maturation. Additionally, it is suggested to outplant at least 10 genotypes of gonochoric species (e.g., *Dendrogyra cylindrus*, *Montastraea cavernosa*, and *Siderastrea* species; see Coral Population Enhancement Metric #1.2) to facilitate matching numbers of males and females at a site when possible (Baums et al., 2019). The goal is to mix and match as many genets as possible within outplanting strategies to maximize genetic diversity, which is the basis of adaptive resilience (Hermisson and Pennings, 2005; Baums, 2008; Whiteley et al., 2015). It is recognized that some genotypes may die out at a restoration site, either through bleaching or disease susceptibility, slow growth or due to non-genetic specific mortality (breakage, predation, etc.).

Outplanting more than the minimum number of suggested genotypes over time should help maintain at least 4–6 genets at a site (Baums et al., 2019). If the number of surviving genets at a restoration site drops below the desired minimum, adaptive strategies such as outplanting additional genotypes and/or resolving the cause of mortality should be employed. Most monitoring methods listed within this Guide are structured to avoid colony fate track monitoring, but monitoring genetic-based success may be of interest to some, if not most, restoration practitioners. Therefore, monitoring strategies to document the success of individual genotypes should be determined as part of additional research goals (see Restoration Goal-Based Performance Metrics Goal 5: Research).

Required Units: Number of genets propagated or outplanted by species, note the method used to determine coral genotype.

Possible Methods

The following are methods that could be used to determine the genotype of your donor and/or nursery colonies. These suggestions are not exhaustive, but are to be used as examples or guidance. Additional details on each of these techniques can be found in the literature cited and the CRC Genetics Working Group review in Ecological Applications (Baums et al., 2019). Whichever technique is chosen, it is important to identify the method used when reporting your results.

Micro-satellites

Low cost, frequently used method in conservation genetics (Puckett, 2017). Evaluates the number of tandem repeats across loci of a coral sample. High heterozygosity allows for accurate assignment of ramets to genets (Baums et al., 2005; 2010; 2012; 2019). Loci are species-specific and may have to be developed de novo. While highly repeatable within a lab, comparison across labs need to be carefully calibrated.

Zack Gold

SNPchip Genotyping (Single Nucleotide Polymorphisms)

A cost-effective approach to genotyping if the genus or ideally the species' SNPMarkers are already identified, such as Acroporids and Orbicellids (Drury et al., 2016; Prada et al., 2016; Devlin-Durante and Baums, 2017; Kitchen et al., 2019). However, if these are not identified, this technique can be costly, as the SNP (single nucleotide polymorphisms) needs to be identified first. SNPchip genotyping is a good option for those programs that do not have easy access to laboratory space or a bioinformatician. Off-the-shelf products such as micro-arrays and microfluidics-based SNP approaches can be purchased to complete these analyses. Data collected through SNPchip genotyping can be reported in the CRC Genetics Working Group database (Appendix 3).

Reduced-Tag-Representation-2bRAD

If the SNPchip is not yet developed for the coral being used for restoration, an alternative cost-efficient technique is reduced-tag-representation-2bRAD (RTR-2bRAD; Altshuler et al., 2000). This technique is particularly useful as it ensures consistency across samples and standardization amongst laboratories. Furthermore, samples that may have degraded DNA can be processed using RTR-2bRAD. However, for this technique practitioners are still responsible for isolating DNA from the corals and analyzing resulting data.

Geographic Distance

The geographic distance between donor colonies can be measured by collecting a GPS point of each of the donor colonies and using mapping software such as Google Earth®, ArcGIS®, or QGIS to determine the distance between colonies. This distance can be used as a proxy for genetic diversity until genetic testing can be completed. Until testing is completed, each donor colony should be treated and tracked as a separate genotype. It is recommended that donor colonies are at least 100 m apart.

Reporting

Genetic diversity should be reported as the total number of unique (putative) genets per species used for restoration at each restoration site. Data collected should be reported in program-specific databases as well as uploaded into the CRC Coral Restoration Database (Appendix 1), which can be found online (Appendix 3).

Sampling Frequency

Genetic diversity of a restoration site should be collected during the time of the initial restoration project and each time new corals/genets are added to the restoration site.

Performance Criteria

Genetic diversity should be maintained or increased at each restoration site. The overall goal should be at least five unique genets (10 unique genets for gonochoric species) added to each restoration site per species used in the restoration project.

Evaluation Tool Criteria Alignment (Appendix 2): Universal Metric #4 aligns with one criterion:

> Outplants contain a high degree of potential/possible genotypic diversity per restoration site (or if genetic info not available, assumed different genotypes based on physical separation of collection sites). If over five genotypes (10 for gonochoric species) per restored species are outplanted per restoration site, a program will receive a score of 1 (Evaluation Tool Outplanting Criteria #8).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).

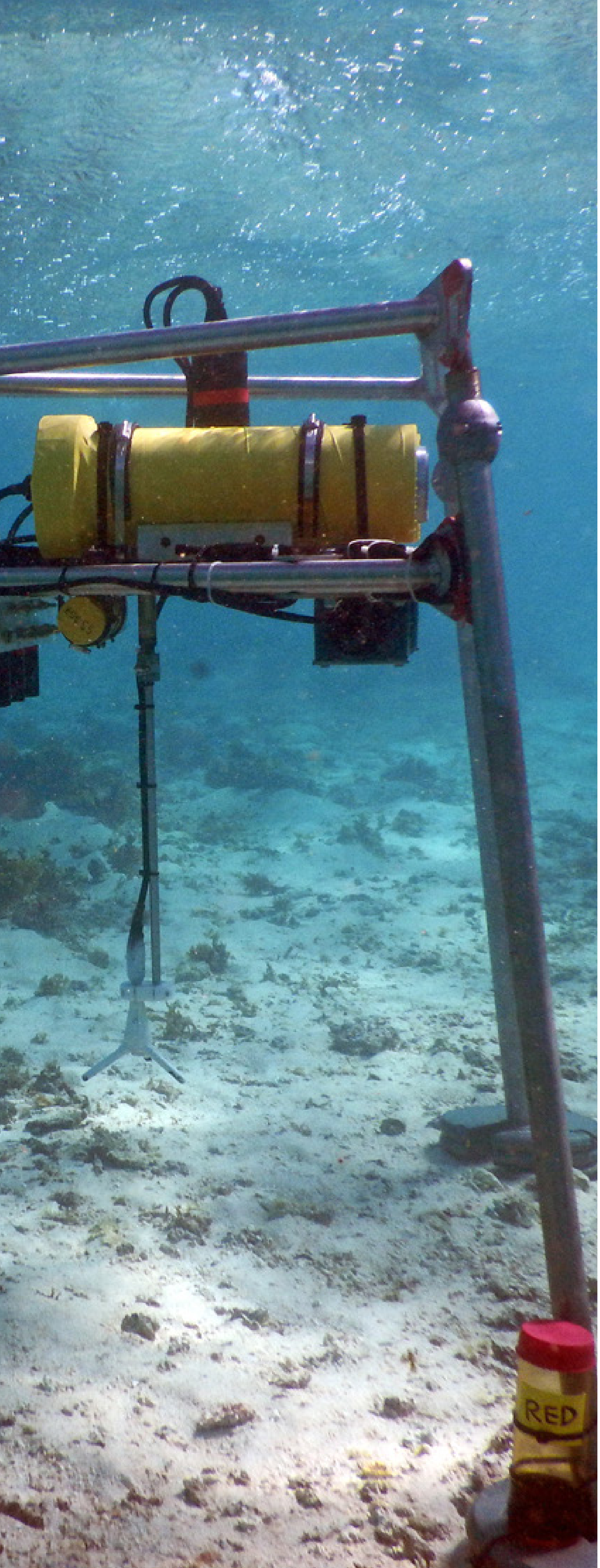
Tiffany Boisvert/FWC

Summary of Universal Metrics

Table 10 provides a brief summary of the Universal Metrics and their associated links to the CRC Restoration Database and Evaluation Tool.

Table 10. Overview and alignment of Universal Metrics to CRC Monitoring Working Group products. RRAD= Restored Reef Areal Dimension.

Universal Metric	Description	Methods	CRC Restoration Database Reporting	Data Outcomes	Evaluation Tool Criteria Alignment
Universal Metric #1: Landscape/Reef-level Metrics: Restored Reef Areal Dimension	Area where corals were planted and extent of reef impacted	Tracing Length/ Width Mapping Mosaics	Report RRAD cumulative area (m^2) per restoration site	Change in RRAD over time	Measure RRAD at initial outplanting event No net decrease in RRAD from initial
Universal Metric #2: Population-level Metrics	Measurement of the distribution of size classes of restored corals	Ecological Footprint Survey Mosaics	Number of colonies per size class Identify if subset sampling was used	Survival Mean coral size Percent per size class Density	Positive net change in coral size Survivorship >80% in first year
Universal Metric #3: Colony-level Metrics	Estimate of the amount of live tissue on restored corals	Ecological Footprint Survey Mosaics Fate Tracking	Number of corals in each class of live tissue Identify if subset sampling was used	Survival Distribution of tissue classes Prevalence of partial mortality Mean percent live tissue Percent Cover	Survival/abundance: >80% in first year >65% years 2-5 >50% >5 years Maintain >80% live tissue per coral
Universal Metric #4: Genetic and Genotypic Diversity	Reporting of the number of unique genotypes used for restoration	Microsatellite SNPchip Genotyping Reduced-Tag-Representation Geographic Distance	Total number of unique (putative) genets per species Identify method used to determine genotype	Genetic diversity of restored corals	At least five unique genotypes per species (10 for gonochoric species) are outplanted per restoration site
Universal Environmental Metric: Water Temperature	Reporting of the water temperature of restoration sites	In situ Logger Open Access Data Computer/ Thermometer	Maximum, minimum, and monthly mean (°C) per restoration or representative site	Annual temperature minimum and maximum	Record or obtain temperature records for each restoration site or representative sites



Curt Storlazzi/US Geological Survey (USGS)

Chapter 6

Universal Environmental Metric

Universal Environmental Metric: Water Temperature

Coral reefs are sensitive to the environment in which they are found and persist. Important to the existence, conservation, and management of coral reefs is water quality supportive of coral growth and a healthy community. Although there is a long list of environmental data that would need to be collected to fully understand the effect of water quality on coral restoration, most are out of the scope of many restoration programs financially and physically (see Community and Habitat Enhancement Metric #2.4 for guidance on collecting additional environmental data). Therefore, water temperature was identified as the universal environmental metric for coral restoration because it is easily obtained, affordable, and comparable across various scales. In addition, **water temperature is one of the key environmental metrics that can assist in defining coral growth, disease, and bleaching.**

Required Units: Monthly minimum, maximum, and mean (°C), report collection method.

Possible Methods

In situ Logger

The most accurate method for collecting water temperature is to deploy temperature loggers close to the seafloor in an open/unobstructed area at each restoration site or a representative subset of your program's restoration sites (Bahr et al., 2016). Most loggers can be programmed to record temperatures at chosen intervals, such as every 1–2 hours. These data points can then be downloaded using the software provided with the logger from which daily mean temperature can be calculated. The length of time a logger can be deployed will be based on the specifications of each logger. It is best practice to check the logger each time you are at the restoration site to ensure the logger is not damaged and is logging (some loggers have indicator lights to inform the user if there is an error). In addition, changing the logger at least annually will minimize the chance of lost data if the logger had malfunctioned during the period it was deployed. Furthermore, if it is feasible for your program, deploying multiple loggers at a site or within a similar habitat will also decrease the chances of missed data if one logger were to fail.

If your program does not have access to temperature logging equipment, check with fellow researchers working in your area to see if they have instrumentation deployed in similar locations as your restoration projects and would be willing to coordinate with you and/or share their data.

Example instrumentation: Onset data loggers, conductivity, temperature and depth (CTD), Yellow Springs Instrument (YSI™).

Open Access Data Sources

Sea surface temperature data may be available in your area from open access resources or environmental monitoring groups such as water management divisions, ocean monitoring buoys, environmental monitoring groups, and predictive models.

Dive Computer/Thermometer

Divers can record the temperature from their dive computer each time that the restoration site is visited. If a dive computer is not available, a glass thermometer (laboratory or pool thermometer) can also be used to record the bottom temperature during site visits.

Reporting

Water temperature should be reported as a maximum, minimum, and monthly mean (°C) at each restoration site or a set of sites representative of the conditions of your restoration sites. Collected data should be reported in program specific databases as well as uploaded into the CRC Coral Restoration Database (Appendix 1), which can be found online (Appendix 3).

Sampling Frequency

Ideally, temperature would be recorded constantly at representative restoration sites to provide daily averages. If the equipment and resources are not available for this frequency, then it is recommended that frequent (seasonal to monthly) temperature points are taken to provide representative changes and ranges in water temperatures.

Performance Criteria

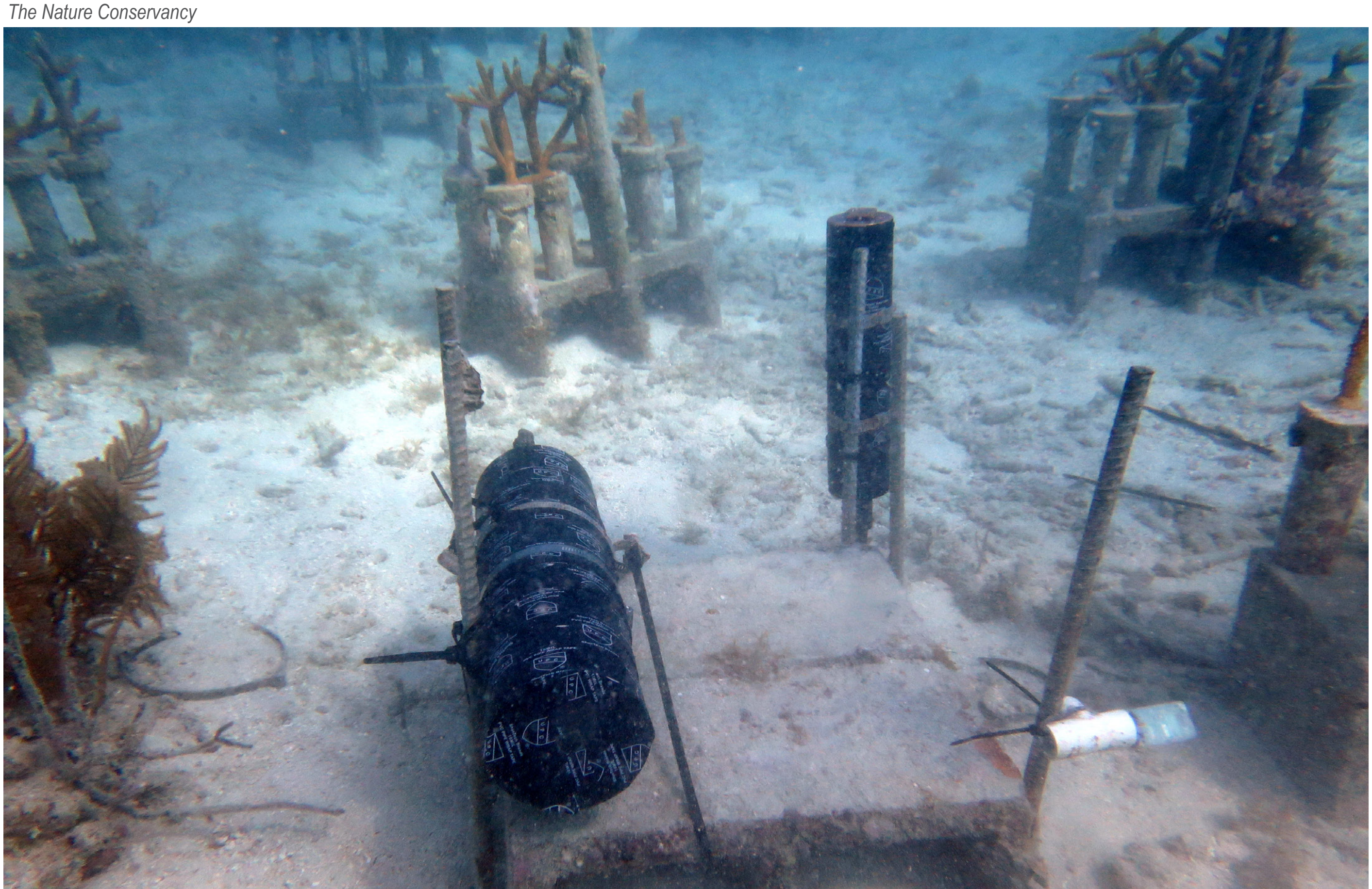
Water temperatures at restoration sites should follow the typical range of water temperatures for areas of similar habitat in that region.

Evaluation Tool Criteria Alignment (Appendix 2): Universal Environmental Metric aligns with one criterion:

> Environmental parameters are measured at outplant sites to demonstrate that the site does not experience large changes in parameters over short periods of time (e.g., minimum measurement of water temperature required, but may also include light, current, sedimentation, turbidity). If environmental parameters (minimum measurement of water temperature required) are measured/monitored a program will receive a score of 1 (Evaluation Tool Outplanting Criteria #4).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).

The Nature Conservancy



Coral Restoration Foundation

Chapter 7

Ecological (Ecosystem) Restoration Goal-Based Performance Metrics

Coral reef restoration, at the ecosystem level, is the process of regaining ecological structure and functionality to coral reefs. Prior to performing ecosystem restoration, a target (i.e., outcome) ecological state or function must be defined based on historical or current reference systems. Ecosystem restoration goes beyond just planting corals on a reef, it involves improving the entire reef community to support long-term ecosystem health and sustainability (Epstein et al., 2003). Such ecosystem restoration may include, but is not limited to, activities such as restoring branching corals to create habitat to support higher fish and invertebrate communities, which may reduce macroalgae and promote coral recruitment. **Restoration of a coral reef ecosystem to meet the goal of Ecological (Ecosystem) Restoration requires success in two objectives: 1) Coral Population Enhancement and 2) Community and Habitat Enhancement.** Each objective includes four metrics and the necessary associated methods to accomplish the objective (Table 11). The objectives and metrics described below are provided as guidance, to provoke thought, assist in restoration program development, and designed to monitor the interaction between the assemblage of outplanted corals and the benthic community of which they will become a part.

These suggestions are not exhaustive and do not guarantee restoration results, but by providing guidance and methods for data collection, we hope to increase the comparability of data amongst practitioners and further identify key factors in Ecological Restoration and define restoration success. The key parameters that enable describing and tracking of community structure include (Done, 1995; Rinkevich, 1995; Thayer et al., 2003; Ruiz-Jaen and Aide, 2005):

Measures of the spatial extent and distribution of each species relative to the others within a defined area can provide the basis for demographic analysis, and add layering and richness to gross measures of live coral coverage—*Universal Metrics #1 and #2 and Coral Population Enhancement Metric #1.1*.

Size distribution of each species can provide an indication of the populations' potential contribution to sexual reproduction and longevity—*Universal Metric #2 and Coral Population Enhancement Metric #1.2.*

Table 11. Comparison of methods proposed for Ecological Restoration monitoring including advantages (✓) and limitations (○) of each method. The symbol (–) in data type, means the method is not suitable to collect that type of data. Blank cells for factors indicate there is no advantage or limitation for that method. Not included in this table are methods for measuring coral reproduction and environmental parameters – see those specific metrics below for methods.

		Method								
		Line Intercept	Point Intercept	Belt	Quadrat / Plot / Area Survey	Roving Diver	Video/Photo Transect	Mosaic/Large Area Imaging	Photoquadrat	Tagging Colonies
Data Type	Percent Cover	✓	✓	✓	✓	–	✓	✓	✓	–
	Area	–	–	✓	✓	–	✓	✓	✓	–
	Abundance	✓	–	✓	✓	✓	✓	✓	✓	–
	Demographics	✓	–	✓	✓	✓	✓	✓	✓	✓
	Complexity	–	✓	–	–	–	✓	✓	–	–
	Health/ Condition	–	–	✓	✓	✓	✓	✓	✓	✓
	Motile Organisms	–	–	✓	✓	✓	✓	–	–	–
Factors	Area Covered (transect/replicate)	○	○	✓	✓	✓	✓	✓	○	○
	Area Covered (Spatially)	○	○	○*	✓	✓	○*	✓	○*	○*
	Fine Scale Data	○	○	✓	✓	○			✓	✓
	Whole Colony	○	○	✓	✓	✓	✓	✓	✓	✓
	Capture Restoration Design	○	○	○	✓–	✓	✓+	✓	○	✓
	Suitable for Transient Species	○	○	○	✓	✓	✓+	✓	○	○
	Cost/Equip. Needs	✓	✓	✓	✓	✓	○	○	○	○
	Speed	✓	✓	○	○	✓	✓++	✓++	✓++	○
	Permanent Record	○	○	○	○	○	✓	✓	✓	
	Expertise Required in situ	○	○	○	○	○				○
	Expertise Required ex situ						○	○	○	○

* unless replicate sampling is used; – area can be made to size of restoration; + use of mosaics or large area coverage; ++ time consuming for ex situ processing.

Species richness and evenness, measured as the number of species in a study plot (*S*) and the evenness of their relative abundances (*J* or *J'*)—*Universal Metrics #2 and #3 and Coral Population Enhancement Metric #1.4.*

Counts and size/age distributions of key motile associates of sessile benthos can provide a measure of potential improved habitat and can include visual censuses of fishes, echinoderms, crustaceans, mollusks, and other motile organisms—*Community and Habitat Enhancement Metric #2.1 and #2.2.*

Measures of species interactions can provide information on coral condition and survivorship, which relates to the potential overall success of outplanting to ecosystem success. Contact interactions (i.e., where other organisms and corals come into contact with each other), as well as predation by motile organisms, disease, and physical trauma, can be described by observing patterns of morbidity and mortality, including those associated with negative and positive contacts with neighboring sessile organisms (e.g., overgrowth, predation, amensalism, commensalism, stand-off)—*Coral Population Enhancement Metric #1.3, #1.5, and #2.4*.

Nova Southeastern University CRRAM Lab

Benthic communities change constantly over time, as the organisms that carpet the benthos and create biogenic structure, grow, reproduce, and die. Appreciation of benthic community dynamics requires repeated sampling of study plots through time.

Objective 1: Coral Population Enhancement

Coral population enhancement is the act of adding or stabilizing corals on a reef to preserve or improve ecological function, genetic diversity, reef health, and long-term sustainability. In order to meet the restoration objective Coral Population Enhancement the following metrics should be considered when developing a monitoring plan for a program:

1. Abundance and Cover
2. Reproductive Capacity or Maturity
3. Coral Health
4. Species Richness and Diversity
5. Indirect Seeding of Sexual Recruits

Coral Abundance, Cover, and Diversity are part of the Universal Metrics for Coral Restoration described in Chapter 5, but are also included here to provide more details and the importance of these metrics specifically related to the objective Coral Population Enhancement.

Coral Population Enhancement Metric #1.1: Coral Abundance & Cover

Tracking the abundance or percent cover of the species used for restoration allows the evaluation of the overall success and progress of Coral Population Enhancement. **Abundance and cover provide an indication of colony growth, population spreading, and survivorship.** Successful programs should either maintain or show an increase in coral abundance and cover following population enhancement activities as previously described in Universal Metrics #2 and #3.

Abundance is the count of the number of individual corals used for restoration. This count should be completed separately for each species used for population enhancement. Prior to any restoration, at a minimum, baseline data should be collected on the presence and abundance of existing colonies at the site of the species that will be used for restoration. Further guidance on what should be included in a pre-restoration survey can be found in the Site Selection chapter of the Guide to Field-Based Coral Reef Restoration (Goergen et al., in review). Collection of data prior to restoration is imperative for describing the impacts and success of population enhancement and defining future abundance and cover measurements (see Chapter 3).

Percent cover of live tissue of restored species at a restoration site is also a valuable metric for evaluating the success of Coral Population Enhancement. Cover, defined as the percentage of space occupied by a species, a group of species, or habitat type, is the most common metric used for tracking trends in coral reef status (Connell et al., 1997; Gardner et al., 2003; Jackson et al., 2014; Edmunds, 2015) and, therefore, can be a very comparable metric for restoration monitoring of some species. However, for many population enhancement programs, cover may be challenging to define for reasons that include: 1) at the time of restoration, coral colonies are often small and sparsely spaced, so effort needs to be high to ensure representation, and 2) defining the area of restoration is historically uncommon, precluding the quantification of cover within the restoration area. Note that each of the common survey methods for cover has different biases; therefore a change in methodology mid-study should include calibration between methods (e.g., Vallès et al., 2019).

Fragments of Hope

Possible Methods

The following are methods that could be used to collect abundance and percent cover data. These suggestions are not exhaustive, but are to be used as examples or guidance. The specific method that is used during a program's monitoring should be identified and described when reporting data.

Details describing the first of two methods to estimate abundance and cover are found under Universal Metric #2:

Ecological Footprint Survey

Conducting surveys for species abundance and cover within the RRAD will provide focused community data for the area within which restored corals are being outplanted. Abundance and cover within the RRAD is valuable as it provides a standardized project size and area of restored reef to evaluate changes over time and gauge the overall impact and success of a restoration project. Example datasheets and additional details of the survey method and area can be found in Universal Metrics #1–3.

Mosaics

Coral abundance and cover can be collected from photomosaics. The result of the mosaic process is a high-resolution photographic archive of all benthic organisms within the area of interest that can be used to identify the number of colonies per species, and even the number of colonies per species per size class at the time of the mosaic survey (methods for obtaining a mosaic are above in Universal Metric #1 and Appendix 4). Coral colonies and changes in community composition can be followed through time based on their geographic location within the mosaic image. For example methods of obtaining coral abundance and cover data from a mosaic, see Appendix 4. Examples from the literature such as Burns et al. (2015); Gintert et al. (2018); and Fukunaga et al. (2019) outline use of this method in depth.

Additionally, the following methods could also be used to describe the abundance and cover of restored corals:

Transects

There are numerous transect methodologies, such as line or point intercept and belt transects, that may be used to describe the abundance and percent cover of restored corals (Rogers et al., 2001; Thayer et al., 2003; Hill and Wilkinson, 2004). Transects can be placed at random, strategically placed, and/or permanent depending on the type of data desired (see Chapter 3). Keep in mind that if the objective of your monitoring is to describe changes in restored corals or the success of restored corals over time, then the placement of transects for monitoring must be within an area where restored corals are located (i.e., transects must include restored corals, therefore random distribution of transects may not be the best choice).

In addition to divers utilizing transects for in-water surveys, belt transects can also be surveyed using photos or video and analyzed ex situ using photo-processing software, such as Coral Point Count with Excel Extension (CPCe), Point Count 99, ImageJ, or Coralnet (Kohler and Gill, 2006; Beijbom et al., 2015; Williams et al., 2019). The advantages to photo and video transects are that they are quick to collect in the field, and there will always be a permanent record of the transect to be referenced in the future.

Further, if the species used for restoration is a transient species (i.e., may dislodge or fragment and reattach readily), such as Acroporids, you may want to consider using large area surveys (Ecological Footprint Survey) instead of transects for tracking change in abundance.

Transects are the most commonly used method for measuring change in coral cover and abundance; they are cheap to set-up and require minimal equipment. Details of data collection techniques along a transect can be found from many of the long-term coral reef monitoring programs such as: Australian Institute of Marine Science (AIMS) Long-Term Coral Reef Monitoring Program (LTMP), Atlantic Gulf Rapid Reef Assessment (AGRRA), Coral Reef Evaluation and Monitoring Program (CREMP), Global Coral Reef Monitoring Network (GCRMN), Great Barrier Reef Marine Park Authority Marine Monitoring Program (MMP), and NOAA's National Coral Reef Monitoring Program (NCRMP).

Plots/Quadrats

To achieve higher site coverage for monitoring abundance or percent cover, plots and/or quadrats can be used. These differ from transects in that they can be rectangular or circular, various sizes, and spread out across a large area. Plots and quadrats may be the preferred method for restoration monitoring as the size of the monitored area or the number of plots/quadrats surveyed can be customized to adequately cover the restored area and/or the surrounding area depending on the species and question (See Chapter 3 – Determining Sample Size). Plots and quadrats can be further divided into smaller scales to include point intercept (i.e., a 25 cm^2 quadrat can be divided into 5 cm squares and point intercept can be determined at each 5 cm corner, Figure 23). For transient species, it is best practice to survey an area larger than

Fragments of Hope

the actual area restored in order to capture fragmentation and relocation within monitoring (Bowden-Kerby, 2001; Goergen and Gilliam, 2017).

Like for transects, photos and video can be used to survey plots or quadrats. Images can then be processed ex situ using photo-processing software to obtain cover and abundance data (Figure 24).

Following the fate of individual colonies can provide detailed demographic data (e.g., effects of bleaching, disease and predation, and growth), but can be a very time consuming method depending on the size of the restored area and number of corals to track (although subsetting can help reduce effort—see Chapter 3). In addition, tracking the fate of a coral requires the corals to be tagged, mapped, or mosaicked to ensure that the same individuals are being tracked over time (Rogers et al., 2001; Thayer et al., 2003; Hill and Wilkinson, 2004).

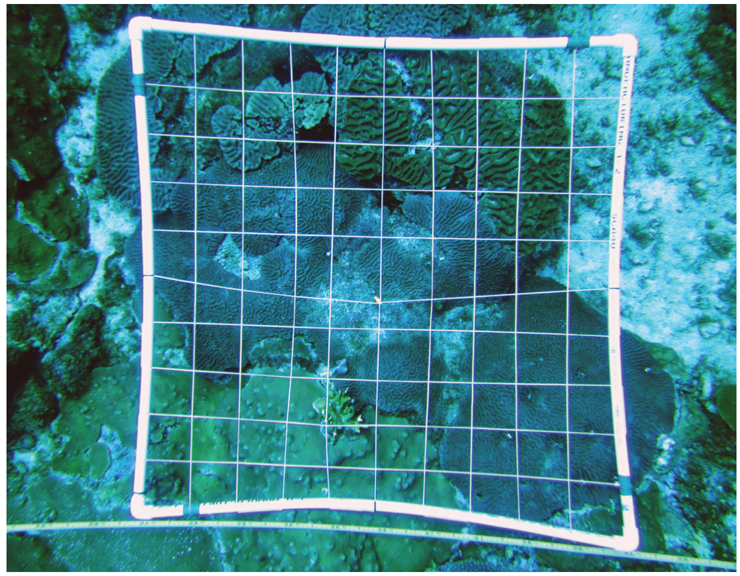


Figure 23. Example grid-quadrat used for in situ point intercept. Image credit: NOAA

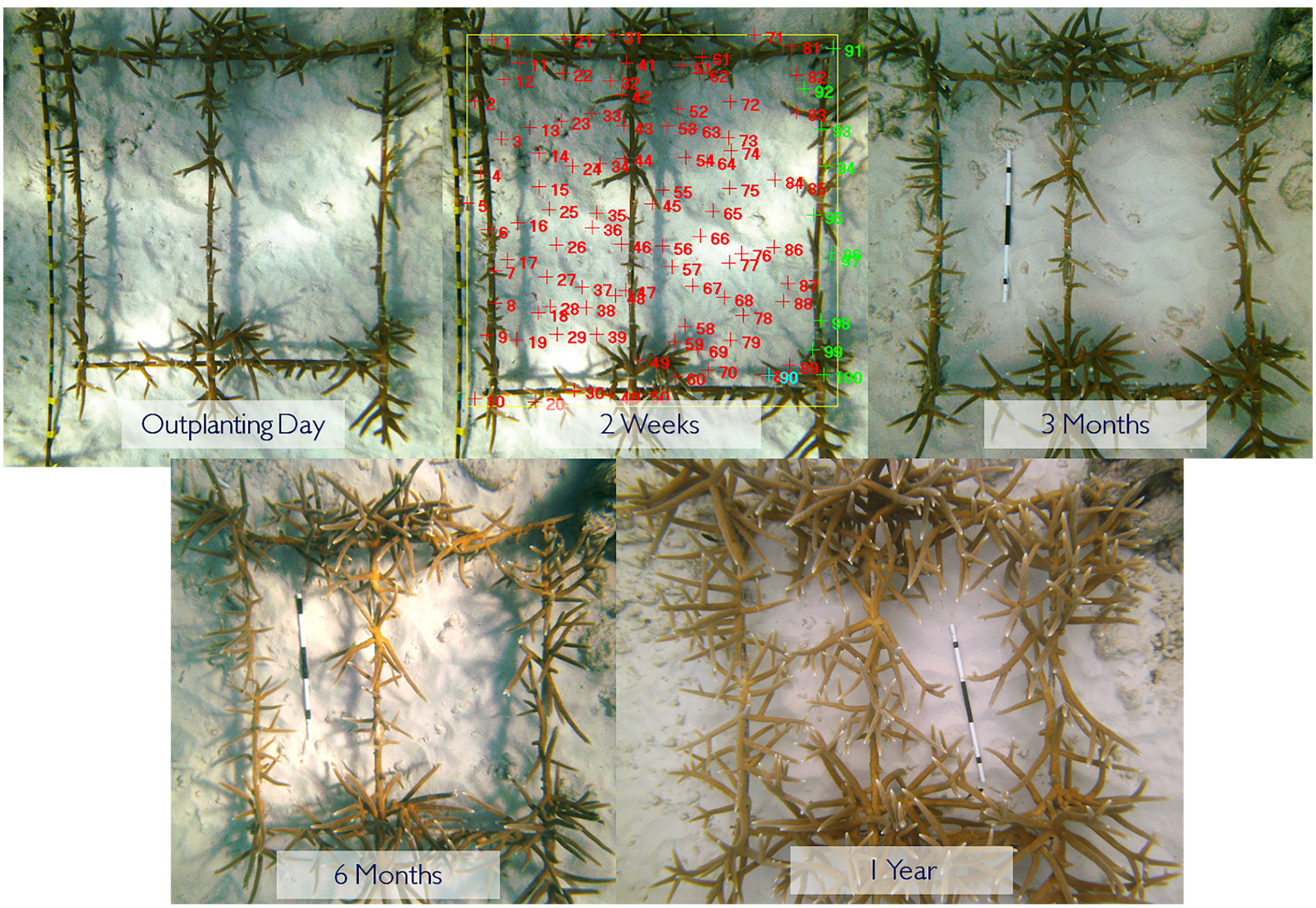


Figure 24. Example of using photo quadrats for monitoring outplanted *Acropora cervicornis*. Collected images were processed using Coral Point Count with Excel Extension (CPCe) to obtain change in cover over time. Image credit: Reef Renewal Bonaire.

What to consider for any method:

- The total survey area of the transects, plots or quadrats covered must be reported.
- Transect/Plot/Quadrat location should be the same during every monitoring event if this metric will be used to describe a change over time in cover or abundance of the same corals. Permanent markers/pins/stakes deployed to guide the placement of transect tapes or quadrat corners are helpful for ensuring repeatability.
- In order to capture the change in cover or abundance of restored corals, restored corals must be measured within the transects. This is an important consideration for random transects. If restored corals are not being captured, methods may need to be re-evaluated for effectiveness.
- Replication is necessary. Replicate surveys at each site may reduce the chance of missing restored corals. The transect survey area is limited to the area under or adjacent to the transect lines (depending on specific method); therefore, they need to be implemented within the restoration area.

Reporting

Coral Abundance should be reported as the total number of restored corals per site. Cover should be reported as the percent cover of the restored corals per site. All data should be reported by species at each site.

Percent cover of restored corals can be determined for photo transects, plots, or quadrats using the following equation. Where Total Points equals the total number of points in the area that you surveyed, which could be a quad, transect or plot depending on how data will be analyzed.

$$Percent\ cover = \frac{\sum Coral\ Points}{Total\ Points} \times 100$$

Using the data from Table 12 and the above equation, percent cover of restored corals for the images analyzed is 308 coral points / 660 total points x 100 = 46%.

Table 12. Example point count percent cover data. Data represent the number of points that were recorded as restored coral per image. For this example, 22 images (60 x 40 cm) were analyzed using 30 points per image.

8	15	13	12	30	25	4	5	17	30	25
5	3	6	23	26	14	0	25	12	4	6

If data are collected using in situ estimates of percent cover along a belt transect the following equation can be used to estimate the percent cover of restored coral.

$$Percent\ Cover = \frac{\sum Area\ of\ color\ per\ quad}{Total\ Area\ Surveyed} \times 100$$

Where the area of coral is first estimated using the following equation, where ***QA*** is the area of the quad and ***% cover of coral$_{q1}$*** is the estimate of percent coral cover per quadrat.

$$\sum Area\ of\ coral/\ quad = QA\ \times \%\ cover\ of\ coral_{q1} + \cdots + QA\ \times \%\ cover\ of\ coral_{qn}$$

Using the data from Table 13 and the above equations, percent cover of restored corals for the quadrats analyzed is 30%. The total area of coral is 4.89 m^2.

Table 13. Example belt transect percent cover data. Data represent percent cover of restored corals and were collected per quad, for a total of 22 quads (1 x 0.75 m).

5%	10%	25%	50%	80%	5%	6%	30%	25%	10%	90%
3%	2%	60%	25%	90%	5%	6%	15%	70%	30%	10%


Tom Moore/NOAA

Sampling Frequency

At minimum, monitoring Coral Abundance and Cover should be completed at every restoration site immediately following an outplanting event. During the initial survey, wild coral abundance and location within the Ecological Footprint should also be noted. Annual monitoring for abundance and cover is recommended to capture restored coral survival, growth, and movement. We highly recommend that monitoring events be continued on a long-term basis (*Evaluation Tool Outplanting Criteria #23 and #24*). In addition, monitoring after disturbance events (e.g., bleaching, disease, and hurricanes) will provide information on disturbance impacts such as coral loss and colony displacement.

Performance Criteria

The abundance and/or cover of restored corals should remain similar to the initial outplanting levels or, more importantly, increase over time. However, caution should be taken with this performance criterion, for an increase in abundance does not always correlate with success. An increase in abundance could also mean that individual colonies became multiple colonies through fragmentation or partial mortality. Qualitative and, if possible, quantitative descriptions of coral appearance and condition should accompany a dramatic change in cover or abundance; details on these notes and data can be found in Coral Population Enhancement Metric #1.3. A general shift towards a reduction in total abundance or cover should be evaluated, and adaptive management strategies should be implemented if appropriate.

Evaluation Tool Criteria Alignment (Appendix 2): Coral Population Enhancement Metric #1.1 aligns with two criteria:

6. Outplants (all species) display positive net change (increase in total linear extension [TLE], % cover, max diameter, % colonies in larger size classes) and/or no net change in abundance. If this goal is met, a program will receive a score of 1 (Evaluation Tool Outplanting Criteria #9).
7. Representative photos are taken prior to, after, and during each monitoring event to document changes to overall abundance, coral cover, and/or reef structure. If photos are collected, catalogued and maintained prior to outplanting, after outplanting, and during each monitoring event a program will receive a score of 1 (Evaluation Tool Outplanting Criteria #11).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).

Coral Population Enhancement Metric #1.2: Reproductive Maturity/Capacity

Coralium

Jennifer Stein

The ultimate goal of coral restoration is that restored coral populations become self-sustaining and contribute to the ecosystem through sexual reproduction and recruitment. **Reproductive capacity of corals is broadly defined as the potential to reproduce sexually.** It is an important metric to measure in restored coral populations/communities, as it will provide an indication of the corals' health, and their potential contribution to the broader ecosystem. This metric can be reported in various levels of detail, including the prevalence of corals that are spawning, the ratio of male versus females spawning at a site for gonochoric species, coral fecundity, etc. Such data can help make informed decisions about restoration design and species population management by answering questions such as:

- Which genets spawn in synchrony and should be outplanted in close proximity?
- Do restored populations spawn in synchrony with wild populations and thereby increase the genetic diversity within the natural pool of larvae?
- Is the health and therefore reproductive capacity of a given genet compromised when outplanted at more degraded sites in comparison to healthier sites?
- When is it best to fragment corals to avoid interrupting their gametogenic cycle (i.e., resorption of immature oocytes)?
- Can restored corals be used as broodstock (gamete/larval collection) for larval propagation efforts?
- Can a restored population be considered self-sustaining because it is expected to maintain itself via sexual recruitment?

If gametes released by restored corals are collected for larval rearing, questions pertaining to the variability in offspring fitness among genotypes can further be investigated.

The time at which outplanted corals will start sexually reproducing (spawning of gametes or release of larvae) varies among species and will foremost depend on their colony size and age, reproductive mode (Table 14), and the environmental conditions at the outplanting site. These factors, therefore, must be considered during the planning phase of a restoration effort, especially if one of the immediate goals of the project is to ensure the contribution of outplanted corals to the ecosystem via sexual reproduction. For example, relatively small outplants (<5 cm diameter) are unlikely to spawn or be reproductively mature within the first few years post-outplanting, whereas larger outplants (>10 cm diameter) or faster growing species may be reproductively mature within a year post-outplanting (Okubo et al., 2009; Nozawa and Lin, 2014). Furthermore, clipping and/or outplanting fragments during the earlier stages of the gametogenic cycle can cause them to redirect allocated energy from reproduction to growth/survival. Thus, the timing of clipping may result in the resorption of immature oocytes and ultimately in the reproductive failure of the outplanted population for that year (Okubo et al., 2007; Okubo et al., 2009).

In addition to the timing and size of fragment clipping and outplanting, several other factors must be considered when designing a coral outplanting program in order to maximize the reproductive capacity of a restored population. For instance, the genotypic diversity that is introduced at an outplanting site should be such that a minimum of five unique genotypes are represented for hermaphroditic species and a minimum of 10 genotypes for gonochoric species (Baums et al., 2019; See Universal Metric #4 and Evaluation Tool Outplanting Criteria #8). Further, different genets should be outplanted in close proximity (3–4 genets within

Table 14. Mode of reproduction and sexuality of Greater Caribbean scleractinian corals from Trnka and Moulding (2008) and Baird et al. (2009). * Listed as threatened under the U.S. Endangered Species Act. † Species may also be hermaphroditic (Neely et al., 2018)

Broadcast Spawning Species		Brooding Species	
Hermaphrodite	Gonochore	Hermaphrodite	Gonochore
*Acropora cervicornis**	*Dendrogyra cylindrus* *†	*Favia fragum*	*Agaricia agaricites*
*Acropora palmata**	*Dichocoenia stokesii*	*Madracis* spp.	*Agaricia humilis*
Acropora prolifera	*Meandrina meandrites*	*Manicina areolata*	*Agaricia fragilis*
Colpophyllia natans	*Montastraea cavernosa*	*Mycetophyllia ferox**	*Eusmilia fastigiata*
Diploria labyrinthiformis	*Oculina varicosa*	*Porites astreoides*	*Isophyllia sinuosa*
*Orbicella annularis**	*Siderastrea siderea*		*Porites porites*
*Orbicella faveolata**	*Solenastrea bournoni*		*Porites furcata*
*Orbicella franksi**	*Stephanocoenia intersepta*		*Siderastrea radians*
Pseudodiploria clivosa			
Pseudodiploria strigosa			

2 m of each other) to increase the likelihood of cross-fertilization (Baums et al., 2019). Finally, when outplanting gonochoric species, one needs to consider introducing an appropriate sex ratio (number of males versus females) at the site. Additional guidance on outplant designs can be found in the Guide to Field-Based Coral Reef Restoration (Appendix 3; Goergen et al., In Review).

Possible Methods

The following are methods that could be used to assess the reproductive capacity of restored corals. These methods are not exhaustive, and are rather presented as realistically/logistically feasible guidelines for restoration practitioners. Methods are listed in order of priority. Whichever technique is chosen, it is important to identify the method used when reporting data.

Spawning Observations

The ideal and least invasive way to determine if restored corals are reproductively active is to observe setting and release of gametes during annual spawning event(s). The timing of spawning will depend on the region and the species observed; most Greater Caribbean coral species spawn around the full moon of July–October (Table 15). Predicting spawning can be complex due to the large variability that exists among species, but also among regions due to differences in seasonal sea surface temperature (SST) regimes, lunar cycles, and sunset times. Environmental variables, such as storms and thermal anomalies, may also alter spawning times. The CRC's Larval Propagation Working Group, along with other experts in the field, have completed an extensive literature review, and compiled a large number of spawning observation data to generate yearly spawning predictions. An example is provided in Appendix 5. These predictions plus additional guidance on how to collect and archive data during observational surveys can be found on the Larval Propagation Working Group's webpage (Appendix 3).

Available tools include the following:

- Coral spawning prediction calendars for the southern Caribbean, the Mexican Caribbean, the Dominican Republic, and the northern Caribbean
- Guidelines to observe and monitor coral spawning
- Templates for data collection and archiving
- A Webinar on Coral Spawning Research and Restoration which contains an extensive section on spawning observations

The Coral Restoration Consortium's Larval Propagation Working Group also hosts bi-annual presentations on how to observe and monitor coral spawning, followed by a question and answer session. These presentations are open to everyone and are intended to guide practitioners across the Greater Caribbean region on how to record spawning observations. Information about these bi-annual presentations is available on the Coral Restoration Consortium's website (Appendix 3).

Because the timing of spawning varies among regions, it is imperative that spawning observations are scheduled based on local predictions. For some species, there may not be any previous records available for a given region. In that case, spawning observations should be scheduled based on predictions from the nearest region, but should be expanded to a wider time window. As such, it is recommended to begin the observations at least two days before the predicted day(s) and at least one hour before the predicted time of day. Observational surveys should last at least two days after the last spawning activity was observed. Once spawning of that species was observed consistently for 2–3 years in a row, yearly observations can be narrowed down to a shorter time window (one day before predicted day(s) and 30 min before predicted time). The number of days required for monitoring spawning activity varies by species, but typically spans over three to four days. During observations, data such as number of colonies observed per species and sex (if gonochoric), number of colonies that spawned, timing and duration of setting and spawning, as well as site related metadata should be reported for every observation attempt (see Appendix 5 for an example datasheet or the Larval Propagation Working Group website to download the datasheet template). All observation attempts during which no spawning activity was recorded should be reported along with positive observations.

Table 15. Predicted spawning month(s) of known northern Caribbean coral species compiled from 2019 spawning prediction guides from the Larval Propagation Working Group and Jordan (2018). Dark blue= most likely month for spawning, and light blue= possible spawning. Predicted times will change annually and regionally (e.g., northern versus southern Caribbean). Therefore, check the Larval Propagation Working Group website (Appendix 3) for the most up-to-date predictions for the region of interest.

	May	June	July	Aug	Sept	Oct	Nov
A. cervicornis			Light blue	Dark blue	Light blue		
A. palmata			Light blue	Dark blue	Light blue		
A. prolifera				Dark blue			
C. natans				Dark blue	Dark blue	Light blue	Light blue
D. cylindrus				Dark blue	Dark blue	Light blue	
D. labyrinthiformis	Light blue	Dark blue	Light blue	Dark blue	Light blue	Light blue	
D. stokesii					Light blue	Light blue	Light blue
E. fastigiata					Light blue	Light blue	
M. meandrites						Light blue	Light blue
M. cavernosa		Light blue	Light blue	Dark blue	Dark blue	Light blue	Light blue
O. annularis				Dark blue	Dark blue	Light blue	Light blue
O. faveolata				Dark blue	Dark blue	Light blue	Light blue
O. franksi				Dark blue	Dark blue	Light blue	Light blue
P. clivosa				Light blue	Light blue	Dark blue	
P. strigosa			Light blue	Dark blue	Dark blue	Light blue	
S. intersepta				Dark blue	Light blue	Light blue	
S. siderea			Light blue	Light blue	Dark blue	Dark blue	

For practitioners tracking the reproductive capacity of restored corals of known genotypes, spawning observations should ideally be reported for each genotype (see Appendix 5 for an example datasheet). These data will provide valuable insights about the variability in the timing of spawning within a species, allowing for better prediction of spawning times and for implementing better-informed restoration designs. For example, if certain genotypes are consistently spawning in synchrony, while others spawn at other times or not at all, it may then be a best practice to outplant the former at the same time and in close proximity to increase the likelihood of cross-fertilization.

To increase coverage/observe more sites, spawning nets built to collect gametes can be used on a few colonies (Figure 25). Nets can be carefully placed over corals before predicted spawning times and kept in place for a few hours over the duration of spawning that evening. Nets should be appropriately anchored, collected, and redeployed each night observations are made to prevent damage to the colonies. Collection nets used across several sites or within a site are a useful tool to assist with determining if particular genotypes are spawning, especially if there are multiple genotypes within one site. The use of spawning nets must be permitted, and local permitting regulations should be followed. It should be noted that gametes collected within the nets, unless crossed shortly after collection, might not be viable except for brooding coral species. Therefore, it is important to consider the number of colonies and the number of genotypes needed for monitoring as to not eliminate the broodstock for successful fertilization and recruitment to the reef site. If practitioners are planning to use the gametes collected within the nets for fertilization, nets will need to be checked within an hour of actual spawning as gamete viability decreases with time.

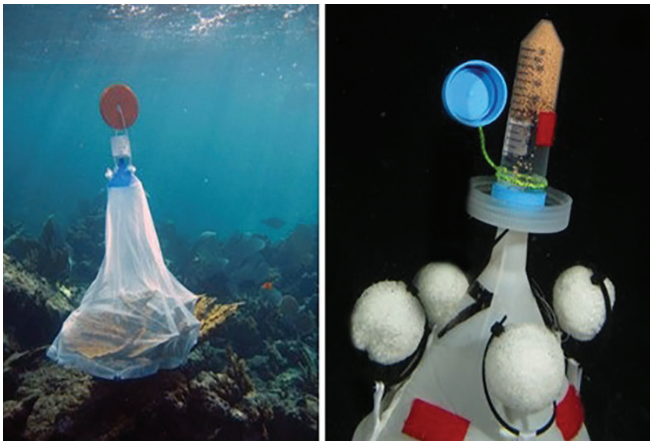


Figure 25. Example of coral spawning net (left; Credit: Christian Voolstra) and option for gamete collection container (right; Credit: Nova Southeastern University Coral Reef Restoration, Assessment, and Monitoring (CRRAM) Lab). Notice the net is not pulled too taut over the colony, but covers the central portion if possible.

Colony Size/Age

The reproductive maturity of a restored coral population/community can be estimated based on colony size and age (Montoya-Maya et al., 2014; Chamberland et al., 2016). The minimum size and age at reproductive maturity is variable among species and thus should be evaluated independently for each outplanted species. An overview of species' minimum size and age at reproductive maturity is available in Tables 16 and 17. Coral colony size (maximum diameter) can simply be measured by snorkelers or divers within the months prior to the predicted spawning event following the methods described in Universal Metric #2.

Liv Williamson

Table 16. Approximate minimum colony area, diameter, and age at reproductive maturity for select Caribbean broadcast spawning coral species. Method of observation includes Histology (H), Spawning Observation (S), and Laval Release (L). Table prepared by T Doblado-Speck, MJ Bennett, and VF Chamberland.

Species	Area (cm^2)	Diameter (cm)	Age (yr)	Method	n	Remarks on methods and interpretation	Source
Acropora cervicornis	-	≥20*	-	H	5-40	Tissue samples were collected biweekly for one year. Colonies with branches <20 cm in length were not gravid.	Szmant (1986)
Acropora palmata	-	30-40	4-8	S	9	Colonies ≥2-years-old were monitored yearly on predicted spawning nights. Two of nine 4-yr-old colonies spawned for the first time. Five of six 8-yr-old colonies spawned four years later.	Chamberland et al. (2016) Chamberland (pers. obs.)
Diploria labyrinthiformis	110	-	-	H	25	Colonies monitored were 100–250, 250–1000, 1000–4000 or >4000 cm^2. Tissue samples were collected monthly for one year and during the spawning season the following two years.	Weil and Vargas (2010)
Meandrina danae	7.8	-	-	H	28	Tissue samples were collected in the spawning season in two separate years. Colonies monitored were 2–37 cm^2.	Pinzon and Weil (2011)
Meandrina jacksoni	305	-	-	H	27	Tissue samples were collected in the spawning season in two separate years. Colonies monitored were 70–2384 cm^2.	Pinzon and Weil (2011)
Meandrina meandrites	263	-	-	H	30	Tissue samples were collected in the spawning season in two separate years. Colonies monitored were 169–2488 cm^2.	Pinzon and Weil (2011)
Montastraea cavernosa	20	-	-	H	63	Tissue samples were collected all year round. This study defined minimum reproductive size as the size of the smallest colony in the first bracket of 20 consecutive colonies of which ≥90% or more are gravid.	Soong (1993)
Orbicella annularis	≥300	-	-	H	5–40	Tissue samples were collected biweekly for one year. All colonies of this size or greater contained mature gonads; most colonies <100 cm^2 had limited or no gonad development.	Szmant (1986)
	>50	-	-	H	15	Colonies monitored were 1–49, 50–99, 100–199, and 200–300 or >300 cm^2. Tissue samples were collected two consecutive years one week before the expected spawning event.	Van Veghel and Kahmann (1994)
Orbicella faveolata	>100	-	-	H	15	Colonies monitored were 1–49, 50–99, 100–199, and 200–300 or >300 cm^2. Tissue samples were collected two consecutive years one week before the expected spawning event.	Van Veghel and Kahmann (1994)
Orbicella franksi	1-49	-	-	H	15	Colonies monitored were 1–49, 50–99, 100–199, and 200–300 or >300 cm^2. Tissue samples were collected two consecutive years one week before the expected spawning event.	Van Veghel and Kahmann (1994)
	170	-	-	H	5–40	Tissue samples were collected biweekly for one year.	Szmant (1991)
Pseudodiploria clivosa	120	-	-	H	79	Tissue samples were collected all year round. This study defined minimum reproductive size as the size of the smallest colony in the first bracket of 20 consecutive colonies of which ≥90% or more are gravid, hence 120 cm^2. Two of five colonies between 15–60 cm^2 were also gravid.	Soong (1993)
	>100	-	-	H	12	Colonies monitored were 100–250, 250–1000, 1000–4000 or >4000 cm^2. Tissue samples were collected monthly for one year and during the spawning season the following two years.	Weil and Vargas (2010)
	195	-	-	H	41	Tissue samples were collected all year round. This study defined minimum reproductive size as the size of the smallest colony in the first bracket of 20 consecutive colonies of which ≥90% or more are gravid, hence 195 cm^2. One of five colonies in the size range of 15–60 cm^2 were also gravid.	Soong (1993)
Pseudodiploria strigosa	>100	-	-	H	17	Colonies monitored belonged to the following size classes: 100–250, 250–1000, 1000–4000 and >4000 cm^2. Tissue samples were collected monthly for one year and during the spawning season the following two years.	Weil and Vargas (2010)
Siderastrea siderea	-	1.0 to 1.9 (females) 5.0 (males)	-	H	72	Colonies monitored were 1.0–1.9, 2.0–2.9, 3.0–3.9, 4.0–4.9, 5.0–5.9, 6.0–7.9 or 8.0–11.9 cm in diameter. Tissue samples were collected during the month of expected spawning. This study defined minimum reproductive size as the size at which colonies contained mature oocytes (Stage IV). 67% of monitored colonies were reproductive. One of seven colonies between 1.0–1.9 cm contained mature oocytes (Stage IV). Males were only present in size classes ≥5.0 cm. Percentage of males increased with size, from 11% in 5–5.9 cm to 54% in 12–53 cm.	Gelais et al. (2019)
	156	-	-	H	117	Tissue samples were collected all year round. This study defined minimum reproductive size as the size of the smallest colony in the first bracket of 20 consecutive colonies of which ≥90% or more are gravid, hence 156 cm^2.	Soong (1993)

No information is available for the following broadcast spawning species: *Acropora prolifera, Dendrogyra cylindrus, Dichocoenia stokesii,* and Colpophylia natans.

Table 17. Approximate minimum colony area, diameter, and age at reproductive maturity for select Caribbean brooding coral species. Method of observation includes Histology (H), Spawning Observation (S), and Laval Release (L). Table prepared by T Doblado-Speck, MJ Bennett, and VF Chamberland.

Species	Area (cm^2)	Diameter (cm)	Age (yr)	Method	n	Remarks on methods and interpretation	Source
Agaricia agaricites	-	10.8	-	L	91	26% of monitored colonies released larvae within one week of observation.	Van Moorsel et al. (1983)
Agaricia humilis	-	2.8	-	L	133	78% of monitored colonies released larvae within one week of observation.	Van Moorsel et al. (1983)
Favia fragum	-	-	1	L	147	1-yr-old F1 generation colonies released larvae in an exhibit aquarium system.	Petersen et al. (2007)
	2.3	-	-	H	129	Tissue samples were collected all year round. This study defined minimum reproductive size as the size of the smallest colony in the first bracket of 20 consecutive colonies of which ≥90% or more are gravid, hence 2.3 cm^2.	Soong (1993)
	-	1.0–1.5 (5 to 10 polyps)	-	H	5-10	Tissue samples were collected every 2–4 days for 30–35 day periods in the winter, spring, and summer. Smallest gravid colonies counted 5–10 polyps, hence approximately 1.0–1.5 cm diameter.	Szmant-Froelich et al. (1985)
Manicina areolata	-	1.5–2.0 (height)	2–3	L	126	Once passed the minimum reproductive size, fecundity did not increase with colony size.	Johnson (1992)
Mycetophyllia ferox	>100	-	-	H	NR	Tissue samples were collected biweekly for one year.	Szmant (1986)
Porites astreoides	70	-	-	L	146	All colonies monitored released larvae. The smallest colony monitored was 70 cm^2 and was gravid.	McGuire (1998)
	70	-	-	H	155	Tissue samples were collected all year round. This study defined minimum reproductive size as the size of the smallest colony in the first bracket of 20 consecutive colonies of which ≥90% or more are gravid, hence 70 cm^2.	Soong (1993)
Siderastrea radians	4	-	-	H	501	Tissue samples were collected all year round. This study defined minimum reproductive size as the size of the smallest colony in the first bracket of 20 consecutive colonies of which ≥90% or more are gravid, hence 4 cm^2.	Soong (1993)

No information is available for the following brooding species: *Eusmillia fastigiata*, *Isophyllia* spp., and *Porites porites*.

Using colony size is a simple and non-invasive method that provides the practitioner with an indication of the reproductive capacity of a restored coral population/community. **It should be noted that it is not a guarantee that corals that have reached a minimum reproductive size are fecund and will spawn**, as the energy a coral invests in reproduction will be influenced by environmental factors such as temperature anomalies, competition, diseases, storms, etc.

Colony age is a useful metric to estimate the reproductive capacity of a population/community that was restored using larval propagation since corals are of a known age. However, because larval propagation is a relatively new field, age at sexual maturity is unknown for most Caribbean species. Any novel observation of a species' age when sexual maturity was first observed should be reported to the CRC's Larval Propagation Working Group so this information can be compiled accordingly and made available to other practitioners.

Branch Breaking (species specific)

For some coral species, in particular Acroporid species, branches can be broken off to assess if a colony is hosting gametes within their tissues close to its expected spawning event (within 1 month). This method is useful for programs with limited capacity to observe spawning in the field, but wish to take their data beyond the assumptions made from coral size and age. An important caveat is that this method is not a guaranteed indicator of spawning. If gametes are found, it is a good sign that spawning is likely to occur; however, if gametes are not found it does not mean that spawning will not occur (i.e., not all surfaces of a colony, and not all colonies may be gravid). To increase chances of a positive result from branch breaking, the following suggestions should be followed: 1) sample from branches from the central portion of the colony to avoid typically sterile regions of a colony (i.e., edges and tips), 2) collect from a minimum of five colonies per species per site, and 3) if genotypes are known, collect from a minimum of 3 colonies per genotype. If a program includes large, potentially reproductive-sized corals within their nursery, it may be advantageous to first inspect colonies within nurseries. If nursery colonies are gravid, similar-sized outplants may be gravid as well, although this is not guaranteed; sampling of the outplants may be necessary. Strategic sampling of nursery corals can help limit the damage incurred to outplants. Samples can be inspected in situ for species known to have large gametes (Figure 26), or ex situ under a dissecting microscope. If more detailed data on egg size and fecundity is desired, it may be necessary to decalcify the samples prior to observations under the dissecting microscope (Soong, 1991; Smith and Hughes, 1999).

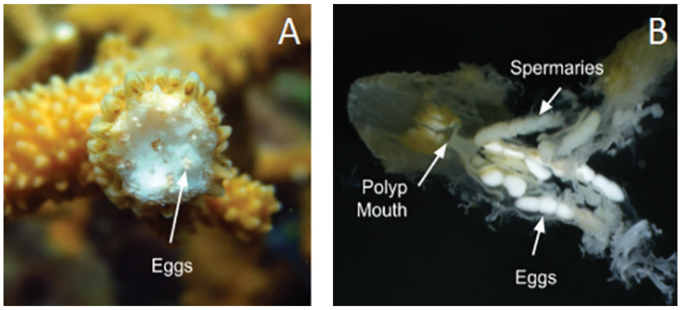


Figure 26. Example of (A) in situ branch breaking and (B) gross dissection observations of *Acropora cervicornis* gametes. Image credit: Liz Goergen

Histology

Coral samples can be collected and preserved for histological analysis to determine reproductive capacity. This method is most useful to determine the reproductive timing of a species or if more advanced studies of reproduction are desired. In addition, this method could be used if a program is not able to conduct spawning observations during the spawning season since samples can be taken 1–2 months prior to spawning. However, practitioners should be aware that this method can be invasive, costly, time consuming, and requires a considerable amount of materials as well as extensive training. Similar to the branch breaking method, collections should include a minimum of five colonies per species per site and, if working with known genotypes, a minimum of three colonies per genotype. Samples should be immediately fixed using Z-Fix™ (recommended fixative for histology). Once fixed, samples should be processed using known histological procedures (Szmant-Froelich et al., 1980; Szmant-Froelich, 1985; Glynn et al., 1991; Soong, 1991).

Coral spawning can be unpredictable and challenging. Just because spawning may not have been observed, it does not mean it did not nor will not happen. There are many factors that may influence spawning, such as the timing of the full moon (within the month and time of day), increasing water temperatures, and decreases in coral abundance, and the presence of bleaching or disease may affect the predictability of spawning (Fisch et al., 2019). In addition, corals used for restoration have likely been altered by fragmentation (possibly repeatedly), transportation, and relocation, all of which can cause stress in the coral and may affect the corals' fecundity and timing of spawning (Smith and Hughes, 1999; Okubo et al., 2007; Okubo et al., 2009; Okubo et al., 2010). It is therefore highly recommended to apply the methods described above as extensively and consistently as possible to obtain a realistic assessment of a restored population/community's reproductive capacity.

Reporting

Reporting of the reproductive capacity of a restored population/community will depend on the method of observation. For spawning observations, data collection should follow the protocols developed by the Larval Propagation Working Group and be reported directly to this working group via their webpage (Appendix 3). In addition to the CRC, there is a highly interactive Facebook page: *Coral Spawning Research*, which includes over 2000 members involved in this field to various degrees (Appendix 3). Members who are conducting spawning monitoring in various regions of the Caribbean report their observations on this site on a daily basis. By following this group, one can stay informed of the trends of coral spawning in nearby locations and re-adjust observation schedules accordingly. It is also a platform where information and guidance is exchanged freely. Reporting for other methods such as branch breaking and colony size or age should include the number of colonies observed (with and without gametes), and size of colonies observed. These data should be recorded in program specific databases.

Sampling Frequency

Sampling for restored coral reproductive capacity should occur from 1–2 months before the predicted spawning times for the species in question. Ideally, a coral health survey (reporting disease, bleaching, or other stressors) should also be completed one month prior to the predicted spawning time. The results of this survey could help identifying underlying reasons for low or no spawning. Colony size measurements can be made up to two months prior to spawning.

Performance Criteria

In an ideal situation, once restored corals have reached a minimum reproductive size/age, they would spawn annually. However, due to variability within and among species, sites, environmental conditions, as well as annual differences in temperature regimes and lunar cycles, consistent annual spawning is unlikely, even in wild populations that have not been "manipulated", although more studies are needed to understand the factors that affect spawning activity. While it should still be a goal of a program to foster an environment where restored corals can grow to a mature size and hopefully further contribute to the ecosystem through sexual reproduction, we realize the latter may be a difficult criterion to meet. Therefore, the performance criterion for this metric is to make as many repeated observations (multi-year) of multiple genotypes and species to increase our collective knowledge and inform future restoration designs.

Evaluation Tool Criteria Alignment (Appendix 2): Coral Population Enhancement Metric #1.2 aligns with one criterion:

> Annual surveys or observations are conducted to determine if outplants (all species) have reached sexual maturity. Sexual maturity may be determined by observing sexual reproduction/gamete production via gametes present in branches/tissue, conducting histological sampling, and/or in situ spawning observations of outplants. If annual observations are conducted, a project will receive a score of 1 (*Evaluation Tool Outplanting Criteria #19*).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).

Coral Population Enhancement Metric #1.3: Coral Condition

Corals are affected by many environmental and anthropogenic stressors at local and global scales, each negatively impacting coral health differentially based on season, geographic location, habitat type, host genotype, and species. **Coral condition is a measure of the presumed health based on the visible signs of diseases, predation, lesions, bleaching, overgrowth, and physical impacts. The impact of these conditions dictates the change (either loss or recovery) in coral health over time.**

Coral stressors can be chronic (predation or disease in some instances; water quality; neighboring organism competition) and/or acute (storm damage; human interaction; predation or disease in some instances), both of which have a long or short-term negative impact on the production of coral tissue or overall survival. Therefore, by obtaining data on the occurrence and relative impact of these negative interactions within a restoration site, targeted preventative maintenance and management can be incorporated into a program's restoration plan. The conditions most commonly described as affecting the condition of corals are disease, predation by motile organisms, physical impacts and interactions, and bleaching.

Coral disease can be observed as a distinct band, jagged edge, focal, multifocal, linear, and/or diffuse and is often associated with tissue loss (Figure 27), although not in the case of dark spot disease. Coral diseases can be caused by bacteria, fungi, viruses, protozoa, or other stressors resulting in loss of tissue, reduced growth rates, and reproductive abilities. In addition, many coral diseases may interact with other stressors to increase loss of coral tissue. Up to 30 coral diseases have been reported, however the causal agent or the mechanisms for transmission for a majority have not been identified (Richardson, 1998; Harvell et al., 2004; Rosenberg et al., 2007; Rosenberg et al., 2009; Mueller and van Woesik, 2012; Maynard et al., 2015).

Coral predators, which typically include corallivorous snails, worms, and fish, can have detrimental impacts on corals if not managed (Miller, 2001; Miller et al., 2002; Shantz et al., 2011; Johnston and Miller, 2014; Miller et al., 2014; Bright et al., 2015; Schopmeyer and Lirman, 2015; Goergen and Gilliam, 2018). Wounds from predation, examples shown in Figure 28, can include tissue denuded branch tips (fireworm predation), scalloped tissue-loss-margin (snail predation), scraping/ loss of corallites (fish and urchin predation), and algal garden chimney (fish predation).

Physical impacts to coral can be caused by storms (wave energy), fishing, boating, and diving activities as well as interactions with other biota (algae, sediment, sponges, and soft corals). These can cause coral colony fragmentation, abrasion, competition, and/or mortality (Figure 29). Some physical interactions such as algal overgrowth or abrasion caused by

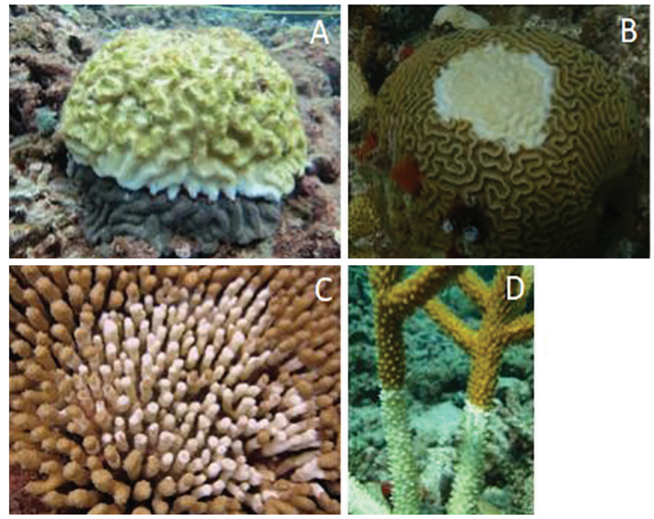


Figure 27. Examples of diseases affecting coral. Image credits: Coral Restoration Foundation (A, B); Nova Southeastern University CRRAM Lab (C, D).

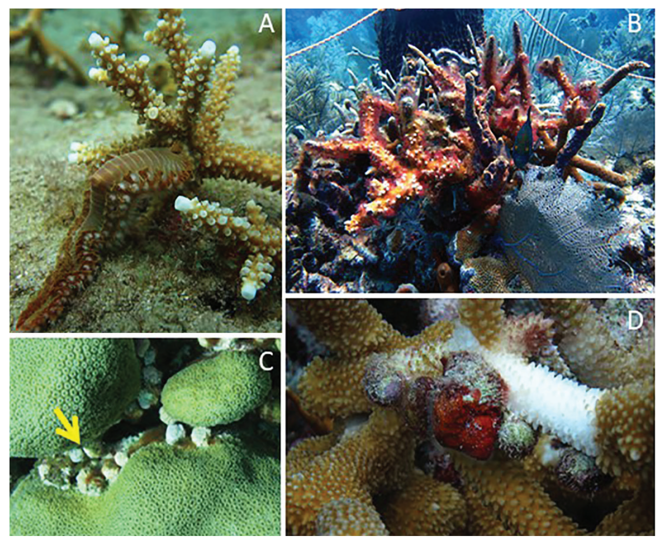


Figure 28. Examples of predation wounds on coral. Image credits: Nova Southeastern University CRRAM Lab (A, B, D); Johnston and Miller (2014; C).

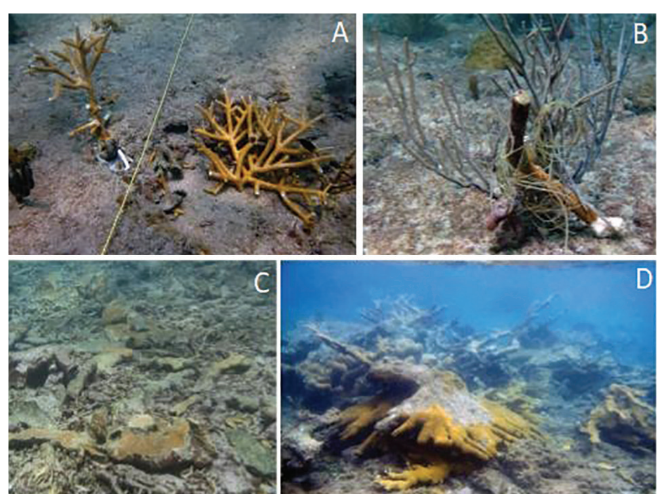


Figure 29. Examples of physical impacts to corals. Image credits: Nova Southeastern University CRRAM Lab (A, B); NOAA (C, D).

loose corals, gorgonians or other biota can easily be managed by removing the negative impact or stabilizing loose corals. If physical impacts to the outplanted corals are chronic, it may be necessary to consider adaptive management actions to help protect restoration activities. Examples of potential adaptive management actions could be changing the restoration site location and/or contacting local authorities to establish no fishing or anchor areas.

Coral bleaching may be observed during extended periods of elevated temperature (Figure 30). Bleaching may appear as pale, partially bleached, or completely bleached and each condition may signal that adaptive strategies should be used when planning restoration activities. If bleaching is a chronic condition at a restoration site, especially if it is associated with mortality, it is advised to not continue further restoration at that site, and just work to maintain previous outplanting. Paling may be an early indicator of potential bleaching or may be the result of other stressors. Therefore, paling should be considered, but not recorded as bleaching. Coral color cards are available to more accurately track coral color over time (Figure 31); while this card was originally designed for Pacific corals, it has been successfully used within the Caribbean as well. There are numerous programs around the world that bleaching and sometimes disease data can be reported to; see Appendix 3 for a list of a few of these programs.

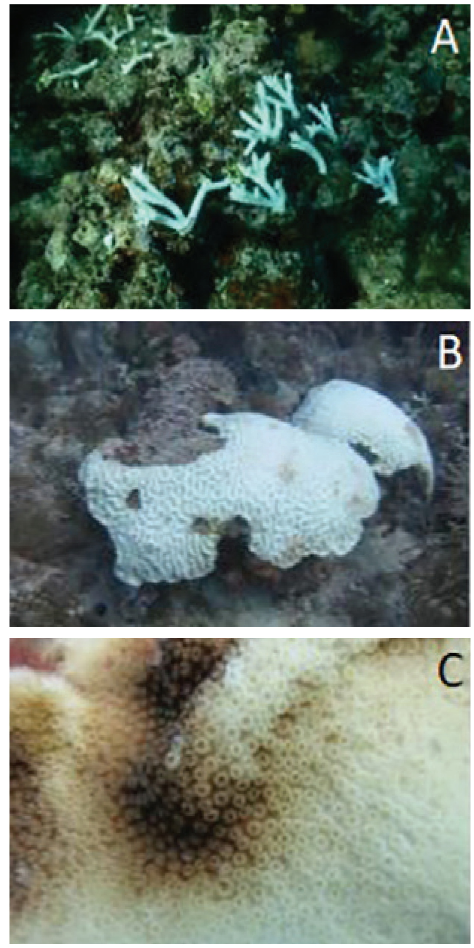


Figure 30. Examples of coral bleaching. Image credits: Coral Restoration Foundation (A); Liz Goergen (B, C).

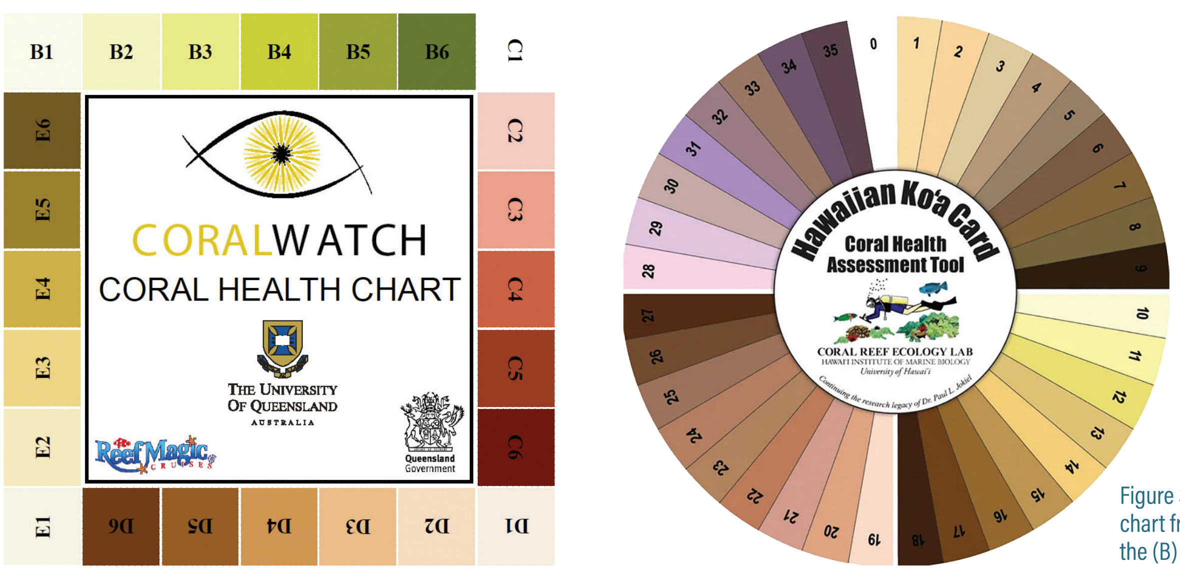


Figure 31. Example coral health chart from (A) CoralWatch and the (B) Hawaiian Ko'a (coral) card.

Whitney Hoot

Possible Methods

The following are methods that could be used to survey the condition of restored corals. These suggestions are not exhaustive, but are presented as a guide. Whichever technique is chosen, it is important to identify the method used when reporting data. **To accurately evaluate the condition of a restored coral population, control sites must simultaneously be evaluated for the same criteria.** If the conditions are being studied on a per species basis, consider species spatial distribution and abundance to assure appropriate sampling sizes (Jordan-Dahlgren et al., 2018). Using a combination of permanent and random/roving diver surveys over time may provide the most comprehensive results.

Details describing the first of two methods to survey coral condition are found under Universal Metric #2:

Ecological Footprint Survey

Conducting surveys for coral condition within the RRAD will provide focused community data for the area within which restored corals are being outplanted. Coral condition data collected within the RRAD is valuable as it provides a standardized project size and area of restored reef to evaluate changes over time and gauge the overall impact and success of a restoration project.

Mosaics

Coral condition data can be collected from photomosaics, although caution must be taken that the imagery collected are at a level suitable for identifying coral conditions. With images, it can be difficult to differentiate a bleached colony from a recently dead colony with exposed white skeleton. Image quality and resolution will affect the ability to capture the presence or absence of polyps from imagery alone. A combination of methods, such as images and roving diver surveys of the same area could be conducted to help differentiate between or identify conditions. The result of the mosaic process is a high-resolution photographic archive of all benthic organisms within the area of interest that can be used to identify coral condition at the time of the mosaic survey (methods for obtaining a mosaic are above in Universal Metric #1 and Appendix 4). For example methods of obtaining data from a mosaic, see Appendix 4. Examples from the literature such as, Burns et al. (2015); Gintert et al. (2018); and Fukunaga et al. (2019) outline use of this method in depth.

Additionally, the following methods described in Coral Population Enhancement Metric #1.1 could also be used to describe the condition of restored corals:

Transects

Belt transects are the preferred type of transect to be used to monitor for coral condition and must be large enough to capture a sufficient number of colonies for the study species, this may require different size belt transects if multiple species are being surveyed (Jordan-Dahlgren et al., 2018).

Point or line intercept transects are not a preferred method for this type of data as they cover a very small area or portion of colonies, requiring many replicates to appropriately describe each condition.

Photo transects/images are a valuable asset to monitoring coral condition for a few reasons: 1) images can be tracked over time to evaluate the amount of tissue lost per condition, 2) some conditions are difficult to identify – images can be distributed to experts and colleagues to aid in identification, and 3) images can be used as a tool for training to ensure data collectors are identifying conditions similarly.

Plots/Quadrats

Following the same advice given for transects above and in Coral Population Enhancement Metric #1.1, plots and quadrats can be used to track coral condition.

Coral Fate Tracking

Fate tracking of individual colonies affected by a condition is the preferred method to determine the effect that a condition has on the loss of tissue such as rate of progression, recovery/regrowth, survival, and secondary infections. See Universal Metric #3 for additional details.

Roving Diver

A roving diver survey may be used to determine if additional survey methods should be deployed to capture prevalence. Roving surveys are meant to be a quick look at a site to observe if a condition is present, this type of survey is often performed to determine if bleaching and/or disease are occurring and require additional monitoring.

Reporting

Coral condition may be reported in three ways: presence or absence, prevalence, and/or percent tissue loss. Whichever method is used, reporting should be by condition for each species, site, and monitoring event. In addition, disease and bleaching data can be submitted to your locations respective program (Appendix 3).

Prevalence of conditions is calculated by dividing the sum of colonies that have the condition of interest (disease, predation, bleaching, etc.) by the total number of colonies surveyed. Depending on the research objectives, each condition could be divided further; for example, predation could be divided into fireworm, snail, fish bites, and/or damselfish algal gardening prevalence.

Percent tissue loss could be reported as the mean percent of tissue lost per colony due to a certain condition (follow methods described in Universal Metric #3) or as a total amount of tissue lost per species. The total amount of tissue lost requires an estimation of each colony size to be able to calculate area lost.

Photographs

Some disease and predation wounds/lesions can be difficult to identify even to the trained eye. Representative photos of the conditions being reported will not only help other practitioners learn the variability of a condition, but will also help the restoration community become more consistent with the identification of coral conditions. In addition, photos can help a program identify the condition by sharing with the restoration community. Photos can be submitted to the CRC working groups and Facebook page who can share them with the restoration community for discussion (Appendix 3).

Sampling Frequency

The frequency of monitoring for coral condition will depend on the program's objectives and goals and the intensity or longevity of the particular condition impacting coral health. Further, each condition may require a different monitoring schedule or frequency and should occur with increased frequency during the time of year where it is more likely to be observed (i.e., bleaching surveys should be conducted during times of peak water temperatures such as August and September in the Caribbean). For fast moving diseases, weekly to monthly observations may be necessary (Rogers et al., 2001). For examples of monitoring that may be required during times of high stress (e.g., disease or bleaching events), see Chapter 9.

Performance Criteria

Restored corals should have low partial mortality, prevalence of disease, predation, mortality from bleaching, and other competitors over time. In addition, restored coral condition should be similar to wild colonies within control and reference sites. Significant changes in restored coral condition should trigger additional more frequent monitoring and adaptive management if applicable. Further, restoration activities should cease until the outbreak has subsided and if possible the cause of mortality defined and addressed. It is inevitable that coral loss (whole coral or partial coral) will occur, however if the general trend in live tissue or the distribution of coral partial mortality is towards an increase in mortality, the restoration site should be evaluated and adaptive management strategies should be evaluated to determine and reduce the cause of the loss of live tissue.

The Ocean Agency/Shaun Wolfe

Evaluation Tool Criteria Alignment (Appendix 2): Coral Population Enhancement Metric #1.3 aligns with eight criteria:

1. Outplants exhibit high coral survivorship within 1st year resulting in positive change in abundance of each outplanted species at an outplant site over time. If annual survival is >80%, a program will receive a score of 1 (Evaluation Tool Outplanting Criteria #12).
2. Restored corals maintain a high percent of live tissue per coral (outside of acute events) during 1st year. If mean live tissue per colony is >80% a program will receive a score of 1 (Evaluation Tool Outplanting Criteria #13).
3. Outplants exhibit low tissue loss (< 5% of outplants) from bleaching. If < 5% of outplants exhibit tissue loss from bleaching a program will receive a score of 1 (Evaluation Tool Outplanting Criteria #14).
4. Outplants exhibit low prevalence (<10%) of disease within the 1st year (outside of acute events). If disease prevalence of outplants is <10%, a program will receive a score of 1 (Evaluation Tool Outplanting Criteria #15).
5. Outplants exhibit low abundance and impacts of coral predators. If annual predation prevalence is < 5%, a program will receive a score of 1 (Evaluation Tool Outplanting Criteria #16).
6. Outplants exhibit limited competition by algae and other competitors (e.g., hydroids, sponges, damselfish). If annual competition mortality prevalence is <5%, a project will receive a score of 1 (Evaluation Tool Outplanting Criteria #17).
7. Outplants experience low levels of physical damage (unnatural colony fragmentation, breakage, and/or dislodgement). If physical damage to outplants is less than or equal to wild colonies (e.g., dislodgement, extreme breakage, fragmentation due to anchor drags, boat strikes, divers) a program will receive a score of 1 (Evaluation Tool Outplanting Criteria #18).
8. Outplants exhibit high annual coral survivorship/abundance during years 2–5. If annual outplant survival is >65% OR if >65% of initially outplanted colonies are present at the site through year 5, a program will receive a score of 1 (Evaluation Tool Outplanting Criteria #23).

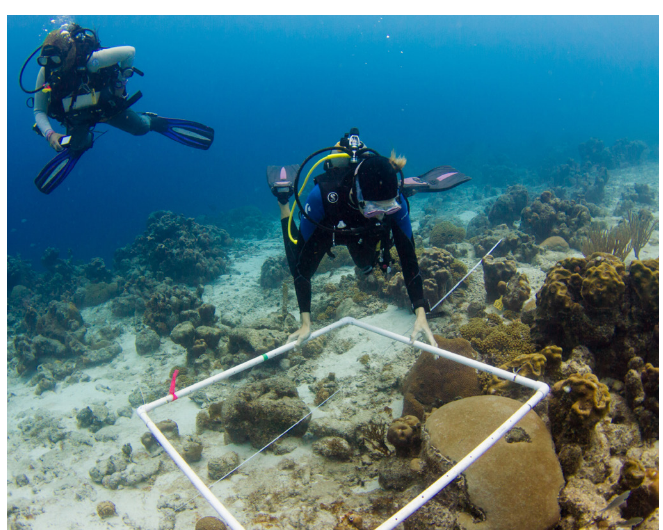
Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).

Coral Population Enhancement Metric #1.4: Species Richness and Diversity

Universal Metric #4 discusses the importance of **maintaining genetic and genotypic diversity of coral species during restoration activities to increase the sexual reproductive potential of an outplanting site** (See Universal Metric #4). Genetic diversity is an important driver of long-term facilitation of species recovery and conservation (Baums, 2008; Drury et al., 2017b; Baums et al., 2019). New genetic combinations resulting from sexual reproduction may add resilience to coral populations, and therefore, restoration activities should attempt to outplant a minimum of five unique genotypes of each species at each outplant site (Baums, 2008; Drury et al., 2017b).

To date, most restoration programs in the Caribbean have focused restoration efforts on Acroporids as these species are amenable to quick propagation and until recently were the only species listed within the U.S. Endangered Species Act (NOAA National Marine Fisheries Service, 2006). However, declines in overall coral cover in recent decades have been accompanied by loss of species. Some monitoring sites in the Caribbean have shown declines in species richness of up to 35% (Porter and Meier, 1992; Hughes and Tanner, 2000). Between 1996 and 2002, 73% of 43 permanent monitoring sites in the Florida Keys showed losses in coral diversity, with a maximum of seven species lost (Causey et al., 2002). Globally, losses in coral species diversity has been accelerated (between 30–60%) in areas severely degraded by human activities (Edinger et al., 1998).

Declines in species diversity may have dramatic effects on the structure and function of the reef ecosystem. For example, the loss of Caribbean major reef building species (e.g., *Orbicella* and *Diploria/Pseudodiploria* species) have caused declines in reef accretion and potential declines in reef capacity to support biodiversity and provide ecosystem services (Alvarez-Filip et al., 2011). Additionally, species diversity can limit resilience from disturbance events, for some species already show a far greater tolerance to climate change and coral bleaching than others (Hughes et al., 2003). Therefore, there is an ever increasing need for restoration programs to focus on multi-species propagation and restoration to ensure the conservation of valuable coral species and maintain potential resilience.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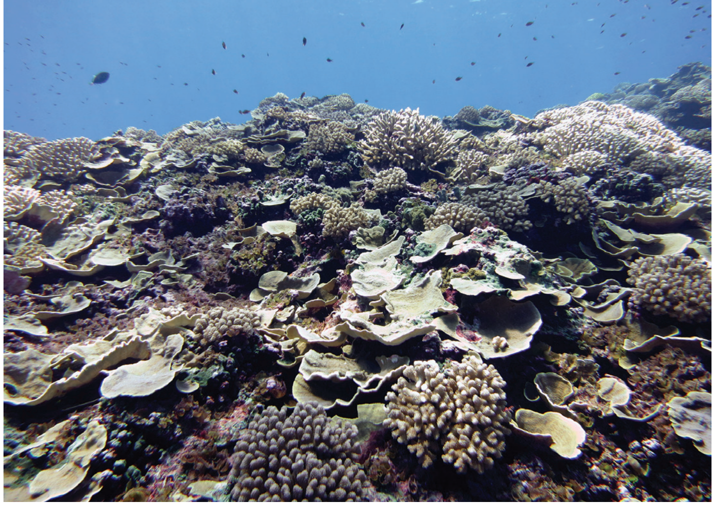
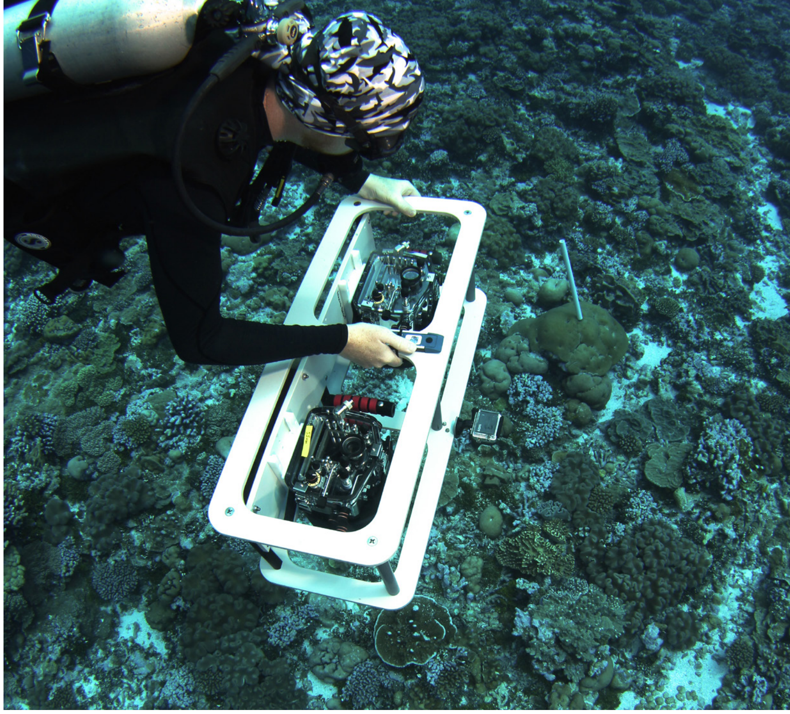


James Morioka/NOAA



100 Island Challenge, Scripps Institute of Oceanography, UCSD

Possible Methods

The following are methods that could be used to survey for species richness and diversity of a restored site. These suggestions are not exhaustive, but are presented as a guide. Whichever technique is chosen, it is important to identify the method used when reporting data. **To accurately evaluate potential changes in species richness and diversity, a survey must be completed prior to outplanting to characterize initial species diversity at a site.** Changes in species diversity through outplanting or potential recruitment can be monitored through subsequent surveys.

Details describing the first of two methods to survey coral condition are found under Universal Metric #2:

Ecological Footprint Survey

Conducting surveys for species richness and diversity within the RRAD will provide focused community data for the area within which restored corals are being outplanted. Species richness and diversity within the RRAD is valuable as it provides a standardized project size and area of restored reef to evaluate changes over time and gauge the overall impact and success of a restoration project. As with roving diver surveys, the number of species, the number of colonies per species, and the number of colonies per species per size class can be determined within the RRAD.

Mosaics

Species richness and diversity can be collected from photomosaics. The result of the mosaic process is a high-resolution photographic archive of all benthic organisms within the area of interest that can be used to identify the number of species, the number of colonies per species, and even the number of colonies per species per size class at the time of the mosaic survey (Methods for obtaining a Mosaic are above in Universal Metric #1 and Appendix 4). Coral colonies and changes in community composition can be followed through time based on their geographic location within the mosaic image. Individual tagging of coral colonies is not needed using the mosaic survey method. For example methods of obtaining coral size data from a mosaic, see Appendix 4. Examples from the literature such as, Burns et al. (2015); Gintert et al. (2018); and Fukunaga et al. (2019) outline use of this method in depth.

Additionally, the following methods described in Coral Population Enhancement Metric #1.1 could also be used to describe the condition of restored corals:

Roving Diver

A roving diver survey may be used to determine initial species richness and diversity and will be able to cover more of the reef area in a short amount of time. Roving surveys are meant to be a quick look at a site to identify the coral species present at a site and then potential changes over time due to outplanting and recruitment. The number of species, the number of colonies per species, and the number of colonies per species per size class can all be determined through roving diver surveys.

Transects

Random and belt transects can be used to evaluate species richness and diversity, but must be large enough to capture a sufficient number of colonies to adequately represent the community of the entire reef. This may require different size belt transects or multiple random transects (Jordan-Dahlgren et al., 2018). In addition, the placement of transects for monitoring, even if random, must be within an area where restored corals will be or are located in order to capture species diversity and richness within the actual restoration area. Point or line intercept transects may also be used within the actual restoration area, but only cover a very small area, thus requiring many replicates. Point or line intercept transects may only provide a limited dataset related to species richness and diversity as some rare species may not be encountered within the outplant area, but should be represented for the entire reef site.

Photo/video transects or roving diver surveys

Photo and video transects or images collected continuously during roving diver surveys may be a valuable asset to monitoring changes in species richness and diversity. The use of image-based surveys allows a larger area to be covered and requires less underwater time as images or videos will be analyzed once back in the lab. Images or video must have high enough resolution for species identification and may also include a scale bar to allow for assessing colony size.


Mia Hoogenboom


The Ocean Agency/Shaun Wolfe

Plots/Quadrats

Following the same advice given for transects above and in Coral Population Enhancement Metrics #1.1 and #1.3. Plots and quadrats can be used to obtain species richness and diversity data; however, replication must be taken into consideration in order to appropriately portray the site.

Reporting

Species richness is a measure of the number of species found at a site. As sample size or reef area increases, we would expect to find more species. Therefore, the number of species is divided by the square root of the number of individuals in the sample. This particular measure of species richness is known as ***D***, the Menhinick's index where ***s*** equals the number of different species at a site, and ***N*** equals the total number of individuals at a site.

$$D = \frac{s}{\sqrt{N}}$$

Species diversity differs from species richness in that it takes into account both the numbers of species present and the dominance or evenness of species in relation to one another. As a measure of species diversity, calculate the Shannon index, where p_i is the proportion of the total number of individuals in the population that are in species "*i*". A higher Shannon Index indicates higher diversity.

$$H = \sum (p_i) \mid \ln p_i \mid$$

Further still, **species evenness** refers to how similar in numbers each species at a site are. Mathematically it is defined as a diversity index, a measure of biodiversity which quantifies how equal the community is numerically. The evenness of a community can be represented by Pielou's evenness index:

$$J' = \frac{H'}{H'_{max}}$$

Where ***H'*** is the number derived from the Shannon Diversity Index and H'_{max} is the maximum possible value of ***H'*** (if every species was equally likely), equal to:

$$H'_{max} = -\sum_{i=1}^{S} \frac{1}{S} \ln \frac{1}{S} = \ln S$$

J' is constrained between 0 and 1. The less evenness in communities between the species (and the presence of a dominant species), the lower ***J'*** is, and vice versa. ***S*** is the total number of species.

Species richness, diversity, and evenness can be calculated for each site. Photographs may be taken during each monitoring event to provide representation of species.

Sampling Frequency

An initial survey should be performed at each site prior to outplanting to determine initial species richness, diversity, and evenness. After outplanting, annual surveys may be performed for up to five years.

Performance Criteria

Restoration programs that outplant more than one species to a site should work to maintain the restored species diversity, richness, and evenness. If a restoration programs capacity allows, species diversity, richness, and evenness similar to nearby reference and/or control sites should be a target goal to achieve Ecological Restoration (see Chapter 3 — Importance of Baseline Data and Reference Sites).

Evaluation Tool Criteria Alignment (Appendix 2): Coral Population Enhancement Metric #1.4 aligns with one criterion:

> Outplant sites contain multiple outplanted species; if more than one species is outplanted a project will receive a score of 1 (Evaluation Tool Outplanting Criteria #7)

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).


Coral Restoration Foundation

Coral Population Enhancement Metric #1.5: Indirect Seeding of Sexual Recruits

This section aims to provide a standardized protocol for collection of data for evaluating coral restoration using larval propagation followed by indirect seeding; that is, settlement of larvae onto an artificial substrate unit that is subsequently outplanted to the reef. This is in contrast to a direct seeding approach, whereby larvae are settled directly on the natural reef substrate. Metrics for the latter approach differ from the former and will not be addressed in this document. Substrates with settlers may be kept ex situ or placed in field nurseries for a grow-out period, or may be transplanted to the reef shortly after settlement. **Specifically, it is useful to evaluate the effectiveness at two crucial life history steps of the restoration pipeline, 1) settlement of larvae onto substrates, and 2) the fate of these substrates and the settlers they harbor over time, regardless of the setting in which they were reared.**

Larval settlers are inherently small, difficult to see and therefore, difficult to monitor. There is likely also some inherent tradeoff between the intensity of effort to observe and quantify survivors (hence accuracy) and the degree of handling disturbance involved (hence also likely affecting this accuracy). Thus, practitioners should consider carefully the goals for monitoring and what interval of monitoring makes sense in their context. While there is an expectation that mortality will be highest in the period directly following the outplanting phase, the data obtained may also be more reliable several months post-outplanting to allow settlers to grow to a more apparent size. Thus, the timing of post-outplanting monitoring will depend on the post-settlement growth rates of the particular species in question.

Possible Methods

The following describes an outplanting/monitoring scheme that can be applied in the case of relatively rapid outplanting of substrates shortly after larvae have settled on them (i.e., within a few weeks post-settlement). Similar tracking of survivors and yield should be undertaken during any extended period of ex situ culture.

Sub-sampling

It is expected that for restoration-scale activities, only a subset of substrates would be manageable to monitor individually. A sample size of at least 30 substrates per site/treatment is recommended, as there is generally a high degree of variability in settlement among individual substrates.

Substrate Count

One of the first steps in tracking the success of outplanting artificial substrates is to track their retention on the reef, i.e., presence or absence of each, or a subset of, the substrates that were outplanted (absence is very important to record). These data will provide information on the effectiveness of the outplanting technique (e.g., gluing, wedging, or loosely scattering) success. Data can be collected in situ using a site referenced outplanting map (similar to the data collection techniques for Ecological Footprint Surveys), georeferenced photo documentation, or a combination of both (Figure 32). Data collection for this method can be aided by bringing previously drawn maps or images of the outplant design (see Guide to Field-Based Coral Reef Restoration [Goergen et al., in review] in Appendix 3) for guidance on creating an outplant field map).

Settler Abundance

The abundance of settlers must be reported prior to outplanting substrates to the reef. These initial counts provide the baseline data necessary to draw any conclusions about success.

Pre-Outplant

This process involves quantifying the number of settlers (which hopefully turn into colonies over time) on each (or a subset) of the monitored substrates. In order to do this, each substrate must be tracked individually; therefore, substrates must be uniquely marked or mapped to allow tracking the fate of settlers after outplanting (Figure 33). The 'Time 0' counts are generally made where larval rearing and settlement have taken place (e.g., land-based tanks or in situ mesocosms).

If a dissecting microscope is available, this is the best way to score early stage settlers. Otherwise, fluorescence detection can be used with whatever form of magnification available.

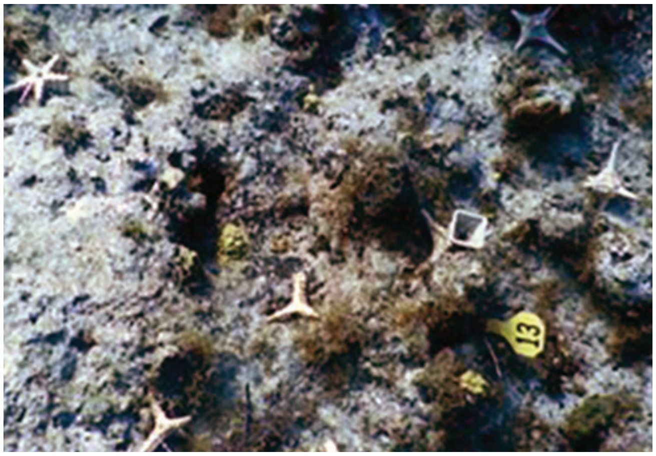


Figure 32. Photo documentation of outplanted settlement substrates. Image Credit: John Parkinson.

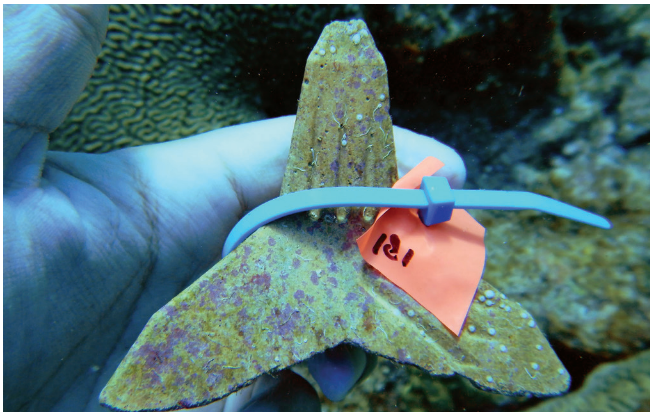


Figure 33. Example identification tag on settlement substrate. Image credit: Kelly Latijnhouwers.

Post-Outplant

In order to assess the fate of settlers after they were outplanted, each substrate, or a subset of substrates, should be examined carefully to record the number of surviving coral settlers. The field data sheet should also include site metadata such as Outplant Plot number and substrate identifier. An underwater map and plot images will aid in relocating outplanted substrates and settlers on substrates.

In early stages, it may be helpful to take a few substrates (preferably not those tracked for monitoring) back to a lab to examine them under a dissecting microscope and with a fluorescence flashlight to ensure that surveyors can confidently identify settlers, which can be challenging to detect at first.

Aid of Fluorescent Protein Flashlights

An important tool for detecting small settlers is fluorescence– many, but not all, coral settlers express green fluorescence proteins. A specialized blue fluorescence exciting light and yellow filter can make small settlers more apparent via glowing green (Piniak et al., 2005; Baird et al., 2006; Schmidt-Roach et al., 2008). However, different species and cohorts of settlers show high variability in their fluorescence, both in terms of intensity and timing of fluorescence (Baird et al., 2006). In addition, some substrate materials such as carbonate substrates auto fluoresce green and can 'wash out' the signal from small settlers. Thus, auto fluoresce might be a relevant factor when considering the material for settlement substrates. The other operational consideration is that fluorescence is a more effective tool against a dark background. Hence, a dark lab or dusk- or night-dives may be best suited for scoring of early-stage settlers with fluorescence. Alternatively, substrates may be temporarily placed in some sort of underwater 'dark box' to aid fluorescence detection.

Settler Size

As the recruits begin to grow, it may also be advantageous to track their size as an indication of health. This may be achieved by either recording the number of polyps or the maximum diameter of the colonies. Maximum diameter can be measured in situ with calipers or a ruler or ex situ via analysis of a scaled digital photograph [e.g., ImageJ or CPCe]. Caution should be taken if measuring settlers in situ as settlers can be damaged or dislodged with measuring tools; the preferred method for measuring recruits, if tools are available, is through image analysis.

Plots/ Quadrats

A visual record of the benthic communities on the substrates themselves as well as surrounding the outplanted substrates can be captured through, a close up picture of the substrate, and a scaled aerial image of the outplanting plot, respectively. These images can be used to derive benthic cover via point-count techniques (e.g., point counting software) or in situ estimates as a covariate to help interpret survivorship rates.

Reporting

From these methods, substrate retention (as a proportion), mean settler survivorship, and yield (as a proportion) can be calculated for each time point.

Substrate Retention: The proportion of outplanted substrates that are relocatable at a given time. This parameter reflects the success of the attachment and/or self-stabilization of the substrate on the reef and is likely most affected by physical characteristics such as the physiography/rugosity of the reef, hydrodynamic forcing, and the shape and weight of the substrate itself.

Settler Survivorship: The proportion of outplanted coral settlers surviving at a given time. This can be scored for each individual substrate to calculate mean/variance and allows statistical hypothesis testing. This parameter is affected more by biology: the physiological state of the coral settler, itself, and the ecological interactions it experiences.

Yield: The proportion of originally outplanted substrates that can be relocated on the reef, and that retain at least one live coral at a given time. This parameter is affected by both survivorship and retention thus integrating the influence of the substrate characteristics and physical and biological forcing, perhaps giving the most holistic indicator of cost-effectiveness (since cost scales most directly with how many substrates are produced and outplanted).

The mean size of recruits can also be used to derive early stage growth rates. Benthic composition in percent cover or presence and absence can be reported to help interpret settler survival.

Sampling frequency

Surveys should be conducted prior to outplanting substrates and at intervals supportive of a program's goals. An appropriate interval for research purposes (and based on detecting Type III survival curves) might be 1, 3, 6, and 12 months. However, for general restoration monitoring, 6 and 12 months post-outplant is likely more appropriate. In addition, monitoring should occur following disturbance events (e.g., storm, disease, or bleaching).

Coralium

Performance Criteria

Although it is difficult to control the number of settlers on each artificial substrate, the ideal is to begin with enough settlers to end up with one coral surviving on each substrate (i.e., a yield of 100%). This ideal of 100% yield is not a likely outcome, and a reasonable criterion for yield is not yet available. The metrics of retention and survivorship are expected to vary greatly among species and receiving habitats and thus, evaluation criteria are not yet available for these fairly new techniques. However, at this time, these metrics do allow a better understanding of the settings in which larval propagation is most effective by comparing these metrics among, for example, years, sites, and/or species. It will, for instance, be very informative to learn that it is three times more effective to outplant species ***x*** than species ***y*** on a specific reef location, or that yield has increased yearly since the start of a given restoration program. Standardizing the collection of these metrics among projects and sites will begin to build the data necessary to establish specific evaluation criteria.

Objective 2: Community and Habitat Enhancement

The main purpose of ecosystem restoration is to ultimately restore ecosystem functionality. Metrics to quantify ecosystem functionality include the enhancement of:

1. Invertebrate Community
2. Reef Fish Community
3. Reef Structure and Complexity
4. Habitat Quality

Community and Habitat Enhancement Metric #2.1:

Invertebrate Community Diversity and Abundance

Coral reef invertebrates have a broad diversity of form and function. Some are attached to the ocean floor while others are mobile. **Invertebrates can perform key functions such as habitat provision, algae control, or serve as an important source of food.** This diversity in form, along with the small size or cryptic nature of some species, can make surveying a challenge. Multiple methods may need to be employed to fully capture community abundance and diversity.

Possible Methods

Sessile, colonial invertebrates are often recorded as a percent cover of the benthos, but may also be recorded as an abundance/density. There are multiple variations of transect surveys that can be useful for recording their presence. Line intercept or belt transects in combination with quadrats or photos/videos, as described in a previous section (Coral Population Enhancement Metric #1.1), are useful for evaluating sessile invertebrates. These methods include surveys of a defined area that can be used to calculate percent cover or density.

Abundance or density of mobile invertebrates can be surveyed using belt transects or a roving diver technique. Belt transects have the advantage of covering a known area, making it easy to calculate density. Roving diver surveys can be used for calculating abundance; however, calculations of density require information on the area surveyed (i.e., Ecological Footprint). Roving diver surveys can cover a large area and searching for macroinvertebrate species that may hide from view.

Perry Institute

A common technique for mobile species is to record indicator species or species of special interest rather than all mobile species encountered. These indicator species often play a key functional role on the reef (e.g., primary grazers or predators). They can be surveyed using the roving diver or belt transects as described above. In the Caribbean, some potential indicator species include:

Urchins (*Diadema, Echinometra*)

Lobsters (Palinuridae, Scyllaridae, etc.)

Caribbean King crab (*Mithrax spinosissimus*)

Coral crab (*Carpilius corallinus*)

Corallivores (*Coralliophila, Hermodice*)

Finally, the presence of small, cryptic species may not be captured using the transect and roving diver survey techniques described above. A potential method to evaluate these species is the use of autonomous reef monitoring structures (ARMS). These are layered structures with fibrous material placed in between where micro-invertebrates settle. The structures are deployed on reefs and collected after a few months. The fibrous material and structures can be searched by hand for presence of cryptic invertebrates (Zimmerman and Martin, 2004) or analyzed through DNA barcoding (Leray and Knowlton, 2015).

Reporting

Macro-invertebrate species abundance can be reported as number or density of individuals (sessile and mobile species) or as percent cover (sessile species only). Cryptic micro-invertebrates are reported as presence/absence. Species diversity, richness, and evenness can be calculated as described in Coral Population Enhancement Metric #1.4.

Sampling Frequency

An initial survey should be performed at each site prior to outplanting to determine initial species richness, diversity, and evenness. After outplanting, annual surveys may be performed.

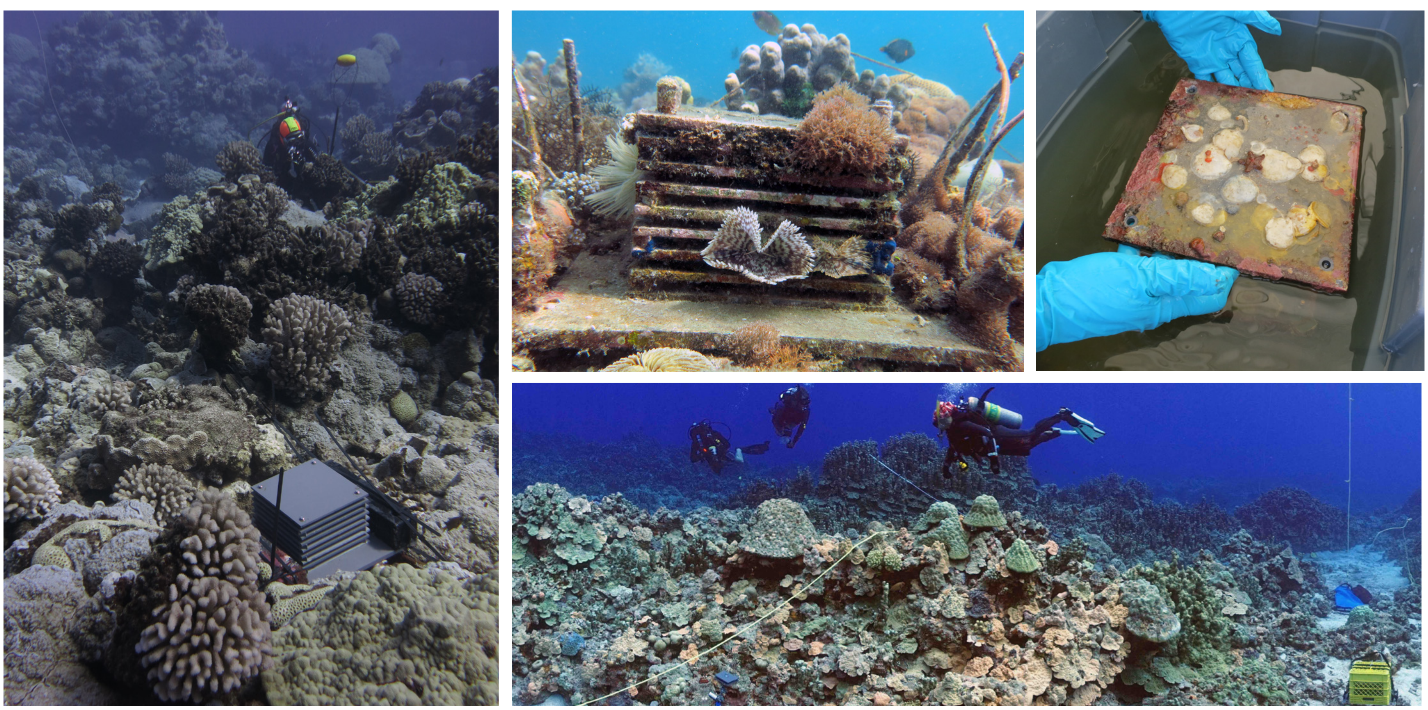
Performance Criteria

Net increase in invertebrates from baseline (defined from pre-restoration survey). Outplants increase net abundance and net functional group diversity of invertebrate reef organisms.

Evaluation Tool Criteria Alignment (Appendix 2): Community and Habitat Enhancement Metric #2.1 aligns with one criterion:

> Outplants improve the ecological value of reef/provide habitat for invertebrates (non-corallivorous). If the presence of outplants increase net abundance of invertebrate reef organisms as determined by pre- and post-outplanting surveys a project will receive a score of 1 (Evaluation Tool Outplanting Criteria #22).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).



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Community and Habitat Enhancement Metric #2.2: Reef Fish Community

There are two primary reasons for monitoring reef fish communities associated with coral reef restoration projects. First, a goal of many coral reef restoration projects is providing functional reef fish habitat to support biodiversity and fishery species by increasing the reef fish abundance and species diversity. Additionally, fish can provide important ecological functions that may promote successful coral reef restoration, including grazing of reef substrata, preying on corallivores and providing nutrient input. **As part of evaluating the effectiveness of coral reef restoration projects, monitoring changes in the fish community is useful to quantify the benefit of increased coral abundance to the reef fish community and to better understand variability in restored coral condition may be related to fish abundance.** There is value in monitoring the response of the reef fish assemblage to inform the effectiveness of restoration techniques at an ecological community scale and to understand the factors that influence habitat utilization of different fish species at restoration sites to inform coral reef restoration design. The following two broad questions are addressed by reef fish monitoring:

> How does the reef fish community at restoration sites change after coral outplanting and corals grow to provide physical structure?

> Is the condition of outplanted corals and the benthos at restoration sites related to fish community metrics (are there positive of negative correlations)?

To answer these questions it is useful to understand how the ecology of reef fish relates to the coral restoration goals. The abundance and species composition of reef fish is strongly tied to the physical structure provided by corals that serves as refuge and foraging habitat; and this relationship varies among species and life-stages. Habitat utilization ranges from highly site attached to more motile species. Additionally there are seascape and environmental factors related to the species life cycle that influence abundance; some species settle in mangroves and move to reefs as they grow. Fishing is an important factor driving the abundance of fish on reefs; grouper abundance may be more strongly influenced by protection of spawning sites than habitat availability. Some basic understanding of the ecology of different species is useful for monitoring the reef fish community associated with coral restoration.

Some groups of fishes are of particular interest for coral restoration since they have been shown to influence coral condition through trophic interaction. Herbivorous fish (i.e., parrotfish) graze on algae promoting a reef condition that supports coral growth and recruitment. Caribbean Acroporid corals are known to provide high quality fish habitat, particularly to newly settling and juvenile stages of coral reef fishes (e.g., grunts, Haemulidae; Gladfelter and Gladfelter, 1978; Mudge et al., 2019). The role of resident schools of reef fishes in the potential benefit to corals through nutrient pathways has been documented and requires further study to understand if it is an important factor in the success of restored corals (Huntington et al., 2017). Predation by fish on coral predators (snails and fireworms) may be a process that promotes coral recovery. Some parrotfish prey on live coral tissue causing partial mortality.

The design of monitoring for the fish community should follow the concepts of fixed/repeated sampling and the sampling of control/reference sites along with the restoration footprint (see Chapter 3).

Nova Southeastern University CRRAM Lab

At the scale of most coral restoration projects, fixed stations will provide more power to determine changes in the fish community given the natural spatial variability in the coral reef habitat. Since fish can move readily across habitats within a reef, it is important to understand how the fish community changes at coral outplanting sites by comparing it with non-restored control sites and/or reference natural reef sites with high coral abundance, if available. Some fish species will settle and recruit to the coral outplanting sites, while other species may move from adjacent reef habitat or use restoration sites periodically. For this reason, it is valuable to understand what fish species and size classes are populating the restoration area. This may also change over time as the outplanted corals grow, and as there are periodic fish recruitment events. Therefore, we recommend that the minimum distance between replicate fish surveys is 30 m. In addition, fish monitoring should compare unrestored areas to areas where corals are restored. A pre-outplanting baseline monitoring is done and then annual monitoring after the corals are outplanted at the site (Figure 34).

Possible Methods

The following are methods that could be used to survey the fish community surrounding restored corals (Table 18). These suggestions are not exhaustive, but are presented as a guide. Whichever technique is chosen, it is important to identify the method used when reporting data. **To accurately evaluate the reef fish community of a restored coral population, control sites must simultaneously be evaluated for the same criteria.**

Stationary Cylinder or Reef Visual Census (RVC)

In the stationary cylinder method, a surveyor at a stationary point samples the fish community within an imaginary cylinder. The surveyor counts fish by species and size during multiple 5-minute time intervals. During the first 5-minute interval, the observer rotates slowly on the point and makes a list of all species within the cylinder. During the subsequent 5-minute time interval, the number of fish by species and size within the cylinder is recorded. The diver trains to visually estimate the boundary of the cylinder using a tape or an APT (all-purpose tool/ 1-meter T stick), which is commonly set at a 15 m diameter (Bohnsack and Bannerot, 1986), but should be reduced for smaller restoration/outplant footprints (i.e., to the size of the Outplant Plot). Dialing down to the appropriate scale of the Outplant Plot and minimizing the influence of any surrounding habitat or structure is appropriate, provided it still captures the site's sphere of influence. If the Outplant Plot is greater than 15 m diameter, a central location in the plot would be suitable. However, fish like vertical structure, and if the edge of the restoration site has any kind of vertical relief, it might harbor a greater concentration of fishes, and should therefore be considered. Cylinders greater than 15 m become impractical for the observer to accurately assess. The center point of each cylinder is marked for repeated sampling over time.

To note:
If the species used for restoration are expected to expand significantly within the timeframe of monitoring (years), such as some branching species, defining the cylinder's diameter to reflect this expected change may be appropriate. For example, branching Acroporid corals were outplanted within a 5 m radial plot and are known to fragment and reattach frequently, therefore the practitioner may choose to define and survey a 9 m diameter cylinder, which includes a 2 m "buffer" round the outplanted corals. Additional research on the specific species, habitat, and region should be completed prior to defining the cylinder's boundary.

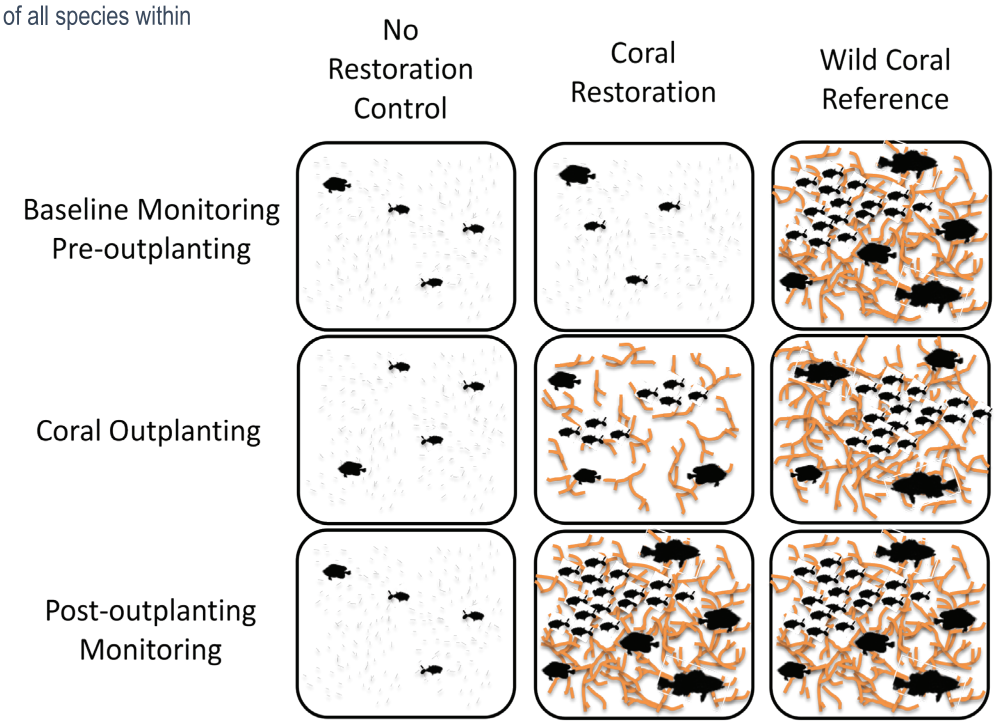


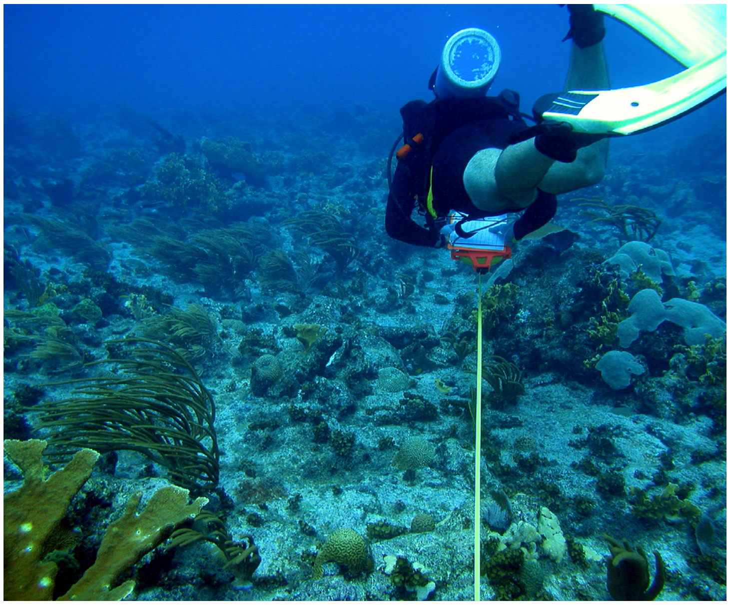
Figure 34. Treatments (or factors) for monitoring reef fish communities at coral restoration sites. The control site with no restoration illustrates degraded reef habitat that is devoid of coral and physical structure that does not change through time. The restoration site is showing increased coral and fish abundance prior to coral outplanting, immediately after outplanting (within one month), and at post outplant monitoring. The reference site (if available) is used to gauge effectiveness of the coral restoration in providing habitat for the fish community.

Table 18. Comparison of reef-fish survey methods. (Adapted from Caldwell et al., 2016).

Method	Area Covered	Strengths	Weaknesses
Belt Transect	20–100 m^2	Good for species density and diversity Portable Easy to execute Repeatable Not greatly affected by poor visibility Widely used in past studies Preferred method for cryptic species (when appropriate time and area are used)	Not as good at capturing large schools or highly mobile species (which often includes many of commercial/recreational importance) Not as practical in strong currents
Stationary Cylinder	50–200 m^2	Good for species density and diversity High efficiency, versatile Low tech/minimal sampling gear Eliminates diver movement Better captures mid-water species Survey area includes entire water column from reef substrate to the surface	Can underestimate cryptic fishes if radius is too wide or visibility impaired Requires practice for cylinder estimation
Roving Diver	Approximately 100–1,000 m^2	Captures high diversity Low tech/minimal sampling gear Quick to employ Captures large area Helps to characterize an area (qualitative vs quantitative)	May overestimate cryptic species Difficult to measure entire assemblages Density cannot be estimated if area surveyed is not accurate Not for generating data amenable to rigorous statistical analysis. Not for repeated measures
Video Transect	Approximately 1–10 m^2	Removes diver effects Provides permanent record Stereo video system can accurately estimate sizes and survey area In situ expertise not needed	Sizing smaller species is difficult Positive species ID can be more challenging, especially depending on size and distance. Traditional methods collect greater species richness Double counts more likely with decreased viewing area Inconsistent census area (visibility) Video viewing and processing is time consuming Expensive

Belt Transects

Belt transects involve counts of fish species and estimates of fish size along a set swath that can vary in dimension (Brock, 1982; Huntington et al., 2017). Common dimensions are 25 x 4 m (100 m^2) to 10 x 1 m (10 m^2); although the size of the coral restoration area will determine which size is suitable. Smaller belt transects will provide more accurate information on species diversity of site attached and cryptic species, whereas larger transects are better suited for larger species. The belt transect is established at the start point and the survey diver slowly reels out the transect tape in a predetermined direction while at the same time enumerating and sizing fish present within the transect width across the established length. It is useful to standardize the time for all transect samples (5–15 minutes depending on transect size). Specifically for cryptic species, a diver can lay out a tape in advance of the survey allowing fishes to acclimate to the tape. The diver is positioned and surveys the fishes within 1 m of the bottom. With slow, but steady speed and a trained eye the transect method can be a good way to quantify cryptics and juveniles. A stake or marker should be installed at the beginning and end of the transect to allow for repetitive sampling.



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Roving Survey (Timed Swim)

The observer swims randomly over the study site recording fish species, abundances, and sizes during a fixed sampling time (Baron et al., 2004; Kilfoyle et al., 2013). In roving surveys, the diver can either actively search for areas where fish refuge (e.g., holes, ledges) or maintain a direction independent of habitat features. The approach should be standardized for all samples in a study and the sampled area must be over the Outplant Plots for the restored counts and over non-restored area for the controls or reference. The sample effort can be standardized by time, or the distance covered can be derived from a GPS. A floating GPS in a waterproof bag can be towed by the diver, and the track used to quantify survey length (see in situ tracing method in Universal Metric #1). Roving surveys of five minutes are generally used to standardize the sample effort. For calculating density, the observer counts fish inside a set width of the swim line (i.e., 5 m). If a set width is not used, the abundance of fish is reported as a count per unit time (number per minute). Roving surveys can also be used for cryptic and juvenile fish surveys, it will generally generate a longer species list, but time may then become a factor in the survey.

Video and Stereo Video Transects

Video survey methods involve recording video of reef fish along transects or timed swim surveys or deploying stationary cameras to record fish on sections of the reef. The video is then reviewed to extract information on fish species and abundance during selected time segments of the video. A stereo video system with two cameras is used when accurate fish size estimates are needed. Video analysis software is then used to extract fish length data (Langlois et al., 2010). Video surveys are directly correlated to the quality of video and are limited in low-light and low-visibility settings. Baited Remote Underwater Video (BRUV) systems are not recommended for coral restoration monitoring, as fish from outside the area of focus will likely be attracted, confounding results. Estimating the size of smaller species and fish within large schools is difficult with video surveys. Although video surveys are an efficient sampling method, a significant amount of time and cost are required for post processing.

Reporting

Species diversity, richness, and evenness can be calculated as described in Coral Population Enhancement Metric #1.4. The basic level of information for monitoring the reef fish community is identifying species and counting the number of individuals within a fixed area or time. This will yield species richness, diversity, and relative abundance or density by species. Obtaining data on the size of reef fish is helpful for comparing size distributions, calculating biomass, and identifying recruitment events. Estimating the size of fish during visual surveys requires training and has been shown to provide useful information for making spatio-temporal comparisons.

Sampling Frequency

Sampling should be done before coral outplanting in order to document how the fish community changes once corals are placed at the site. At a minimum, annual post-outplanting surveys should be conducted at the control and outplant sites as well as reference sites if available. In the Caribbean, this is recommended to occur in August to incorporate fish recruitment and relates to coral health. This approach allows for determination of changes due to the outplanted corals and increased physical structure (coral growth) as well as identifying wider scale changes that may occur naturally over all treatments (i.e., recruitment).

Andrew Gray/NOAA

Performance Criteria

Net increase from baseline (defined from pre-restoration survey). Outplants increase net abundance and net functional group diversity of reef fish. Fish community on restored sites trends toward community structure at adjacent wild reference areas, this will depend on the time it takes for the outplanted corals to reach a size and density that provide functional habitat structure.

Evaluation Tool Criteria Alignment (Appendix 2): Community and Habitat Enhancement Metric #2.2 aligns with one criterion:

> Outplants improve the ecological value of reef/provide habitat for reef fish. If the presence of outplants increase net abundance of reef fish as determined by pre- and post-outplanting surveys, a project will receive a score of 1 (Evaluation Tool Outplanting Criteria #21).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).

Community and Habitat Enhancement Metric #2.3:

Reef Structure and Complexity

Reef structure and complexity is a measurement of the vertical structure of the coral colonies and the reef structure used for restoration. This metric is important as it can be used as a proxy for habitat complexity and creation (McCormick, 1994; Gratwicke and Speight, 2005; Sleeman et al., 2005; Graham et al., 2006; Wilson et al., 2010; Dustan et al., 2013). In addition, reef height is one of the most important metrics considered when calculating a reef's contribution to coastal defense (World Bank, 2016). Over time, Reef Structure and Complexity should show an increasing trend. Reef structure and complexity includes the restored corals as well as any engineered substrate added as part of the restoration. An increase in reef structure and complexity from coral restoration is related to the growth rate of the coral species that were restored. For example, in the Caribbean, branching *Acropora* species will generally have a fast increase whereas the slower growing boulder coral species (e.g., *Pseudodiploria* species) or plating coral species (*Agaricia* species) may have very minimal change in restored reef height. Inclusion of any engineered structures will also change reef structure and complexity.

Possible Methods

The following are methods that could be used to quantify the structure and complexity of a restored reef. These suggestions are not exhaustive, but are intended as examples or guidance. Whichever technique is chosen, it is important to also identify the method and accuracy of the equipment used when reporting data.

Maximum Height of Restored Corals

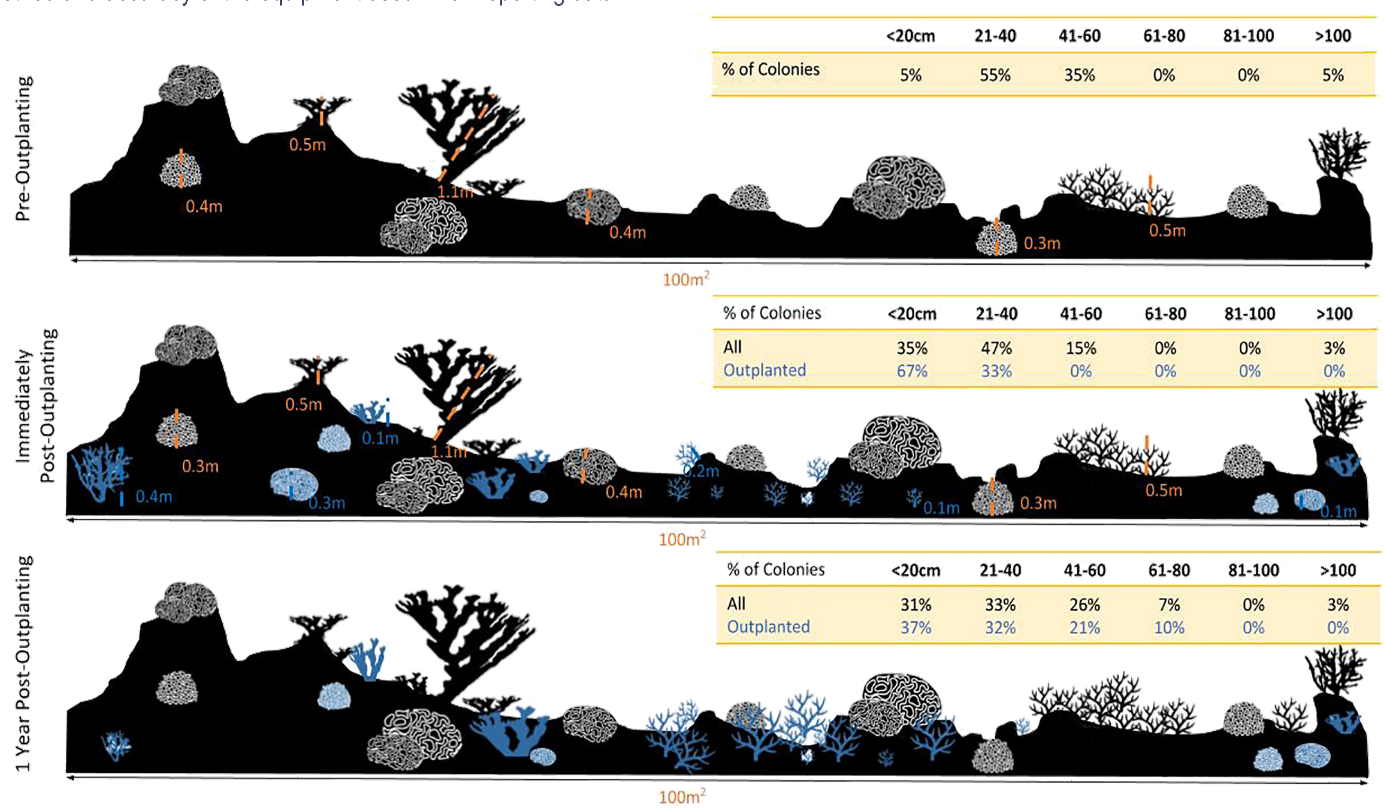
Restored reef height can be collected by measuring the maximum height of the restored coral, by species. The maximum height of a coral is measured from the substrate through the growth axis to the tallest living point on the coral. A successful restoration can become indistinguishable from a natural reef. Therefore, unrestored coral height in the restoration area and in control areas can be used for comparisons of restoration trajectories. For restorations that include restoring reef height as a goal (e.g., coastal protection), additional measurements can include heights of the entire reef structure, including restored corals. Exact colony height can be reported or height bins can be used (Figure 35). The techniques below are suggestions that could be used to collect this type of data.

In situ Measurements

Using a measuring device such as a marked PVC measuring stick or ruler, a diver or snorkeler records random height measurements that are statistically representative of the restored corals within the restoration area.

Photopoint Monitoring

Photopoint monitoring utilizes repeated photos from permanent locations over time to show change (O'Connor and Bond, 2007). A scale bar should be included in the photos in order to derive height measurements ex situ.



Pre-Outplanting:

	<20cm	21-40	41-60	61-80	81-100	>100
% of Colonies	5%	55%	35%	0%	0%	5%

Immediately Post-Outplanting:

% of Colonies	<20cm	21-40	41-60	61-80	81-100	>100
All	35%	47%	15%	0%	0%	3%
Outplanted	67%	33%	0%	0%	0%	0%

1 Year Post-Outplanting:

% of Colonies	<20cm	21-40	41-60	61-80	81-100	>100
All	31%	33%	26%	7%	0%	3%
Outplanted	37%	32%	21%	10%	0%	0%

Figure 35. Estimated height of coral colonies pre-outplanting, immediately post-outplanting, and 1 year post-outplanting using height bins.

Rugosity

Rugosity is a simple measure of the surface roughness, complexity, or topographic contour of a reef that is commonly used by coral reef biologists. Rugosity of a coral reef can reflect the positive effects of population enhancement and also the negative effects of disturbances and stressors on the reef such as ship groundings, storm damage, coral mining, or ocean acidification. The ecological importance of higher rugosity include habitat/sheltered spaces and physical niches for reef organisms and substrate for corals to attach and grow. Reefs with higher rugosity can support higher biodiversity (Tews et al., 2004; Gratwicke and Speight, 2005) and increase the carrying capacity of the habitat (Kostylev et al., 2005).

Chain length

To measure rugosity using the chain method, a 10 m fine-link chain (one link = 1.5 cm) is laid directly over the substrate and is made to conform as closely as possible to all contours and crevices. A measure of the actual surface distance relative to linear distance is obtained by measuring the distance the chain reaches with a meter transect tape. The ratio of chain to distance determines the substrate rugosity index (Risk, 1972; Luckhurst and Luckhurst, 1978) which can be used as a measure of reef complexity.

Reef Height

Using a measuring device such as a marked PVC measuring stick or ruler, a diver or snorkeler records height measurements of the restored corals along a transect within the restoration area (NOAA Coral Reef Conservation Program, 2018).

Photopoint Monitoring

Photopoint monitoring utilizes repeated photos from permanent locations over time to show change (O'Connor and Bond, 2007). A scale bar should be included in the photos in order to derive height measurements ex situ.

Photomosaic

Large area imagery (e.g., photomosaics, Structure from Motion) can be collected and processed to allow for calculation of 3-dimensional reef complexity (Figueira et al., 2015; Leon et al., 2015; Fukunaga et al., 2019; Rossi et al., 2020). Imagery can be collected for photomosaics by divers or via remote-sensing platforms such as autonomous vehicles. More information on diver-based photomosaics is available on the CRC–Reef Resilience Network webinar on photomosaics from July 2019 (Appendix 3).

Reporting

Reporting of reef structure and complexity of a restoration project will depend on the method used for quantification. Restored Structure and Complexity should be reported as a mean (cm) of all measurements recorded at each restoration site by species used for restoration.

Sampling Frequency

At a minimum, reef structure and complexity sampling should be completed at a restoration site immediately following a coral outplanting event and, if applicable, after the addition of any engineered reef structure. Additional recommendations for restoration monitoring to detect change in reef complexity over time include sampling prior to restoration, sampling at the frequency (based on species growth rates) to detect change, and sampling after a disturbance event. Sampling prior to restoration provides a baseline for before-after comparisons for change in complexity after restoration. For fast growing coral species, annual sampling of reef height is recommended to capture change in habitat creation (inferred from the change in reef height) and reef growth. For slow growing coral species, sampling should be conducted at the temporal frequency at which change can be detected. Sampling after a disturbance (e.g., wave event, bleaching or disease event) will provide data on restoration disturbance impacts in terms of the amount of complexity lost (i.e., corals and engineered structure).

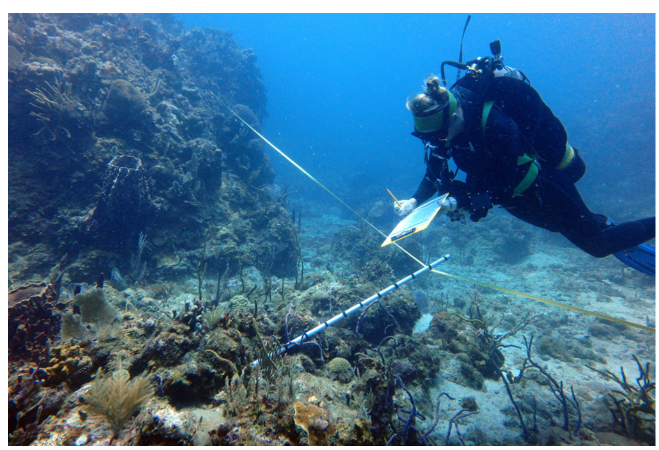
Performance Criteria

Restored Structure and Complexity should increase or stay the same across time until the maximum height for the restored coral species is achieved. The maximum achievable height at a site for a given species is likely dependent on site characteristics such as substrate type, depth, or wave energy. Net decreases in mean reef height from the initial measurements should be evaluated, and adaptive management strategies should be used if appropriate.

Evaluation Tool Criteria Alignment (Appendix 2): Community and Habitat Enhancement Metric #2.3 aligns with one criterion:

> Outplants increase reef height/rugosity of site (*Acropora*/ branching species only). If outplants increase reef height/ rugosity of reef site, as determined by pre- and post-outplanting surveys, a project will receive a score of 1 (Evaluation Tool Outplanting Criteria #20).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).



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Community and Habitat Enhancement Metric #2.4: Habitat Quality

As restored corals grow and flourish, there is an assumed positive feedback loop with the ecosystem that the quality of the direct (Ecological Footprint) and surrounding habitat quality will change. A healthy reef ecosystem will not only provide a balance of diversity and abundance of invertebrates and vertebrates, and reef structure and complexity as described above, but should also host **a supportive quality of water, reduced negative interactions, and increased recruitment of corals.** This metric aims to capture the change or effects that restoration has on habitat quality through water quality measurements, sedimentation, benthic composition, and recruitment rates. By establishing comparative metrics and parameters related to habitat quality, we will have a better understanding of the impact that restoration activities have beyond coral outplanting and will help explain restoration success or failure.

A positive change in the quality of habitat at a restoration site may take years to observe. However, these data are equally important if a restoration site is unsuccessful as some of these parameters may quickly reveal a reason(s) why, such as increased sediment load or high levels of nutrients such as dissolved inorganic nitrogen (indicating a nearby terrestrial run-off).

Water temperature, as described in the Universal Environmental Metric Chapter 6, is the basic key parameter describing the environment at a restoration site; however, there are many additional **water quality parameters** to describe the quality of water. Parameters may include, but are not limited to: dissolved inorganic nutrients, dissolved organic carbon, dissolved oxygen, phosphorus, nitrogen, chlorophyll, pH, salinity, light, Photosynthetically Active Radiation (PAR), and turbidity and should be selected based on the programs objectives (Fabricius, 2005; Cooper et al., 2009; Wagner et al., 2010). Restoration practitioners are not able to manipulate water quality at restoration sites, but they can monitor for changes, seasonal, event-driven, or otherwise, to better understand the environment in which corals flourish. The composition of the water column around a restoration site can greatly influence the success of coral outplants, particularly if they are small colonies and/or have increased susceptibility to waterborne diseases (Richardson, 1998; Voss and Richardson, 2006).

Water quality can quickly change and can often be associated with weather patterns; a heavy rain event will lead to increased run-off and likely an increase in inorganic nutrients on the reef, where as a drought, in association with high temperatures, will cause an increase in salinity. Changes in water quality may also be chronic due to an altered run-off regime. Therefore, it is important to develop a water quality monitoring plan to be able to differentiate between chronic and acute effects.

Sediment can occupy benthic space for coral growth and recruitment and potentially smother living corals. Rates of **sedimentation**, the process of settling sediment, will vary based on habitat type, geographic location, and environmental (wind, rain, and run-off) and anthropogenic (coastal construction, beach nourishment) factors. Depending on the type of sediment and environmental conditions, **turbidity** (transparency of water) may also be affected. Sedimentation and turbidity may affect the success of a restoration if rates are over what corals can endure (high accumulation of sediment on the reef) or are chronically present in high levels (Roy and Smith, 1971; Rogers, 1990; Anthony and Larcombe, 2000) and in some cases can lead to increased disease (Figure 36; Pollock et al., 2014; Miller et al., 2016b). High rates of sedimentation will also negatively affect recruitment rates (Birkeland, 1977; Bak and Engel, 1979; Birkeland et al., 1981; Rogers et al., 1984).

While the rate of sedimentation and turbidity may not change due to population enhancement activities, it is a valuable indicator for the success of restoration activities. Turbidity measurements can also indicate the amount of light that is available for photosynthesis; this could also be measured as PAR using a Quantum sensor. When selecting a restoration site or even the microhabitat where a coral is to be outplanted, the surrounding sediment should be taken into account.

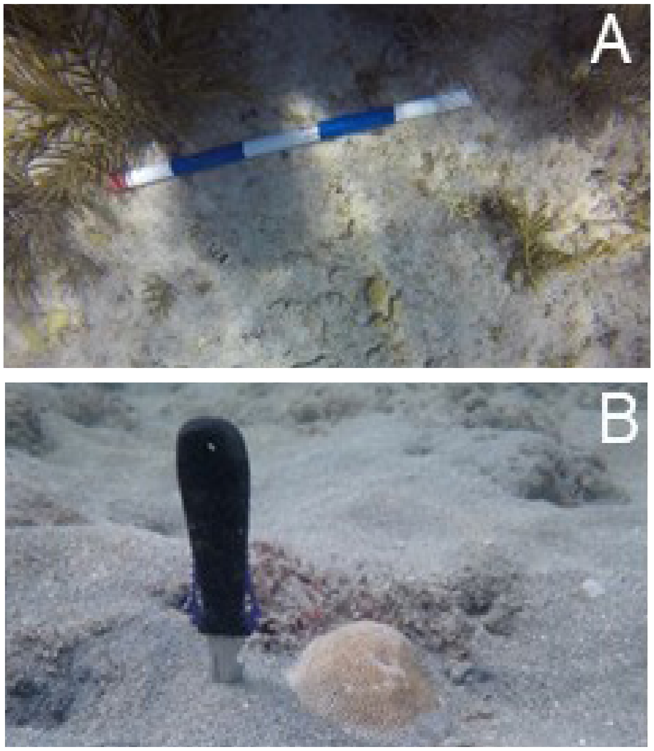


Figure 36. (A) Nine out of 10 outplanted elkhorn corals dead from sedimentation and (B) storm driven sedimentation causing outplant mortality. Image credit: Coral Restoration Foundation (A) and Nova Southeastern University CRRAM Lab (B).

One of the most visible changes that may occur following restoration is a change in **benthic composition**. Changes that may be observed are a reduction in algae, space competitors (e.g., zoanthids, encrusting sponges and tunicates), and homogeneity of the community as a reef transitions from a baseline reef to a healthy productive ecosystem. This transition may take years to occur, but is extremely important to understand in terms of understanding the reef's ecological succession following restoration.

Coral recruitment should increase following restoration as coral reefs begin their transformation to a healthier more supportive ecosystem (Miller and Barino, 2001; Montoya-Maya et al., 2016), although it may be many years before this is observed, due to the nature of coral reproduction. Recruitment may increase faster at sites with a larger abundance of brooding coral species. Observance of an increase in the abundance or cover of crustose coralline algae, known to increase the likelihood of coral recruitment, is also a good sign that the restored reef is showing signs of possible increased recruitment in the future. Documenting an increase in coral recruitment is part of the ultimate goals of restoration; creating a self-sustaining/maintaining coral reef ecosystem. While the recruitment is not necessarily from the corals used for restoration, this will help support that restoration has created a community that is producing the settlement cues necessary for new corals (Kingsford et al., 2002; Sponaugle et al., 2002; Gleason et al., 2009; Dixson et al., 2014). Ideally, recruitment would occur from a wide diversity of species, but will ultimately be determined by the diversity of the source reefs, which in most cases will be unknown. However, if coral species diversity is still low or not similar to reference or surrounding reefs following restoration and numerous recruitment events, it may be in the best interest of the restoration program to initiate the addition of additional species to the site through restoration.

The ultimate goal of a restoration program should be to improve a reef site's habitat quality or at the very least, not let it become more degraded. Not all of the factors listed above must be monitored in great depth, but any combination of them can inform the status of the habitat.

Possible Methods

The following are methods that could be used to measure habitat quality. These suggestions are not exhaustive, but are presented as a guide. Methods are grouped by parameter.

Water Quality

Water quality sampling, depending on the parameter being evaluated, will likely require additional equipment and processing expertise. Defining and outlining specific methods for each parameter are beyond the scope and expertise of this document; however, the following are a few publications and guides specific for coral reefs or coastal communities to help a program begin to develop a monitoring program suited to their needs and objectives. In addition, we advise that programs reach out to local researchers or agencies (government/non-government) for additional support and guidance, there may be others in your community who have the resources to assist in implementing a water quality monitoring program.

Australian and New Zealand Guidelines for Fresh and Marine Water Quality

Online resource providing information on developing and managing a water quality monitoring program, key elements to consider:
https://www.waterquality.gov.au/anz-guidelines

Florida Department of Environmental Protection Water Quality Assessment Program

Online resource providing examples and guidance on monitoring water quality over time:
https://floridadep.gov/DEAR/Water-Quality-Assessment

Guidance Manual for Optimizing Water Quality Monitoring Program Design

Canadian Council of Ministers of the Environment (2015) provides support and guidance in developing a water quality monitoring program. Although this guide is focused on Canadian Ecosystems, which do not include coral reefs, it provides applicable examples, guidance, and case studies of monitoring program development and execution.

Marine Water Quality Monitoring: A review

Karydis and Kitsiou (2013) provides a review of marine water quality monitoring including data analysis and international conventions with examples.

Hatsue Baily/NOAA

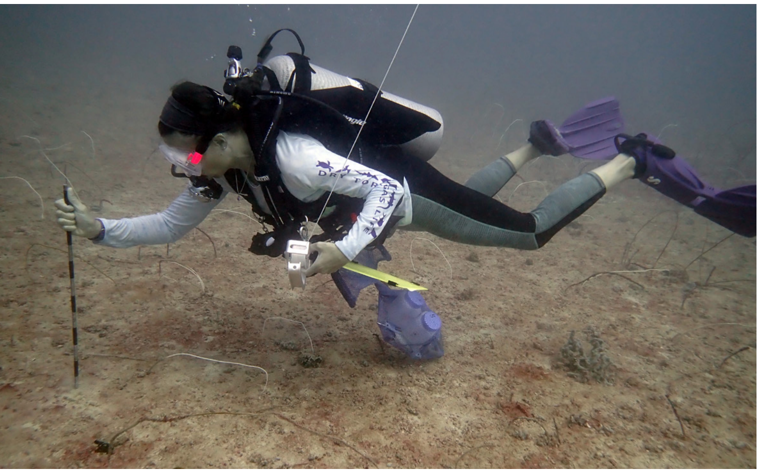
Colin Howe

Sedimentation/ Turbidity

Sedimentation and turbidity can be measured using a variety of methods ranging from a ruler to satellite imagery. Sedimentation measurements can include sediment composition, depth, and rate. Turbidity measurements include depth of Secchi disc, PAR, or NTU/FNU/FTU (Nephelometric Turbidity Unit/Formazin Nephelometric Unit/ Formazin Turbidity Unit).

Sedimentation can be measured using semi-permanent sediment traps (Nodder and Alexander, 1999; Gardner et al., 2003; Storlazzi et al., 2011), collecting depth measurements of sediment along a transect (Miller et al., 2016b) or randomly across the site, documenting the size of sediment patches along a transect or by using satellite imagery (Pollock et al., 2014)

Turbidity can be measured using a Secchi disc, light meter/ PAR (Storlazzi et al., 2015), or a nephelometers/turbidimeter (Telesnicki and Goldberg, 1995; Omar and Matjafri, 2009).



Mauricio Lopez Padierna

Benthic Composition

Details describing the following two methods are found under Coral Population Enhancement Metric #1.1, both techniques can capture the diversity and abundance of benthic cover and composition.

Transects

Belt transects can be used to evaluate benthic composition, but must be large enough to capture a sufficient area to adequately represent the community of the entire reef. This may require different size belt transects or multiple random transects (Jordan-Dahlgren et al., 2018). In addition, the placement of transects for monitoring, even if random, must be within an area where restored corals will be or are located in order to capture benthic composition within the actual restoration area. Point or line intercept transects may also be used within the actual restoration area, but only cover a very small area, thus requiring many replicates. Choice of transect type will depend on the type of benthic data wanting to be obtained.

Plots/Quadrats

Plots and quadrats are also a valuable method for evaluating the benthic composition. The defined area of a plot or quadrat allows for an easy estimate of percent cover. However, because the typical plot or quadrat are small in size this method will require replication across the RRAD in order to appropriately portray the benthic composition.

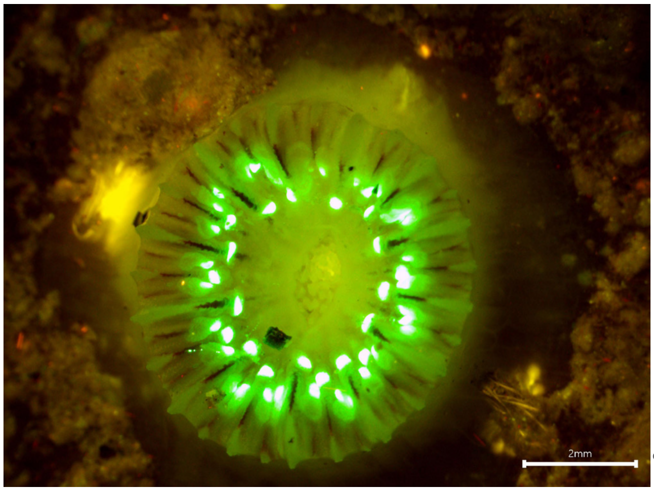
Details describing the following method are found under Universal Metric #1 and #2:

Photomosaics

Benthic composition of a restoration site can be obtained from a photomosaic. The result of the mosaic process is a high-resolution photographic archive of all benthic organisms within the area of interest that can be used for functional group identification, cover, size, and distribution at the time of the mosaic survey (Methods for obtaining a photomosaic are above in Universal Metric #1, #2, and Appendix 4). With images, identification of some functional groups may be difficult. Although some equipment is better than others are for producing fine-scale detail mosaics, a combination of methods, such as images and roving diver surveys of the same area could be conducted to help differentiate between or identify conditions.

Coral Recruitment

Monitoring for coral recruitment is a time consuming task that can require specialized species identification, so be sure to plan accordingly for fieldwork and post-processing in your monitoring plan. Coral recruits should be identified to species, when possible, measured, and tracked over time. By following coral recruits over time, indication of survival and site health can be made. Fluorescence-exciting lights may be another valuable tool to increase efficiency in locating coral recruits (Piniak et al., 2005; Baird et al., 2006).



Liz Goergen

Details describing the following two methods are found under Coral Population Enhancement Metric #1.1:

Transects

Random and belt transects can be used to evaluate coral recruitment, whereas line or point intercept transects are not suitable for capturing coral recruitment due to the sparsity of coral recruits. A smaller transect area than what is used to capture benthic composition is also warranted due to time it takes to survey for coral recruits.

Plots/Quadrats

Plots and quadrats used for coral recruitment surveys are typically smaller than those used for documenting changes in benthic cover or adult colony sizes and are generally between 25 x 25 cm and 50 x 50 cm.

Additionally, settlement plates could be used to monitor for coral recruitment:

Settlement Plates

Settlement plates/tiles/materials can be deployed within a restoration site to estimate coral recruitment. There are a variety of materials that have been used as settlement materials such as terra-cotta, concrete, granite, coral skeleton, glass, etc., each of which have their limitations and advantages (Harriott and Fisk, 1987; Mundy, 2000; Burt et al., 2009). Settlement plates should be deployed approximately one month prior to the predicted spawning season and collected a few months following the last predicted spawning to allow for settlement after spawning.

Reporting

Habitat quality reporting is dependent on the method used to capture the metric. Any water quality and sedimentation/turbidity parameters should be reported as collected, based on the sensor. Sedimentation can be recorded in several ways, including seasonal or annual sedimentation and resuspension rates, two-way sediment flux (the total mass of sediment that has been deposited and resuspended at a site), and sediment particle size distribution (Browne et al., 2012). Benthic composition should be reported as abundance, cover, and/or diversity, as number of individuals, or percent cover. Species diversity, richness, and evenness can be calculated as described in Coral Population Enhancement Metric #1.4. Coral recruitment should be reported as species diversity, abundance, and size. Collected data should be reported in program specific databases as well as uploaded into the CRC Coral Restoration Database, which can be found online (Appendix 3).

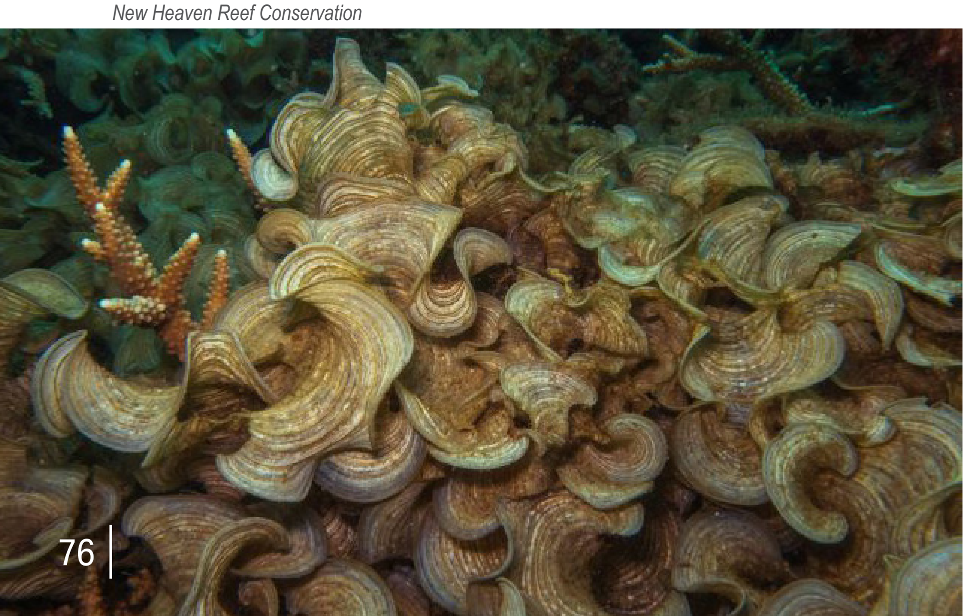
Sampling Frequency

This metric must be assessed through time in order to provide a comprehensive look at the change in habitat quality. At a minimum, we recommend sampling habitat quality immediately prior to outplanting, annually, and in response to stress events. Additional sampling may be conducted before, during, and/or after stress events such as eutrophication, algae blooms, or wind or wave events. Water quality and sedimentation/turbidity change frequently and seasonally, therefore seasonal or more frequent monitoring is suggested to capture the range of each of these parameters. Additional sampling may also be included to address specific project goals. For example, if a restoration project goal is to increase coral recruitment, then this metric should be assessed more regularly around specific times of year (e.g., coral spawning season) in order to understand how the habitat quality affects the success of the coral outplants.

Performance Criteria

Habitat quality should increase over time as restoration efforts progress. Many, if not all of these metrics will require years of data before benefits or changes in habitat quality are measurable; for example, an increase of recruitment to the site may not be reported until many years following restoration. The need for these long-term data are invaluable in determining when the effects of restoration on ecosystem function are occurring and at what time point post-restoration each criteria should be evaluated. Net decreases in habitat quality, across any and all methods used, should be evaluated and adaptive management strategies should be used where appropriate.

New Heaven Reef Conservation



Mauricio Lopez Padierna

Evaluation Tool Criteria Alignment (Appendix 2): Community and Habitat Enhancement Metric #2.4 aligns with two criteria:

Environmental parameters are measured at outplant sites to demonstrate that the site does not experience large changes in parameters over short periods of time (e.g., minimum measurement of water temperature required, but may also include light, current, sedimentation, turbidity). If this goal is met, a project will receive a score of 1 (Evaluation Tool Outplanting Criteria #4).

Benthic composition of outplant sites are surveyed long-term (>5 years) and outplant species exhibit positive change in abundance (may include recruitment of outplant species at restoration site) and growth as compared to baseline surveys. If benthic composition is surveyed annually and exhibits positive change when compared to baseline surveys, a project will receive a score of 1 (Evaluation Tool Outplanting Criteria #25).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).

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Chapter 8

Socioeconomic Goal-Based Performance Metrics

Coral reef restoration is a technological, social, and political endeavor, shaped by human needs and specific, shifting, locally defined outcomes like those presented in this guide. Restoration projects provide practitioners and their communities a chance to address systemic local environmental degradation and participate in the rehabilitation of the reef, to conserve species, maintain community connection to place, and recover critical ecosystem services. Ecosystem services are the benefits provided by ecological assets that benefit human well-being directly or indirectly (Bateman et al., 2011), such as the contribution of a coral reef to the local tourism economy, resilient fish stocks, or shoreline protection (Table 19). The ecosystems services model is just one way to measure the success of a restoration project, narrowly defining the value of coral reef ecosystems through human use (Schröter et al., 2014).

How socioeconomic goals of restoration are defined, will drive the metrics necessary to monitor for determining restoration success. For example, the economic value of these benefits vary depending on how ecosystems services are quantified. Coral reefs have been valued from US$352,249/ha/yr (Costanza et al., 2014) to over US$2 million/ha/yr (de Groot et al., 2012). Considering coral-related tourism expenditures alone, coral reefs could generate over US$36 billion globally (Spalding et al., 2017); at the same time, if one broadly considers economic, social, and iconic value, the Great Barrier Reef alone is estimated to provide US$56 billion in goods and services (Deloittes Access Economics, 2013). Whether economists consider the intangible contributions of a coral reef ecosystem or restoration project to a community, like how a reef defines personal, cultural, and communal connection to place, can additionally impact the ultimate valuation and understanding of that ecosystem.

Socio-ecological systems are complex, and capturing ecosystem services and co-benefits in an era of global coral reef ecosystem decline requires immense human effort. Social (e.g., community involvement and support), economic (e.g., sustained funding and potential economic benefits), and governance (e.g., regulatory framework and institutional support) goals must align to invest in ecological health and successful restoration (Valentin and Spangenberg, 2000). Coral restoration is logistically challenging, it requires significant capacity and financial support to implement

Table 19. Assessment example of ecosystem services provided by Hawaiian coral reef ecosystems, highlighting direct socioeconomic services from coral restoration projects themselves. Table adapted from Bishop et al. (2011).

Goods		Services				
Renewable Resources	Nonrenewable resources	Physical Structure	Biotic	Biogeochemical	Information	Social and cultural
Commercial and recreational fisheries	Coral blocks and sand for building materials	Construction of complex structural base for habitat by hermatypic corals	Maintenance of coral reef habitat processes and functions	Nitrogen fixation	Historical record of contaminants	Recreation such as ecotourism, diving, and snorkeling
Pharmaceuticals and medical raw materials	Raw materials for production of lime and cement	Protection of shallow aquatic nursery and feeding habitat from severe wave action	Provision of spawning, nursery, breeding, and feeding areas for many species	Carbon cycling	Historical record of salinity	Cultural and religious values
Raw materials (primarily seaweed) for production of agar, carrageenan, and fertilizer	Mineral oil and gas	Protection of shoreline property from severe wave action and erosion	Maintenance of species and genetic diversity	Calcium sink	Historical record of sea temperature	Maintenance of traditional lifestyles
	Shells and corals for jewelry and souvenirs	Construction of new land	-	Export of dissolved organic matter, nutrients, and plankton to nearby habitats	Monitoring of environmental pollution impacts	Aesthetic values and artistic inspiration
Live fish and corals for aquariums	-	Provision of sand to tropical beaches	-	Assimilation of waste (particularly petroleum)	-	-

Original Source: Adapted from Moberg and Folke (1999), Table 2.

and ensure the program achieves its goals while minimizing unintended consequences like overuse. Consideration of the socioeconomic benefits and risks of coral restoration and collaborative consensus building with coral-reef-adjacent communities are critical to achieving project goals.

Reef-dependent tourism economies are not necessarily sustainable, and must be well managed to capture potential co-benefits (Hein et al., 2019). Coral restoration can improve local fisheries and attract coastal hotels and businesses, as well as provide valuable ecosystem services like coastal protection. Restoration projects can also lead to new business opportunities for dive tour operators and promote environmental awareness for dive professionals. At the same time, restoration-related tourism can also create negative environmental impacts to coral reefs from such new infrastructure development, intercultural conflict between tourists, hospitality staff, and locals, and overload local carrying capacity (Diedrich, 2007; Daldeniz and Hampton, 2013; Wongthong and Harvey, 2014). Increased diving and snorkeling pressure can, if poorly managed, lead to the degradation of and loss of marine life (Hasler and Ott, 2008; Lamb et al., 2014; Albuquerque et al., 2015). In addition, the influx of tourists to an area can have indirect impacts on coral reef health arising from poorly planned coastal development, including dredging, building on intertidal spaces, and increases in pollution and solid waste (Davenport and Davenport, 2006; Wongthong and Harvey, 2014). When restoration and conservation-related enterprises act as local or regional development projects, they can alter local cultures and infrastructure needs (West, 2008). Prior to developing a tourism component to a restoration project, restoration practitioners should assess the vulnerability of the reef site to unsustainable development practices (Calgaro et al., 2014), economic sustainability, and cultural conflicts between user groups (e.g., fishermen, local leaders, and tourism operators).

Programs should center equitable coastal access and local priorities for coastal zone users by collaborating with stakeholders and environmental resource managers to set restoration objectives and ensure comprehensive ecosystem health. Access to coastal resources, from clean air to food to open space, is a significant environmental justice issue and is inseparable from the social and economic issues underlying sustainable environmental and resource management (UNEP, 2012; Reineman et al., 2016). Centering traditional needs cannot only foster support for the project, but is a critical socioeconomic metric for the long-term success of the restoration project. Local government or permitting agencies should be included in program planning to ensure that reef resources being used by restoration programs are properly managed and not over-exploited. Local buy-in in terms of responsibility and financial support includes clear communication of the long-term costs of a restoration project, and does not displace undue risk or responsibility on local managers. Without realistic goals and continuing programmatic support or capacity, restoration programs and coral restoration efforts are unsustainably designed from the outset. These failures can foster negative perceptions about reef restoration and restoration-related ecotourism.

Curt Storlazzi/USGS

The following suggestions for Socioeconomic goals do not represent the entirety of social, cultural, or economic relationships between communities and their coral reefs. Furthermore, this guide does not address the diversity of equity issues at stake in coral restoration projects of any scale. At the same time, those unique relationships drive community investment in restoration projects and the strategies necessary to ensure long-term sustainability and success. By providing examples of ways scholars have captured the systemic impacts of restoration projects, we hope that practitioners can identify key benefits and opportunities to fully integrate restoration projects into their socioeconomic environment.

Objective 1: Economic

Coral reef restoration can provide a diverse array of ecosystem services and economic benefits. From coastal protection, to increased tourism revenue, to promoting the health of local natural reefs through reduced natural reef visitation or the cultivation of coral and other reef species, restoration projects increasingly demonstrate economic benefits to reef-adjacent communities. However, program success is dependent upon the economic sustainability and financial equity of the project (e.g., financial transparency, distributed project benefits, and responsible financial planning), from implementation to maintenance and operation.

Economic Metric #1.1: Coastal Protection

Climate-related stressors such as sea-level rise (Church et al., 2013), a more powerful global wave climate (Reguero et al., 2019), and more frequent and intense hurricanes (Bender et al., 2010; Knutson et al., 2010; Anthony, 2016) are increasing flood risk to coastal infrastructure and communities. Coral reefs can act as natural breakwaters that dissipate wave energy through wave breaking or friction (Gourlay, 1996a,b; Sheppard et al., 2005; Quataert et al., 2015; World Bank, 2016). Healthy coral reefs absorb 97% of wave energy and buffer shorelines from currents, waves, and storms (Ferrario et al., 2014). This contributes to the prevention of loss of life, economic activity, and property (Ferrario et al., 2014). Recent studies estimate that reefs mitigate up to US$1.8 Billion in damages from coastal flooding in the U.S. every year (Storlazzi et al., 2011; Beck et al., 2018).

The potential benefits that coral restoration can provide for coastal protection are controlled by reef and coral features at multiple spatial scales, including the coastal zone, reef, and coral scales, and multiple temporal scales, including short-term and long-term benefits (Viehman et al., In Review). Siting restoration projects for coastal protection needs to consider the hazards, exposure and vulnerability, and valuation (van Zanten et al., 2014), as well as where potential restoration benefits will be feasible and realistic. The potential for effective wave energy reduction by coral restoration is controlled by the location, size, structural complexity, and depth of the reef and corals. As with other coral restoration projects for other purposes, the sustainability of the restorations relates to the restoration trajectories of restored corals; however, restoration for coastal protection also needs to consider potential impacts of wave energy over short time-scales (i.e., when benefits will be provided) and long time-scales (i.e., how long will the restoration benefits be provided). The intended time frame for the implementation of coastal protection benefits also relate to coral design: for more immediate benefits, larger corals with more complex morphologies may need to be outplanted rather than small corals. For more immediate return of coastal protection services or for severely degraded reef structure, the addition of gray infrastructure (i.e., engineered structure) or a hybrid gray-green infrastructure (i.e., combination of engineered structure and ecological corals; Reguero et al., 2019) may need to be considered. Artificial reefs (i.e., gray infrastructure) have been deployed to protect beach areas for tourism and other recreational purposes in locations including the Bahamas, China, Maldives, Mexico, and Indonesia (Ranasinghe and Turner, 2006; Scarfe et al., 2009; Moore, 2019).

Possible Methods

Scaling up coral restoration for coastal protection is an area of active multi-disciplinary research and development. We caution that quantitative measurement of the contribution of a restoration project to localized coastal protection requires significant multi-disciplinary institutional support; partnerships with subject-matter experts are strongly recommended. Scientists are beginning to establish a direct link between nearshore coral reefs and shoreline stability (Frihy et al., 2004; Ruiz de Alegria-Arzaburu et al., 2013; van Zanten et al., 2014; Reguero et al., 2019). Much of the extensive nearshore oceanographic research conducted on coral reefs and wave energy can be applied to coral restoration scenarios, although few of these efforts have yet incorporated restoration. Recent studies have leveraged remote sensing data to compare shoreline change over time, propagate oceanographic wave and current models ground-truthed with local oceanographic data, and apply coastal engineering models to design coral reef restoration and quantify the coastal risk reduction benefits provided by restored coral reefs (Reguero et al., 2019).

We suggest that a combination of methods are relevant to monitor the success of coral restoration for coastal protection. Without conducting research akin to the resource-intensive studies that measure coral reef benefits to shoreline protection cited above, restoration groups or collaborators should track the following values of coastal protection:

Economic Value of the Coastal Economy

Numbers of tourists, coastal properties, and natural infrastructure contribute to the economic value of the coastal economy. Tourist use can be represented by numbers of visitors (individual and family), how much travel and tourism activities contributed to the gross domestic product, and potentially the economic activities of your coastal town or city. Economic valuation of natural resources, such as a beach protected by coral restorations, can be represented by local activity (i.e., direct tourist visitation to the beach). Coastal property valuation is also a metric to represent coastal hazards risk.

Costs of Existing Coastal Protections

If there have been local or regional investments in engineered coastal protection in the form of breakwaters, seawalls, bulkheads, groins, or jetties, the construction and maintenance costs of those installations can be evaluated. Non-governmental organizations (NGOs) such as The Nature Conservancy have incorporated similar evaluations into their Insuring Nature projects in Mexico and Hawai'i (World Bank, 2016; Spalding et al., 2017; The Nature Conservancy, 2019; Reguero et al., 2019).

Wave energy

Wave energy across the reef to the shoreline should be evaluated before the restoration implementation, at regular intervals during the development of the restoration, and when the restoration is considered fully mature. Additionally, these field measurements can be used to ground-validate coastal oceanographic models to relate wave energy to coastal inundation. A wide range of potential wave conditions should be modeled to project the change in coastal protection provided by the restoration both as the restoration develops and under a wide range of potential oceanographic conditions.

Curt Storlazzi/USGS

In addition, we suggest that monitoring of coral restorations related to coastal protection needs to quantify not only metrics for restored coral species, abundance, and colony size, coral cover, and reef structural complexity as detailed by this Guide, but also wave energy across the reef to the shoreline, and coastal infrastructure valuation. If engineered infrastructure is included, additional monitoring of structural integrity is necessary. This specific objective is early in the research and application phase and is an area of active research.

Reporting

Quantitative monitoring data should be reported in program specific databases and/or permitting and funding reports. Reporting on the risk reduction of the coral restoration within the context of the value of the coastal economy is important to demonstrate the long-term value of these programs.

Sampling Frequency

Sampling should be completed at a restoration site before, immediately following a coral outplanting event and, if applicable, after the addition of any engineered reef structure. Additional recommendations for restoration monitoring to detect change in coastal protection services provided over time include: sampling prior to restoration, sampling at the frequency (based on species growth rates) to detect change, and sampling after a disturbance event.

Performance Criteria

Coral restoration for coastal protection should reduce coastal risk from hazards such as wave-driven flooding. The coral restoration should decrease wave energy that reaches the shore, and therefore reduce risk to coastal infrastructure. Because risk reduction will vary depending on the magnitude of the coastal hazard (i.e., hurricane strength and duration), this metric should be modeled and evaluated within a wide range of potential scenarios, from normal conditions to moderate events and to extreme events.

Economic Metric #1.2:

Responsible Ecotourism Opportunities

Tourism can both contribute to the local economy and extract resources from the local environment and economy. Within coastal communities bordering coral reef ecosystems, the environmental impacts of tourism can range from beach nourishment, to uncontrolled development, to loss of fishery resources. However, there are numerous opportunities for a community to leverage tourism development and change the impact of those activities on the environment, such as developing responsible ecotourism. At minimum, ecotourism is "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education" (The International Ecosystem Society, 2015). Locals should be empowered to define what responsible tourism activity looks like for their community during the planning process and ensure their plan is completed. Beyond good intentions, ecotourism requires effective planning and local management of resources in order to prevent potential negative impacts of travel-related emissions, infrastructure development, and community disenfranchisement (Nelson, 1994; Shani et al., 2012; Wearing and Schweinsberg, 2018).

> Given the broad array of economic and social benefits that coral reefs provide, there are growing attempts to build more sustainable approaches to reef-related tourism (Diedrich, 2007; Townsend, 2008; Arkema et al., 2015), some including the development of coral restoration projects as attractions themselves (Stolk et al., 2007; Meyers, 2016). Developer interest in environmental appreciation has recently increased in the dive tourism industry along with rapidly growing accessibility of remote coral reef areas due to budget airlines and proliferating tourism infrastructure (Harriott et al., 1997; Dimmock, 2006; Garrod and Gossling, 2008; Burke et al., 2011). Tourism development, while able to attract additional participation and investment in coral restoration efforts, can have systemic impacts on local carrying capacity and exacerbate environmental stressors (See Sociocultural Metric #2.2). However, the dive industry has been slow to develop resilience frameworks or strategies to withstand economic and ecological disruption created by the increased stress of tourism on local reefs and economies (Hillmer-Pegram, 2013).

Coral reef restoration projects are just one example of an ecotourism opportunity that can generate economic investment in the community. Moreover, **a well-developed, responsible coral reef restoration ecotourism program has the ability to attract visitors to participate in a unique experience that can shape tourists' relationship to the marine environment and foster global stewardship of coral reef ecosystems. The economic benefit from these activities can extend to dive and snorkel shops, hotels, and local shops and restaurants.** Coral reef restoration ecotourism can also improve the existing coral reef socio-ecological community through habitat development and enhanced local investment in reef health, which could provide economic benefits to other reef users like anglers. Restoration projects that have the goal of increasing tourism should do so responsibly, and with the awareness that tourism infrastructure can exacerbate environmental stressors, economic inequality, and erode local sovereignty (Moore, 2019).

Possible Methods

The following are methods that could be used to evaluate tourism activities related to reef restoration. The Infrastructure Census may require collaboration with social scientists. These suggestions are not exhaustive, but are presented as a guide:

Participation

Track the annual number of participants in restoration-related dives and on-shore activities (e.g., building of nursery structures on land) and the number of dives and/or snorkel excursions to restored reefs. To track visitation of restored sites versus natural reefs, request that dive shops report the number of dives on each site each month, rank the dive sites by how frequently that dive shop visits that site, or bring a map around the dive shops and docks to ask reef-users what the most heavily-used reef areas are before and after project implementation. Assessments should include participant metadata (e.g., nationality, ethnicity, education level, occupation, net income, household income).

Corales de Paz

Reef-Related Dive Tourism Revenue

Measure the number of dive shops, number of employees and trainees at each dive shop, and the number of conservation-oriented certifications being offered at those shops who work with a project. Annually, ask the shops to report the number of divers who visit their shop per year, and track the number of shops referring to conservation or restoration activities on their websites or social media accounts.

Restoration-Oriented Diver Trainings with Local Shops

Track the number of trainings conducted by local dive shops for restoration-related dive certificates, and the number of trainings conducted to include dive shops in restoration-related activities. Document who owns the shop and whom the shop employs (e.g., What percentage of employees are foreign or local? What is the average education/experience level? How long does the average employee stay in that area?).

Albert Manduca


Corales de Paz

Infrastructure Census

As coral reef ecosystem health improves or declines, tourism infrastructure dependent on reef health can also expand or contract. To understand potential inputs to the reef ecosystem, it is critical to monitor the types of local infrastructure currently available and how that infrastructure can impact your project (i.e., How effective is the sewer plant at maintaining good water quality?).

Note:
When new developments or public facilities are constructed, there are several open-source tools available to structure this census. The European Tourism Indicator System is a management, information, and monitoring tool specifically designed as a locally-owned and -led process for collecting and analyzing statistical data at the local level to assess the impact of tourism on a destination aligned with the United Nations World Trade Organization's Sustainable Development Goals (European Commission, 2016; Appendix 3). Managers can also refer to the US Forest Service's Limits of Acceptable Change program to help achieve sustainable development adjacent to protected areas (Brunson, 1997).

Reporting

Quantitative monitoring data should be reported in program specific databases and/or permitting and funding reports. This is also an opportunity to share these results with the community through public media like newspaper articles, public meetings, radio interviews, and flyers.

Performance Criteria

If the purpose of a restoration project or program is to increase opportunities for tourism, performance criteria should evaluate the trends in tourist participation in reef restoration activities, tourism revenue generated by restoration projects, and visitation of reef restoration sites. Annual tourism participation should increase initially after restoration programs are established and will likely level off over time. Coral restoration programs have the potential to reduce negative pressure placed on coral reefs by dive or snorkel related activities. Therefore, it is important to monitor both natural and restored reefs to evaluate condition. Evaluation of coral resources and condition should follow Chapter 5 and Chapter 7 of this Guide.

Evaluation Tool Criteria Alignment (Appendix 2): Economic Metric #1.2 aligns with four criteria:

1. Volunteer restoration participants have an increased awareness about the status of coral reefs and the need for coral reef restoration. If a pre- and post-participation survey is conducted, a program will receive a score of 1 (Education and Outreach Evaluation Tool Criteria #1).
2. Program includes adequate (frequency, metric, etc.) monitoring to determine success (defined in guides). If a program conducts survival monitoring of outplants, the program will receive a score of 1 (Restoration Program Evaluation Tool Criteria #9).
3. Program shows financial robustness and stability. If a program has at least a 3 year financial plan, the program will receive a score of 1 (Restoration Program Evaluation Tool Criteria #11).
4. Program can be managed and maintained by the staff and resources locally available. If a program's nursery structures or corals are properly maintained and gross mortality is not observed due to neglect (i.e., colonies fallen in sand, dislodged colonies, colonies overgrown by competing organisms, broken structures, abrasion), the program will receive a score of 1 (Restoration Program Evaluation Tool Criteria #12).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).

Objective 2: Sociocultural

While restoration focuses on coral reef ecosystems and ecological characteristics, there is also the potential for restoration activities to improve the resilience of the local communities through education, engagement, and empowerment. Programs that pursue financially responsible, place-based, community-driven restoration may achieve significant sustained participation that ensures the economic viability of the program in the future. For example, improving local stewardship through education, and educating restoration practitioners about the local community, can minimize further direct impacts to the reef, reducing restoration costs in the long-term and fostering sustained community engagement. Some restoration projects prioritize such objectives.

Sociocultural Metric #2.1: Cultivating Stewardship through Education and Outreach

Coral restoration is increasingly used to educate local communities, stakeholders, and ecotourists about the value of healthy reefs and to create stewardship for coral reef ecosystems and other marine resources. Many existing restoration programs now incorporate an education and outreach component to not only educate participants, but also to leverage volunteer participation and additional resources (e.g., participation fees) to increase the number of corals that can be outplanted. As popular awareness of coral restoration grows, new restoration programs have been created by local dive shops, NGOs, for-profit companies, or ecotourism-related ventures (e.g., hotels, resorts) to organize environmentally-minded tourists or to serve as a form of mitigation in response to declines in reef health (in many cases due to coastal construction or other local stressors). It is important that these projects be taken up with a commitment to sustainable project management, thorough and ongoing community engagement, and preferably in concert with other conservation efforts to promote successful restoration efforts.

Corales de Paz

Regardless of the reason for the restoration, the long-term success of a coral restoration and conservation program can benefit from effective education and outreach. Conveying key context and the science behind restoration, communicating the personal and community impacts of reef degradation, and involving as many people as possible in the actual coral reef restoration process generates awareness and is an integral part of restoration success (see next section). As media representation of coral reef vulnerability becomes widespread and generates broad community involvement, participatory coral reef restoration can cultivate stewardship and help bring environmental awareness into the mainstream.

Cultivating stewardship can produce benefits that reach far beyond the reef. Stewards can directly impact the coral restoration community by increasing awareness about specific programs, providing a helping hand to restoration programs through community and volunteer participation, developing divers' scientific literacy and stewardship, increasing investment in restoration efforts through ecotourism and a sense of investment in restored corals, and increasing awareness of systemic environmental issues. Tourism projects that promote an awareness of coral reef conservation have been demonstrated to both improve support of conservation projects in study communities and perceptions of local quality of life (Diedrich, 2007).

Coral outplanting conducted as part of an education and outreach component of coral restoration programs should be monitored using the Universal Metrics and Goal-Based Performance Metrics provided within this Guide to measure restoration success. Restoration program operators should ensure that both propagation/outplanting techniques and monitoring methodologies meet the current standards outlined by best management practice guides and permitting agencies. Monitoring conducted should be able to track program success.

In addition to environmental metrics for restoration monitoring, community participation and increased stewardship may be quantified to measure the impact of education and outreach on restoration success. Concepts to develop when establishing a restoration program for education or improving stewardship include communication strategies, marketing, participation demographics, and post-participation behavioral changes. Measuring such impacts may be complicated unless the proper tools and monitoring are established from the start.

Many restoration programs utilize volunteers and ecotourists within their outplanting strategies with an aim to educate and increase stewardship for local coral reefs. Some of these include Oceanus, A.C., Reef Check, Fragments of Hope in Belize, and the Coral Restoration Foundation. In the U.S., Rescue A Reef at the University of Miami focuses on education and research to quantify the impact of stewardship on the success of restoration. Additionally, stewardship programs like the U.S. National Marine Sanctuaries' Blue Star program or watershed awareness training like the U.S. EPA's Get in Step program are successful programs that may provide models for stewardship program development.

Communication between restoration and stewardship programs and other community organizations that are integral to the communities in question, particularly those with similar goals or geographies, will help share lessons learned and maximize the capacity of your project.

Possible Methods

In addition to monitoring for the success of reef population enhancement by following Universal Metrics methods, the following techniques can be used to measure the impact of educational and outreach programs on community members impacted by coral reef restoration projects. These suggestions are not exhaustive, but are presented as a guide.

Event/Campaign Statistics

Record the type of event (e.g., conference, speaking engagements, dive, festival, and classroom), number of participants, time, location, and date of event, cost of event, and demographics of participants. Note any sponsors or collaborators.

Participation Assessment

Regardless of the techniques used for outreach or education, a pre- and post- assessment must be completed (Oliveira et al., 2018). Restoration programs can educate reef stewards about proper dive techniques and the fragile state of local coral reefs, which may help alleviate pressure at dive sites by providing reef enthusiasts with important knowledge about how to take care of local reef resources. Such perception can be evaluated using pre- and post-dive surveys and positive growth or survivorship of outplanting conducted by participants could demonstrate a reduction of pressure on local reefs.

Assessments should include participant metadata (e.g., nationality, ethnicity, education level, occupation, net income, household income), questions regarding their opinion of the activity they participated in and the impact of restoration, and participant observation (description of the customs of individual peoples and cultures; Meyers, 2018). Post-participation surveys can be distributed in-person or by email, and can promote ongoing communication with volunteers. For examples of a coral restoration participant survey, see Appendix 6.

Reach

If a program's education and outreach tactics utilize social media, online resources, outside media coverage, or other technologies, track the reach of each post or campaign. This can be performed by using a variety of online resources, such as Google Analytics, which tracks items like the number of times a page is visited, from what country of origin, and from what type of device (mobile or desktop).

Ongoing Engagement

Track number of participants/volunteers per event and number of repeat participants/volunteers throughout the year.

Outplanting Scope

Number of corals outplanted (per species) by volunteers, and participant monitoring/observation data (to be analyzed by coral restoration program per Chapter 5 and Chapter 7 Metrics) can document steward contributions to the project over time.

Reporting

Environmental awareness reporting may be dependent on whether program operators conduct participant surveys (qualitative) or outplant monitoring (quantitative). For qualitative data, survey data may be statistically analyzed to provide quantitative data regarding participant perception of the environment or the impact of coral restoration on participant behavior. Change in participation over time is a simply generated engagement metric that, when broken down by demographic data, can describe who is currently participating in the restoration effort and which new communities could be targeted to diversify engagement. Pre- and post-participation surveys can inform local managers or program

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operators on the impact that awareness programs have on public perception and conservation efforts. Quantitative monitoring data should be reported in program specific databases as well as uploaded into the CRC Coral Restoration Database where applicable, which can be found online (Appendix 3).

Sampling Frequency

Pre- and post-certification or participation surveys should be conducted for each education and outreach event. In addition, if program participants or operators are collecting initial or post-outplanting monitoring data, sampling should be conducted as recommended in Chapter 5 and Chapter 7 of this guide.

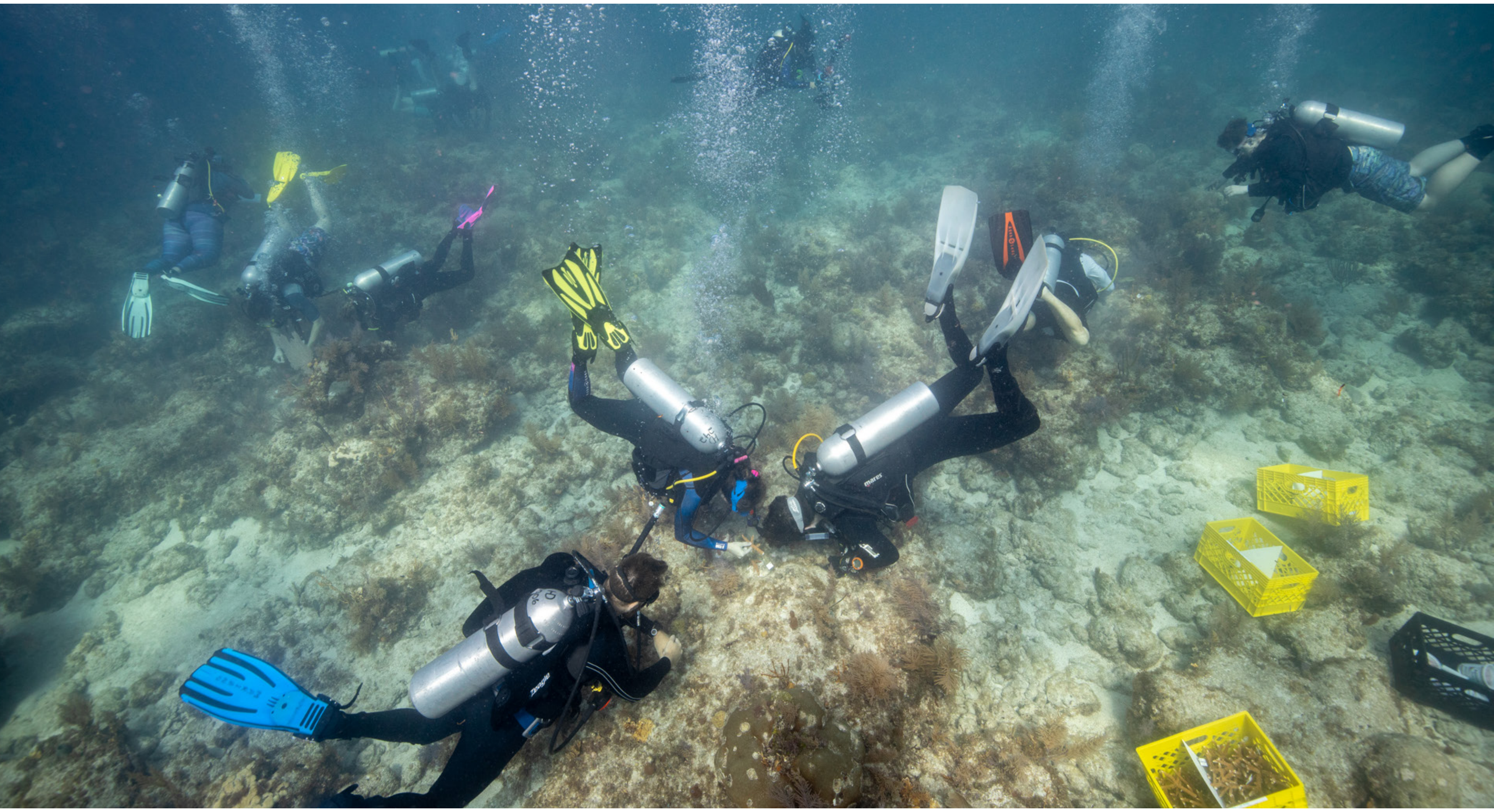
Performance Criteria

Pre- and post-participation survey analysis should show an increase in the overall knowledge about coral reef ecology, the status of local coral reefs, and restoration methodologies. In turn, restoration practitioners should incorporate results into future program implementation. Participation in citizen science restoration programs should also influence the perception of the need for coral restoration. Over time, the total count of participants should increase. Regular engagement from the local community and repeat visitors is critical; the number of repeat participants may be relatively static, but is important to document as a measure of continued investment over time. Although large-scale coral condition and survivorship monitoring is not the focus of socioeconomic coral restoration programs, data on the status of the corals outplanted by program participants must be collected to ensure proper techniques are being used. Although program participants or operators may not be considered "coral restoration experts," data should confirm that corals used as part of educational restoration are surviving and contributing to the overall restoration of the coral reef community (Hesley et al., 2017).

Evaluation Tool Criteria Alignment (Appendix 2): Sociocultural Metric #2.1 aligns with two criteria:

1. Program/certification participants have an increased awareness about the status of coral reefs and the need for coral reef restoration. If a pre- and post-participation survey is conducted, a program will receive a score of 1 (Education and Outreach Evaluation Tool Criteria #1).
2. Corals outplanted as part of educational, stewardship or capacity building programs have similar condition and survival to other local restoration programs. If corals outplanted as part of educational programs show positive growth and survivorship over time, a program will receive a score of 1 (Education and Outreach Evaluation Tool Criteria #2).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).



Coral Restoration Foundation

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Sociocultural Metric #2.2:

Capacity Building

Future investment in coral restoration depends upon whether the restoration program is economically sustainable and has the capacity to locally operate and maintain the coral restoration activity. Capacity building is the cultivation of the diversity of skills, knowledge, and information necessary to increase long-term economic sustainability and organizational capacity in the community, and ultimately meet community standards for sustainable coral restoration. In a coral restoration context, economic sustainability is when a program's costs are less than or equal to the estimated cost of the beneficial resources created directly or indirectly through restoration. Economic benefits provided by coral reef ecosystems are assessed against the local costs of restoration to ensure that the community has sufficient support to manage the project in the long-term, and that restoration is the most effective approach for mitigation and adaptation. Coral reefs are some of the most expensive ecosystems to restore, and costs vary greatly between developed and developing countries (Bayraktarov et al., 2016). Conservation and restoration projects tend to be more sustainable and successful when designed, implemented, and managed by local community members (Brooks et al., 2013; Hargreaves-Allen et al., 2017; Reyes-García et al., 2019). Financial and administrative support can help community members shoulder the risks and responsibilities of restoration work. Project managers must budget for the cost of materials and techniques they use, which can range from US$10,000/ha to over US$2 million/ha (Spurgeon and Lindahl, 2000; Edwards, 2010; Bayraktarov et al., 2016; Chamberland et al., 2017), in addition to staff salaries, vessel and vessel related expenses, and administration costs. These costs remain poorly documented and unevenly distributed across stakeholders, yet are a significant factor in determining the success of the restoration project.

Economic stability also includes the long-term viability of the restoration project, including a sustainable restoration plan with long-term financial support, citizen science participation, meaningful community relationships, oversight by resource management agencies, and appropriate response plans to minimize coral mortality and/or abandonment. Projects should be designed to ensure that participants, tour operators, and local partners do not lose interest or the resources necessary to maintain the site after the initial stages of a new restoration program. “Orphan” nurseries where corals continue to grow but are not maintained or, worse, never outplanted, result in mortality of corals (Lirman and Schopmeyer, 2016). Furthermore, unattended corals or poorly managed nursery and outplanting sites foster negative perceptions about reef restoration, which may reduce volunteer engagement and organizational capacity.

Coral reef restoration projects can help develop local organizational capacity, sovereignty, and empowerment to manage and monitor coastal resources. Ideally, management strategies for coral reef restoration projects should be developed with consideration of the biophysical, sociocultural and managerial settings of a given site, and pre-determined with local partners and stakeholders before project implementation to sustainably meet long-term organizational goals (Wongthong and Harvey, 2014; Lucrezi et al., 2017). Co-benefits of reef restoration projects will be more efficiently captured if projects plug into existing environmental management plans that integrate local and indigenous knowledge into adaptation planning, economic development decision making, and scientific understanding at multiple levels (Drew, 2005; De Souza and Clarke, 2018). Including qualified locals as volunteers in the installation, maintenance, and monitoring of the restoration project can build support and buy-in for the project while conducting effective scientific monitoring.

Citizen science is public participation in formulating research questions, conducting scientific experiments, collecting and analyzing data, interpreting results, making new discoveries, and developing technologies and applications. Citizen science is a novel, reliable, and cost-effective model for monitoring, and data accuracy from these efforts can be improved by including iterative project development, volunteer training and testing, expert validation, replication across volunteers, and statistical modeling of systematic error (Kosmala et al., 2016). Incorporating citizen science participants into adaptive management through existing organizational infrastructure can promote individual, community, and regional science-based management (Cooper et al., 2007; Marshall et al., 2012).

Citizen science that centers on the participation of local residents improves project engagement, acceptability within the community, and equity through skill-sharing and access to educational resources. Many citizen science projects employ a “Participatory Action Research Model,” which elevates the participant’s identified issues, interests, and capacity to define problems and research priorities at a larger scale and in coordination with specific goals (e.g., long-term coral reef resilience). Indeed, management recommendations are not truly evidence-based unless they integrate sociopolitical factors like land use and community buy-in; community participation can identify these issues early on (Mathevet and Mauchamp, 2005).

Citizen volunteers are particularly helpful for coral restoration projects and can perform tasks such as installing and maintaining nursery structures, outplanting corals on the reef, removing coral predators like *Hermodice* fireworms, *Coralliophila* snails, *Acanthaster planci*, and documenting fragment measurements (Branchini et al., 2015; Meyers, 2016; Hesley et al., 2017; Hein et al., 2019). With sufficient funding, citizen engagement in restoration can be used to provide for alternate livelihood opportunities, such as training and employing fishers to perform restoration. Additionally, citizen engagement in coral restoration can lead to increased awareness of coral reef condition and promote stewardship (Hein et al., 2019). Effectiveness and endurance of coral restoration programs are strongly linked to such community support and involvement (Ammar, 2009; Schrack et al., 2012; Hernández-Delgado et al., 2014).

Possible Methods

Suggested methods to measure the sustainability of restoration program operation and maintenance, track education and citizen capacity building and the economic sustainability of the project. Many of these methods are also included in Economic Metric #1.2 and Sociocultural Metric # 2.1. The Budget Analysis is easily achievable by restoration program staff. The following list provides suggestions but is not exhaustive.

Participation Assessments

Pre- and post-certification or participation survey assessment (Oliveira et al., 2018) which includes participant metadata and ethnography (description of the customs of individual peoples and cultures; Meyers, 2018). Test participants before and after going through the program to assess knowledge, awareness, or understanding gained through training and their restoration efforts. A helpful guide to measuring learning outcomes for citizen scientists is the Cornell Lab’s User’s Guide for Evaluating Learning Outcomes in Citizen Science (Appendix 3; Phillips et al., 2014), or survey participants to gauge the impact of participation on citizen stewardship (Hein et al., 2019).

Ongoing Participation

Track the annual # of participants/volunteers and certification level, # of repeat participants/volunteers, # of dives, diver skill deficiencies (i.e., where do they need additional training to better implement coral restoration projects?). Survey participants for any costs they associate with the project (e.g., travel to restoration sites, gear acquisition and upkeep, hours taken off from an hourly job).

Outplanting Scope

Number of corals outplanted (per species) and participant monitoring/observation data (to be analyzed by coral restoration program per Chapter 5 and Chapter 7 Metrics). If citizens perform outplanting or data collection, monitoring results should be compared to data collected or outplanting performed by experts to gauge accuracy of data collection and efficacy of outplanting by volunteers.

Budget Analysis

Consider the total costs of project planning and implementation, including person-hours and communications materials. Track the costs of the restoration project, including: nursery material costs (e.g., PVC, rope, epoxy, tools, baskets, holding tanks), labor costs (person-hours spent preparing and implementing project [paid and unpaid], number of tanks of air, surface support crew hours), communications costs (promotional materials costs, person-hours at community meetings or conducting trainings), amount of vessel fuel used, vessel hours used, costs of permits, and local environmental impact assessments, etc.

Reporting

Data collected here should be reported within program specific databases and/or permitting and funding reports. This is also an opportunity to share both quantitative and qualitative results with the community through public media like newspaper articles, public meetings, radio interviews, and flyers. Quantitative monitoring data, collected following guidelines in Chapter 5 and Chapter 7, should be reported in program specific databases and where applicable, uploaded into the CRC Coral Restoration Database, which can be found online (Appendix 3).

Consider that many potential volunteers cannot take time away from their work and/or family care responsibilities, or might not be physically able to participate in active restoration activities, but can provide other support through reporting, communications, and data processing. As you report your activities to the broader community, articulate the diversity of ways volunteers have contributed.

Sampling Frequency

Surveys should be conducted before and/or after each program event. In addition, if volunteers or program staff are collecting coral monitoring data, monitoring should be conducted as described in Chapter 5 and Chapter 7 of this guide.

Performance Criteria

For gauging the success of citizen involvement in restoration, there should be:

> High retention rate of volunteers/citizen scientists
>
> Minimal difference in survival and condition of colonies outplanted by volunteers and those outplanted by experts,
>
> A positive impact on volunteers though increased awareness, knowledge, or stewardship,
>
> Minimal difference in results of monitoring performed by volunteers and paid staff.

Programs to evaluate the efficacy of educational initiatives and identify areas that may need improvement through increased volunteer training can use these metrics.

Evaluation Tool Criteria Alignment (Appendix 2): Sociocultural Metric #2.2 aligns with six criteria:

1. Corals outplanted as part of educational, stewardship or capacity building programs have similar condition and survival to other local restoration programs. If corals outplanted as part of educational programs show positive growth and survivorship over time, a program will receive a score of 1 (Education and Outreach Evaluation Tool Criteria #2).
2. Supports wider conservation, management (MPAs, no-take zones, etc.), and restoration actions. If restoration is more than just one of the conservation tools implemented as part of a development- or tourism-based coral restoration project, a program will receive a score of 1 (Restoration Program Evaluation Tool Criteria #6).
3. Program has appropriate exit strategies for nursery and outplant stock. If a program has the ability to properly outplant remaining nursery stock and complete required monitoring, a program will receive a score of 1 (Restoration Program Evaluation Tool Criteria #7).
4. Monitoring of all programs includes recommended data, methods, and frequency outlined within the Monitoring Guide's Universal Metrics. If monitoring data is collected per the Monitoring and Field-Based Working Group Guides, a program will receive a score of 1 (Restoration Program Evaluation Tool Criteria #9).
5. Program has financial robustness and stability. If the program has established a three-year financial plan for the implementation and maintenance of the restoration project, a program will receive a score of 1 (Restoration Program Evaluation Tool Criteria #11).
6. Program has established an outreach and community engagement strategy that includes training volunteers to meet the coral husbandry and outplanting standards of each restoration program. If the program meets its training and outreach plan, a program will receive a score of 1 (Education and Outreach Evaluation Tool Criteria #4).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).

Nova Southeastern University CRRAM Lab

Sociocultural Metric #2.3:

Reef-User Satisfaction

How a community perceives the benefits of a coastal management project improves early involvement and participation, which in turn ensures that ultimate benefits will in fact be those desired by the community and maintained in the long run (Pomeroy et al., 2005). Stakeholders, such as reef-users, a diverse suite of anglers, park rangers, beach users, and more, provide invaluable input into the value and impacts of a restoration project. They understand the indirect benefits of coral restoration and conservation, like restoring coastal protection for vulnerable communities, enhancing fish stocks, and providing wave breaks for surfing, all benefiting the people who live with the reef. **Monitoring reef-user satisfaction is a good indicator of the success of your communication strategy and project integration with community use priorities.**

Possible Methods

Reef-User Survey

Semi-structured interviews with reef-users and non-reef users can illustrate how users are using the reef and if they perceive and value the effects of coral restoration. As an example, NOAA's National Coral Reef Monitoring Program uses surveys to quantify reef use (NOAA Coral Reef Conservation Program, 2014; Appendix 3). Questions might include:

> Do you fish, surf, or swim in the ocean?
>
> Where do you use the reef?
>
> Do you think you get benefits from a healthy reef? If so, what are they?
>
> What should I know about the reef?

Structured questions asked to be evaluated on a scale of 1 to 5 (known as a "Likert Scale") might include:

> How often do you go in or near the ocean? ("Never" to "Every day")
>
> Do you see improvements in reef? ("Not at all" to "Absolutely")
>
> Are you satisfied with reef condition as you see it through social media?

Community-Owned and Led Project Design

Restoration projects are more sustainable and successful when designed, implemented, and managed by local stakeholders. Using participatory mapping, identify types and zones of coastal use to monitor use conflict and identify reef-user benefits over time. By asking reef-users to identify where on a map they fish, swim, boat, surf, etc., once or twice a year, you can monitor changing use patterns and anticipate impacts on nurseries, outplanted coral, and other components of the marine ecosystem.

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These maps can additionally be used to minimize conflict through coordination with stakeholders such as the local tourism board, departments of environmental management, regional non-profits, local anglers, teachers, beach-users, and dive tourism owners and operators, in the project planning phase.

Resident Engagement

Monitor how local, resident community members engage the coral restoration project. Through stakeholder interviews and observation, regularly (daily or weekly) note how ongoing restoration empowers or disenfranchises local coastal users. Ask reef-users:

> Do you feel involved? Would you like to be more involved?
>
> What are your concerns about the reef, mangrove, or beach?

Reporting

Survey results should be recorded in program-specific databases as well as distributed to survey participants and the public to increase awareness about the potential positive impacts of reef restoration.

Sampling Frequency

Surveys are distributed to reef users through dive shops, charter vessels, or visitor centers annually to assess the opinion of reef users to restoration activities.

Performance Criteria

The satisfaction of reef-users should increase after restoration. If the satisfaction of reef-users does not change or decreases, adaptive management strategies may need to be used, which could include, but are not limited to, increasing awareness of restoration projects and the impacts they could have or changing the restoration design to elicit the changes that the community surveyed would like to see.

Evaluation Tool Criteria Alignment (Appendix 2): Sociocultural Metric #2.3 aligns with one criterion:

> The satisfaction of reef-users to coral reef conditions or their experience on coral reefs is increased after restoration activities. If the satisfaction of reef-users post-restoration is increased, a program will receive a score of 1 (Education and Outreach Evaluation Tool Criteria #3).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).


Mia Hoogenboom

Chapter 9
Event-Driven Restoration Goal-Based Performance Metrics

Unplanned disturbances can impact corals on natural reefs and on coral restoration sites. Some disturbances can be specific to corals, such as coral disease and bleaching. Other disturbances such as cyclones, wave events, vessel groundings, dredging, and mining can impact corals as well as the underlying geologic structure of the coral reef. Depending on the nature and severity of the event, additional monitoring may be needed to assess impacts to reefs and corals. Event-Driven Restoration monitoring can be implemented in addition to regularly scheduled restoration monitoring. In the development of the restoration monitoring plan, consideration needs to be given to the capacity needed to monitor in response to unplanned events. As with all restoration monitoring, local permitting regulations must be followed. Additional safety considerations may apply to Event-Driven Restoration monitoring. These vary depending on the type of event. For example, when monitoring coral disease impacts to restorations, the most up-to-date best practices should be considered to avoid coral disease transmission between corals or sites (for decontamination protocols related to Stony Coral Tissue Loss Disease, see Appendix 3). When monitoring restorations after wave events or storms, consideration should be given to diver safety from hazards such as limited water visibility or marine debris.

Objective 1: Disease and Bleaching

The impact of coral disease or bleaching events on coral restoration is two-fold: 1) coral diseases and bleaching events can cause mortality to outplants and adaptive management strategies should be implemented to prevent further losses; and 2) coral restoration may be conducted in response to mortality from disease or bleaching events. Outplant monitoring may be used to document the potential effects of disease and bleaching on outplants while data provided by larger-scale reef monitoring would help determine if restoration should be a response to disease and bleaching mortality. In the case of the latter, data collected as part of reef monitoring programs may be useful: Australian Institute of Marine Science (AIMS) Long-Term Coral Reef Monitoring Program (LTMP), Atlantic Gulf Rapid Reef Assessment (AGRRA), Florida's Coral Reef Evaluation and Monitoring Program (CREMP), Global Coral Reef Monitoring Network (GCRMN), Great Barrier Reef Marine Park Authority Marine Monitoring Program (MMP), and NOAA's National Coral Reef Monitoring Program (NCRMP).

The Ocean Agency

Obtaining data on the occurrence and relative impact of diseases and bleaching within a restoration site, allows for targeted preventative maintenance and management to be incorporated into a programs restoration response plan. The frequency of monitoring for changes in coral condition will depend on the program's objectives, goals, and intensity of the condition. Further, each condition may require a different monitoring schedule or frequency and should occur with increased frequency during periods of higher stress, such as summer months when bleaching is prevalent or during known disease outbreaks within a region (i.e., bleaching surveys should be conducted during times of peak water temperatures such as August and September in the Caribbean, while surveys for coral diseases should occur in the months following severe bleaching). For fast moving diseases, weekly to monthly to weekly observations may be necessary. Monthly observations (or more frequent) are suggested as the most effective for monitoring cause and effect changes (Rogers et al., 2001). In addition, it is useful to monitor for potential recovery or partial survival from disease and bleaching events. For an example of monitoring efforts to evaluate the effects of the emergent Stony Coral Tissue Loss Disease, see Alvarez-Filip et al. (2019).

Monitoring and reporting for coral disease and bleaching is similar to the monitoring outlined for Coral Population Enhancement Metric #1.3: Coral Condition. Changes in coral condition documented through regular monitoring (e.g., presence or absence, prevalence, and/or percent tissue loss) will provide information on the distribution, extent, and severity of diseases or bleaching throughout the region. To assess the effects of coral disease and bleaching, it is best to monitor individual colonies using methods such as roving diver and area surveys or coral fate tracking. If corals are fate tracked as a program's means of monitoring, mean percent live tissue per coral (in %) and percentage or number of corals in each ranking of mortality (in % or #) should be documented. Other methods such as random transects, belt-transects/quadrats, and point intercept surveys may also be used, but other methods may be more suitable to capture occurrences of bleaching and disease which target specific species, densities or habitat types. Additionally, image-based techniques such as mosaics may be beneficial to document larger-scale changes over time as a result of mortality from disease and bleaching; however, the time required for image processing and analyses may inhibit the ability to capture smaller- or short-term events. With images, it can be difficult to differentiate a bleached colony from a recently dead colony with exposed white skeleton. Image quality and resolution will impact the ability to capture the presence or absence of polyps from imagery alone. A combination of methods, such as images and roving diver surveys of the same area, could be conducted to help differentiate between conditions.

It is important to note that if bleaching and/or disease is noted within a plot, reef, or region where restoration is being conducted, restoration activities should be discontinued until the severity and extent of the event is understood and the stress or mortality from the event has subsided. Transportation and handling stress may make outplants more susceptible to bleaching or disease; therefore, it is not advantageous to continue to outplant more corals if they will be introduced to potentially deadly stressors. For example, Johnson et al. (2011) suggests avoiding summer months when water temperatures and the possibility of bleaching is high to reduce outplant mortality. It may be possible to continue outplanting non-susceptible species to certain diseases (i.e., outplanting of Acroporid species may be possible if evidence of black band disease is observed on massive species). However, care should be taken to verify that the reef conditions allowing other diseases or bleaching to occur, would not potentially allow flare-ups of other conditions in the species you are outplanting.

If coral restoration will be conducted in response to mortality following a bleaching or disease event, caution should be taken to ensure that conditions within the reef environment are healthy enough to support outplanting. With the cost and resources involved with coral restoration, it is important to avoid wasting time, funds, and corals. Often, coral restoration will result as a management decision following widespread mortality and all restoration activities should follow comprehensive restoration plans that take into consideration genetic management plans (see Universal Metric #4: Genetic and Genotypic Diversity). In addition, coral restoration should be conducted in collaboration with other conservation strategies to help prevent future outbreaks or mortality events. **Monitoring for Event-Driven Restoration following a bleaching or disease event should follow other monitoring metrics outlined in this guide, but may need to be conducted more frequently to better observe outplant colony conditions and evaluate prevalence, mortality rate, and tissue loss in the event that outplants succumb to conditions which caused the initial mortality.**

Objective 2: Physical Impacts

Coral restoration may be implemented after physical impacts to coral reefs. Coral reefs can be damaged by anthropogenic impacts, such as unplanned (e.g., ship groundings; Bruckner and Bruckner, 2001; Riegl, 2001) or planned (e.g., dredging, blast fishing; Jaap, 2000; Fox et al., 2003) events, or by event-specific disturbances, such as wave energy from storms or swell events (Stoddart, 1962; Woodley et al., 1981). These impacts can also affect coral restoration sites as well as natural reefs. Impacts to reef structure, coral colonies, or both can include fragmentation, destabilization, or overturning (Figure 29; Bruckner and Bruckner, 2001). Coral reefs can also be pulverized into unconsolidated reef rubble by wave energy (e.g., Stoddart, 1969; Harmelin-Vivien, 1994). Decisions about the need for emergency stabilization of substrate will depend on the nature of the impact (Fox et al., 2019). Restoration may be required for anthropogenic impacts, depending on relevant policy and legislation. For other impacts, decisions about emergency stabilization will depend on the spatial extent and location of the impacts, the species, sizes, and morphologies of impacted corals, the general status of the reefs and species within the geographical context, and the likelihood for potential success. If the reef or corals are likely to stabilize or recover without intervention, restoration may not be necessary. However, if the coral species impacted are rare, populations are vulnerable, and/or a large area is impacted, restoration may have a substantial contribution to conservation. Restoration after physical impacts such as wave events may be needed if the impacted reefs are important for coastal protection.

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After the physical impact, affected corals may be stabilized in place if the reef condition is suitable (e.g., consolidated hardbottom substrate). Alternatively, affected corals may be reattached at a different reef site that is environmentally similar to the pre-impact condition of the source reef, or used as donor colonies for nurseries (U.S. Coral Reef Task Force, 2016, Viehman et al., 2020). This approach can be an opportunity to reintroduce coral species to reefs where they were once abundant. Fragment mortality and growth are dependent on fragment size and the substrate where reattached (Bowden-Kerby, 2001). Physical impacts can also be associated with subsequent coral disease events and increases in coral predation (Knowlton et al., 1990; Bruckner and Bruckner, 2001; Williams et al., 2008; Brandt et al., 2013; Miller et al., 2014; Bright et al., 2016).

All relevant regulatory permits must be in place before response. Additional monitoring may be required in compliance with any legal and/or regulatory requirements.

Event-Driven Restoration Metric #1: Post-Impact Survey

A post-impact survey can be conducted to evaluate if coral restoration could or should be implemented. An objective survey design is highly recommended so that the post-impact assessment is representative of the damage rather than focused on the most highly damaged areas. **The survey should assess the spatial footprint of the impact and impacts to the reef stability, structural complexity, coral density, species, and sizes.** The appropriate survey design for post-impact assessment depends on the spatial area of the impact (localized vs. widespread). The survey design and methodology needs to address the goals of the assessment effort. To relate local effects to trends and patterns over a large-scale, event survey methods should be complementary to ongoing ecosystem or restoration monitoring efforts, although additional metrics may be needed to meet goals. For example, an assessment of physical impacts for a large spatial area should be complementary to ongoing coral reef ecosystem survey design and methodology to allow for comparisons (e.g., Dahlgren and Sherman, 2020; Viehman et al., 2020).

If the post-impact assessment outcome indicates that restoration is warranted and feasible, and coral reef restoration is implemented, the restoration should be monitored with a design and methodology complementary to other coral restorations. As with restoration for other objectives, quantitative monitoring is required to determine the subsequent success of restoration efforts.

Possible Methods

The post-impact assessment monitoring design should provide the information needed to determine whether coral restoration include the guidance and metrics described previously in this document to address the specific goals of the restoration. For example, monitoring could include the Universal Metrics as well as Goal-Based Performance Metrics for Coral Condition, Abundance and Cover, Reef Structure and Complexity, Species Richness and Diversity, and Disease and Bleaching to quantify the change in coral communities (e.g., species, numbers, diversity, condition), reef structure, diversity, and disease and bleaching.

Reporting

Reporting on physical impacts is dependent on the methods used to capture the metric and the type of physical impact. At a minimum, the physical impact to corals and to reef structure needs to be quantified, within both the restored area and reference area. Quantitative monitoring data should be reported in program specific databases and/or permitting and funding reports.

Sampling Frequency

Post-event assessments should occur as soon as possible after the event and environmental conditions allow (e.g., safety, feasibility). For physical impacts, assessment would ideally be conducted within a timeframe when dislocated corals are still alive on the seafloor. For disease and bleaching, multiple surveys may need to be completed to determine when the disease and bleaching impacts have subsided. If restoration is conducted, subsequent monitoring should occur at the frequency recommended for each Universal and Goal-Based Performance Metric deemed necessary.

Performance Criteria

Coral restoration can be an invaluable tool to promote recovery from coral disease, bleaching and physical impacts such as hurricanes, ship groundings, dredging, and diver damage. Event-Driven Restoration in response to events should only be considered after a post-event survey has been conducted to determine the extent of the damage to the reef structure and ecological function of a site. In some cases, coral restoration may not be feasible based on the amount of physical restoration that might be needed to repair the reef structure to support coral outplanting. If outplanting is conducted, the performance criteria will be similar to other Universal Metrics (RRAD, Population-level Metrics, and Colony-level Metrics) and Event-Driven Restoration monitoring plans should be designed to include the same monitoring vigor as for any other restoration program. For example, the Ecological Footprint should increase or stay the same, showing no net decrease over time from the original Outplant Plot area for all species outplanted. If a net decrease in the Ecological Footprint is observed due to outplant mortality, adaptive management strategies should be evaluated to determine the cause of the decrease in area restored.

Evaluation Tool Criteria Alignment (Appendix 2): Event-Driven Restoration Metric #1 aligns with two criteria:

1. Benthic surveys are conducted post-event to determine: A) the extent of the damage to the reef structure and ecological function, and B) if coral restoration through triage or outplanting is feasible. If post-event surveys are conducted and data is analyzed to determine if restoration is feasible/required, a program will receive a score of 1 (Event-Driven Restoration Criteria #1).
2. Event-Driven Restoration is monitored according to relevant outplanting metrics. If Event-Driven Restoration is monitored using similar monitoring protocols and recommendations such as those listed for outplanting in the Restoration Monitoring Guide, a program will receive a score of 1 (Event-Driven Restoration Criteria #2).

Further descriptions and supporting research of the Evaluation Tool Criteria can be found in Appendix 2 and online (Appendix 3).

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Chapter 10

Climate Change Adaptation Goal-Based Performance Metrics

Climate change due to greenhouse gas emissions has been implicated in mass coral bleaching events (Ainsworth et al., 2016), disease outbreaks (Bruno et al., 2007), and ocean acidification (Andersson and Gledhill, 2013). Increased frequency of mass bleaching has led to large coral die-offs and reduced ability of coral communities to recover between events (Riegl and Purkis, 2009; van Hooidonk et al., 2013; Riegl et al., 2018). While actions like reducing local and regional stressors and restoring coral communities are important for conservation, climate change impacts threaten the very existence of coral reefs as we know them.

While the global community works to reduce carbon emissions and curb climate change, the coral reef restoration community has recognized the need to improve reef resilience to allow reefs to persist in the face of committed warming from past emissions and predicted future warming (van Oppen et al., 2017). Several genetic, ecological, and environmental interventions have been identified that may improve reef resilience to climate change and enhance the persistence of coral reefs (Riegl et al., 2009; National Academies of Sciences, 2019). Testing and use of some of these interventions is in the early stages, mostly on smaller spatial scales (Bowden-Kerby and Carne, 2012; Bliss, 2015; Towle et al., 2015; Pausch et al., 2018; Morikawa and Palumbi, 2019), but there is still uncertainty surrounding the efficacy and policy/regulatory implications of these novel approaches (Fidelman et al., 2019; Filbee-Dexter and Smajdor, 2019). Below, we describe some of the more accessible and less risky interventions currently available to the scientific and restoration community. Success of all the identified interventions will be dependent on coral survivorship and ability to successfully reproduce and pass on positive traits. A key assessment for any intervention is that corals are more resilient than they would have been without it (National Academies of Sciences, 2019).

For the next three objectives, improve Reef Resilience, Assisted Evolution, and Stress Hardening, objective specific metrics were not developed. Measurement of the success of each of these objectives will likely come from a combination of previously described metrics throughout this document. We did not suggest specific metrics because these are all still currently developing fields. Current literature should be reviewed to determine which combination of metrics are best suited for the restoration project or program (i.e., what metrics are needed in order to determine if stress hardening is successful).

Objective 1: Improve Reef Resilience

Resilience refers to the ability of individuals, populations, and ecosystems to recover after a disturbance. For individuals, this means the ability to survive and recover important functions like growth and reproduction. For populations, this means retaining the ability to recruit new individuals, and for ecosystems, resilience means recovering traits such as productivity, diversity, and trophic function.

Most interventions involving individual corals (physiological, genetic, reproductive interventions) and coral communities are intended to Improve Reef Resilience. Under this objective, we discuss genetic and reproductive interventions of managed selection and breeding. We discuss coral community interventions of assisted gene flow and migration under Assisted Evolution (Objective 2), and physiological interventions of pre-exposure and manipulation of algal symbionts and microbiome under Stress Hardening (Objective 3).

Managed selection is the identification of individuals that have a high tolerance to stressors, such as disease or warm temperatures, and using them in restoration and other interventions (Bowden-Kerby and Carne, 2012; Drury et al., 2017a; Morikawa and Palumbi, 2019). These stress-tolerant individuals are likely to be found in extreme environments, locations exposed to a wide range of fluctuations, and surviving on reefs after a disturbance has passed through. They may also be identified experimentally. Differential tolerance often has both a genetic and acclimation component, and variations in tolerance across populations enhances their capacity for adaptation through natural selection (Baker, 2001; Baker et al., 2004; National Academies of Sciences, 2019). Efforts to identify corals with high stress tolerance should be undertaken, but it should be noted that increased tolerance to one type of stressor (e.g., temperature) may not confer tolerance to another type of stressor (e.g., disease) and that there may be trade-offs in other positive functions (e.g., growth).

Managed breeding is the restoration of diverse coral populations through artificial propagation to increase population size and fitness (National Academies of Sciences, 2019). It may involve crossing individuals that have a high tolerance to stressors to increase these positive traits in the population. It could also involve crossing gametes either within or between populations to increase genetic diversity and potential fitness. Managed breeding relies on collection and fertilization of gametes, either in a controlled laboratory setting or in the field. It may be enhanced through techniques like cryopreservation that preserve sperm or other living material so they remain viable after being thawed. Managed breeding can be labor intensive, but is one of the most feasible interventions to increase genetic diversity. Risks include loss of fitness from outbreeding depression due to loss of local adaptation or disruption of co-adapted gene complexes (National Academies of Sciences, 2019).

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Marie Roman

Objective 2: Assisted Evolution

Assisted evolution refers to interventions that accelerate the rate of naturally occurring evolutionary processes. Interventions aim to increase positive traits such as growth, reproduction, and stress tolerance to improve resilience to changing environmental conditions (e.g., van Oppen et al., 2017; Chan et al., 2018). Two interventions, assisted gene flow and assisted migration, are discussed under this objective, but most interventions under the goal of Climate Change Adaptation fit into the category of Assisted Evolution.

Managed relocation is the movement of individuals from a source area to locations beyond their historical distribution. Managed relocation may involve movement within or outside a species' range. Assisted gene flow is the movement of genotypes within a species' range to enhance the spread of genotypes with higher stress tolerance (National Academies of Sciences, 2019). For instance, genotypes that occur in areas exposed to higher temperature fluctuations may be moved to areas with lower variability in an effort to increase resilience of the population to temperature stress. Assisted migration is the movement of a species beyond its range to promote colonization of new areas with presumably more favorable conditions. It is particularly valuable for species with limited natural dispersal (National Academies of Sciences, 2019). Risk of these interventions increases as distance from the source population increases and can include introduction of pathogens, parasites, and predators. Generally, moving gametes and larvae can be less risky than moving adults since they are less likely to contain "hitchhikers".

Objective 3: Stress Hardening

Stress hardening is manipulation of individuals of coral so that they are more tolerant of stress in the future (Middlebrook et al., 2008). Pre-exposure is the gradual exposure of individuals to stress in the hopes that they will convey some tolerance upon re-exposure to similar conditions. An example is gradually exposing corals to warm temperatures so that they might not suffer mortality during anomalous temperature events. Pre-exposure has been shown to have a beneficial effect, but responses vary in longevity from short term (hours to days) to longer term (months to years) (National Academies of Sciences, 2019).

Other manipulations that could fall under the category of stress hardening include algal symbiont and microbiome manipulation. In these interventions, the algae, fungi, bacteria, or viruses living in association with corals are changed in favor of types that enhance the stress tolerance of the coral host. Algal symbiont manipulations have been successfully achieved in adults only in laboratory conditions that mimic bleaching events (National Academies of Sciences, 2019). However, because the majority of gametes do not contain algal symbionts, manipulations at the early life stages provide more opportunity to introduce algal symbionts. The microbiome can influence coral host health and may be manipulated through inoculations, adding beneficial bacteria to the holobiont, subjecting the coral to stress to select for microbiome members, and through genetic manipulation (National Academies of Sciences, 2019). However, to be effective, more research on the functions of organisms in the microbiome are needed. Success will be dependent on the longevity of the altered associations and ecological trade-offs that may occur.

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Chapter 11

Research Goal-Based Performance Metrics

Coral propagation and restoration activities provide many resources and opportunities to advance restoration science through research. Developing techniques and methodologies for successful propagation and outplanting has been the focus of most restoration research over the past few decades, but additional research is needed to advance restoration practices to be effective at an ecosystem level (Chennu et al., 2017; Bajjouk et al., 2019; Foo and Asner, 2019). Therefore, the monitoring that accompanies any restoration activity is essential to determining the success and managing the outcomes of restoration science. The topics presented herein are not meant to be exhaustive, rather they are meant to serve as examples of ways to combine metrics and survey methods to answer complex research questions.

Because some research questions may exist beyond the scope or funding of a specific program, it is often valuable for practitioners to enlist the help of local researchers to assist with project design, funding, implementation, and analysis. Research efforts, on top of required permit- or project-related monitoring can be costly and resource-intensive, but are often essential to improving the success of restoration projects. Research associated with coral restoration can inform practitioners and managers on the efficacy of propagation and outplanting techniques, the viability of a restored population based on genetic diversity and the contribution of outplants to revitalizing genetic stock, the success of sexual reproduction in response to increased abundance and genetic diversity, the effect of outplanting on coral community structure and the structure of organisms who rely on coral for food and habitat such as fish and other invertebrates, how to scale up restoration efforts from a small to a large-scale focus, and other research questions. Each of these research questions has the potential to trigger adaptive management strategies and thus improve the outcome of restoration projects over time.

The process of propagating corals within in or ex situ nurseries provides an excellent opportunity to learn about individual coral species, in particular, their growth rates, survival rates, genetic diversity, response to stressors, and perhaps even their reproductive capacity. Corals propagated within nurseries also provide a renewable stock of corals for research without the need to potentially damage or harm existing wild populations. Furthermore, there is the opportunity to use strategic outplantings to provide information about the contributions of coral, species, genotype, and environment on the success of reef restoration. These types of research to improve restoration require a rigorous experimental design, quantitative data collection, and timely analyses.

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more than one species should collect these data separately for each species. While change in these population-level metrics will be very slow for most massive coral species, this metric is very important for branching and fast growing species as changes can occur quickly and frequently (Lirman, 2003; Riegl and Purkis, 2009; Vardi et al., 2012; Mercado-Molina et al., 2015; Riegl et al., 2017; Goergen et al., 2019).

Monitoring performed as part of Universal Metric #3: Colony-level Metrics, such as coral fate tracking, abundance, and percent cover, can provide data for research questions relating to outplanting techniques and coral health. Data capturing the live tissue combined with coral abundance will provide a more accurate measure of the success of restoration at a site, as dead colonies are not included in success metrics. Fate tracking of only a subset of outplanted corals should still be included in this calculation with abundance and/or percent cover to yield a more accurate measure of success.

The monitoring approaches described in this Guide will provide some data towards research efforts; however, additional monitoring will be needed to answer specific individual research questions. For example, data collection for Universal Metric #2: Population-level Metrics utilizes the measurement of restored corals to describe mean coral size, abundance, size-frequency distribution, and when combined with Universal Metric #1, density and percent cover. Such data can be used to answer questions on population maturity, increased habitat complexity, overall coral growth and health, and coral survival and retention within an outplant site. However, research related to actual growth rates of outplants as compared to growth within a nursery or for wild colonies requires more detailed data on colony size, such as total linear extension, or precise measurements of colony size, such as maximum diameter, maximum width, and maximum height. As another example, research related to the effect of coral diseases on restored colonies may require the quantification of partial mortality through measurements of lesion size or documenting the condition of the coral based on the condition type (e.g., tissue loss, color loss, discoloration, or growth anomaly), distribution of lesions (e.g., focal, multifocal, or diffuse), tissue margin (e.g., regular, irregular, color loss, discoloration, band), or rate of lesion expansion (e.g., acute or chronic). Answering these more detailed research questions requires more frequent monitoring in order to track and properly identify the stressor impacting the colony.

Coral size-frequency distribution, when combined with Restored Reef Areal Dimension (area of restored reef), will allow practitioners to roughly estimate the proportion of the restored reef that is covered in coral (percent coral cover) and calculate the density of restored colonies per m^2. Restoration projects using

Photomosaics are a powerful tool to visualize reef areas at multiple scales, from a large reef area to a zoomed-in specific coral cluster or individual colony. Mosaics provide lasting visual data of a single snapshot in time of the reef substrate, which can be referenced repeatedly into the future. This archival character of imagery in general is made more powerful by the spatial scaling and referencing capabilities of mosaics. Thus, multiple metrics can be extracted on an “as needed” or “funding available” basis from one data collection event (Table 11). Mosaics collected under poor visibility, with lower-quality cameras, or with low spatial resolution can be limited in answering research questions pertaining to fine scale colony-level detail. Moreover, mosaics are not well suited to capture data for cryptic or motile organisms, such as the surrounding fish community. In these cases, the use of multiple survey methods is encouraged.

With mosaics, it can be difficult to differentiate a bleached colony from a recently dead colony with exposed white skeleton, as the ability to discern the presence or absence of polyps from imagery alone depends on the image quality and resolution. For example, to understand coral growth over time in comparison with bleaching and disease events, divers should capture a photomosaic and conduct a roving diver survey of the same area. The mosaic can be used to meet general survey requirements (e.g., monitoring and measuring 20% of corals with computer software) while the qualitative survey will provide data on the stressors actively impacting the mosaicked corals. This in-water diver can also remove predators such as corallivorous snails or fireworms. Combining these two methods allows for a birds-eye view and broad understanding of site performance and captures the nuanced differences between bleaching and newly dead corals.

Summary of Goal-Based Performance Metrics

Tables 20-21 provides a brief summary of the Goal-Based Performance Metrics and their associated links to the CRC Restoration Database and Evaluation Tool.

Table 20. Overview and alignment of **Ecological Restoration** Goal-Based Performance Metrics to CRC Monitoring Working Group products.

Goal	Objective	Metric	Description	Methods	Reporting	Data Outcomes	Evaluation Tool Criteria Alignment
Ecological Restoration	Coral Population Enhancement	Abundance and Cover	Evaluation of restored coral abundance and cover	Ecological Footprint Survey Mosaic Transects Plots/Quadrats Fate Tracking	Number of corals per site Percent cover of restored corals Reported to CRC Restoration Database	Change in abundance and cover of restored corals	Positive or no net change in abundance or cover Representative photos of site changes were obtained
		Reproductive Capacity	Observation and documentation of restored coral reproduction	Spawning Observations Colony Size Branch Breaking Histology	Reporting to CRC Larval Database	Observations of timing, genotypic variability, and percent of corals spawning	Sexual reproduction is observed in restored corals
		Coral Condition	Documentation of restored colony condition	Ecological Footprint Survey Mosaic Transects Plots/Quadrats Fate Tracking Roving Diver	Report within program specific database	Presence/Absence Prevalence of conditions Percent tissue loss	See UM #3 Prevalence of Conditions: <5% bleaching mortality <10% disease <5% predation <5% competition <= physical impacts on wild corals
		Species Richness and Diversity	Measurement of species diversity at a restoration site	Ecological Footprint Survey Mosaic Transects Plots/Quadrats Roving Diver	Report within program specific database	Species richness, diversity, and evenness	At least two species of coral are outplanted per restoration site
		Indirect Seeding of Sexual Recruits	Evaluation of outplanting of sexual recruits	Substrate Count Settler Abundance Settler Size Plots/Quadrats	Report within program specific database	Retention of substrates, settler survival, and yield	*see footnote
	Community and Habitat Enhancement	Invertebrate Community	Evaluation of invertebrate community abundance and diversity	Ecological Footprint Survey Transects Plots/Quadrats Roving Diver ARMS	Report within program specific database	Invertebrate abundance/ density Presence/Absence Species richness, diversity, and evenness	Increase the net abundance of invertebrate reef-organisms
		Reef Fish Community	Evaluation of fish community abundance and diversity	Reef Visual Census Belt Transect Roving Survey Video and stereo video transects	Report within program specific database	Species richness, diversity, and evenness Abundance Size distribution	Increase the net abundance of vertebrate reef organisms
		Reef Structure and Complexity	Measurement of restored coral height and complexity	Maximum coral and Reef Height Photopoint Monitoring 3D Photomosaics Chain Length	Report within program specific database	Mean coral height Mean structure height Chain length	Increase in reef height or rugosity
		Habitat Quality	Reporting of the change in habitat quality following restoration	Water Quality Monitoring Sediment/Turbidity Measurements Benthic Composition (Transect, Plots/Quads, Mosaics) Coral Recruitment (Transect, Plots/Quads, Settlement Plates)	Report within program specific database	Water quality parameters Sedimentation rates and characterization Secchi disk depth Percent cover and diversity of functional groups Abundance, diversity, and survival of coral recruits	Record or obtain environmental parameters for each restoration site or representative sites Benthic community structure is surveyed long-term (>5 years) following outplanting

* Evaluation tool criteria or performance criteria we not created for this objective herein, these will be based on the specific metrics that will be chosen by the practitioner to determine the success of the objective. If metrics described within this document are used, the associated performance criteria may be applicable.

Table 21. Overview and alignment of **Socioeconomic** *and* **Event-Driven Restoration, Climate Change Adaption, and Research** Goal-Based Performance Metrics to CRC Monitoring Working Group products.

Goal	Objective	Metric	Description	Methods	Reporting	Data Outcomes	Evaluation Tool Criteria Alignment
Socioeconomic	Economic	Coastal Protection	Evaluation of the benefits of coral restoration to coastal protection	Shoreline Stability Assessment Remote Sensing Modeling Economic valuation of tourism and shoreline Evaluation of coastal protection projects	Report within program specific database	Change in shoreline erosion over time Summary of costs associated with coastal projection and the economic benefits	*see footnote
		Responsible Ecotourism Opportunities	Methods for including responsible tourism in coral reef restoration	Track Participation Monitor outplants Survey reef-related tourism Conduct Conservation-Oriented Diver Trainings with Local Shops Infrastructure census	Report within program specific database	Number of participants Evaluation of trends in participation and revenue generated Coral Condition Metric Outputs	Pre- and post- surveys are completed Survey of coral outplants for survival is completed Three year financial plan is developed
	Sociocultural	Cultivating Stewardship Through Education and Outreach	Stewards of Coral Restoration and the community are created through education and outreach	Event/Campaign Statistics Participation Assessment Reach Outplanting scope	Report within program specific database	How many participants return Which events created the most reach Change in volunteer opinion on restoration Survival of corals	Pre- and post- surveys are completed Corals show similar survival and growth to non-volunteer outplants
		Capacity Building	Tracking the change in a programs capacity (financial and volunteer)	Participation Assessment Outplanting Scope Budget Analysis	Report within program specific database	Retention of volunteers Program financial plan	Corals show similar survival and growth to non-volunteer outplants Supports wider conservation Devised appropriate exit strategies
		Reef-User Satisfaction	How does a community perceive restoration	Reef-User Survey Monitor engagement	Report within program specific database	Summary of how reef-users perceive restoration	Increase in reef-user satisfaction
Event-Driven Restoration	Disease and Bleaching	Post-Impact Survey	Assessment of disease or bleaching impacts for the need for restoration	Survey of impacted area using methods to address the needs and goals	Report within program specific database	Prevalence of colonies impacted Description of diseases present Determination if restoration is feasible	Post-event surveys are completed and analyzed If restoration occurs post-event monitoring is completed following above guidelines
	Physical Impacts	Post-Impact Survey	Assessment of physical impacts for the need for restoration	Survey of impacted area using methods to address the needs and goals	Report within program specific database	Summary of damage extent Determination if restoration is feasible	Post-event surveys are completed and analyzed If restoration occurs post-event monitoring is completed following above guidelines
Climate Change Adaptation	Improve Reef Resilience	Undefined Herein	Interventions to improve the resilience of restored corals and communities	Survey of individuals response to multiple stressors Managed Breeding	Report within program specific database	Identification of corals which have tolerance to certain stressors	*see footnote
	Assisted Evolution	Undefined Herein	Procedures to accelerate naturally occurring evolutionary processes	Assisted Gene Flow Assisted Migration	Report within program specific database	Percent success rate of assisted gene flow or migration	*see footnote
	Stress Hardening	Undefined Herein	Manipulation of corals to be more stress tolerant	Various Manipulation Methods	Report within program specific database	Percent of corals manipulated that show increased tolerance	*see footnote
Research	Various	Undefined Herein	Research focused on coral reef restoration	Based on research question(s)	Report within program specific database	Based on research question(s)	*see footnote

* Evaluation tool criteria or performance criteria we not created for this objective herein, these will be based on the specific metrics that will be chosen by the practitioner to determine the success of the objective. If metrics described within this document are used, the associated performance criteria may be applicable.

Closing Remarks

This guide is the result of consultation and discussion with restoration practitioners, CRC working group members and researchers and aims to provide comprehensive guidance for monitoring coral reef restoration projects and programs with various restoration goals and at scales obtainable by all practitioners, scientists, and managers. While every effort was made to address as many situations as possible, we recognize that as this field develops, some metrics may need to be improved, modified, or eliminated. We therefore present this Guide as a living document to be updated as necessary so it remains relevant and representative as the field evolves.

The five Universal Metrics were developed through much thought and discussion, as means to describe and compare restoration projects. These five metrics were chosen because they can be collected by all practitioners regardless of their skill level, goal, or budget in a comparable and reliable manner, they cover a range of scales, are meaningful to the field of restoration, and have been suggested by practitioners and managers as useful to compare between projects. The Universal Metrics do not cover all aspects of restoration, which is why Goal-Based Performance Metrics were developed. The most common restoration goals, identified through literature and practitioner interviews, were used as the basis for developing the Goal-Based Performance Metrics in this Guide. One recurring issue we encountered was that while most practitioners stated that the purpose of their restoration project was to improve the ecosystem or enhance coral reefs, very few were actually using metrics that could determine if they were meeting this goal. To address this problem, this guide provides guidance on what should be measured to determine if these goals are being met. Some of the goals, such as Socioeconomic and Climate Change Adaptation are an important component of restoration; however, they are whole fields unto themselves, are developing quickly, and are therefore less developed within this Guide. As these topics are better understood and incorporated into the coral reef restoration field the metrics for measuring the goal's success will become more refined.

This Guide should be used to measure and describe the progress of coral restoration projects towards meeting restoration goals. The CRC Monitoring Working Group has developed a complementary Coral Restoration Database and Evaluation Tool, which should be used in conjunction with this Guide. The Coral Restoration Database allows the input of data from the Universal Metrics and select Goal-Based Performance Metrics allowing for standardized comparison between restoration projects, programs, and regions. The Coral Restoration Evaluation Tool allows the practitioner to score the performance of their project, program, or region and determine what is working well and what needs improvement. Feedback provided by practitioners through the use of this Guide, Database, and Evaluation Tool will help improve the evaluation of coral restoration success.

The metrics in this guide were developed and are implemented by practitioners, researchers, and managers whose work has primarily focused on restoration in the Greater Caribbean and Atlantic Ocean; therefore, some examples may need modifications to be applied in other regions. However, these restoration metrics were developed from globally applied coral reef monitoring techniques and should be broadly applicable to all geographic locations. We expect and hope that practitioners use this as a starting point and collect data beyond what is outlined in this document to further inform the restoration community and future versions of this document.

Whitney Hoot

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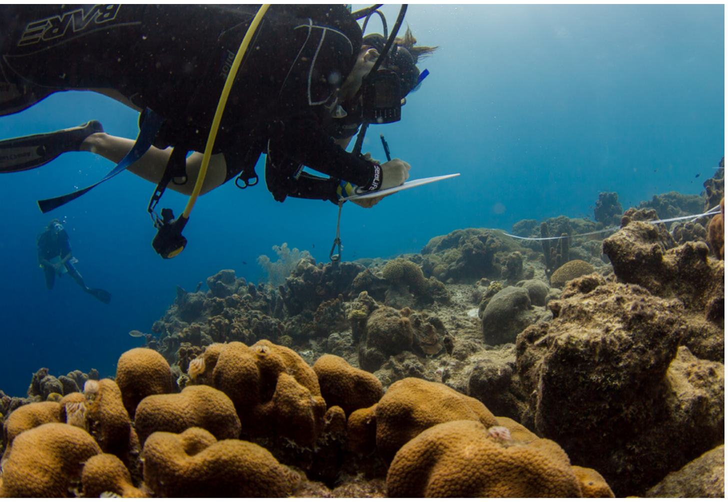
Tom Moore/NOAA


Corales de Paz

Appendix 1: Coral Restoration Database

The Coral Restoration Database was developed by the Coral Restoration Consortium's (CRC) Monitoring Working Group. The CRC identified a need to track coral nursery and restoration to better demonstrate the collective impact of individual efforts. The input fields were developed to reflect information desired by researchers, nursery operators, and managers and were developed in conjunction with the universal monitoring metrics identified in this document and the restoration evaluation tool. A map of coral nursery and outplant locations can be found at https://bit.ly/CRCRestorationMap. The database will eventually be placed online for uploading and querying data. For more information, contact Alison.Moulding@noaa.gov.

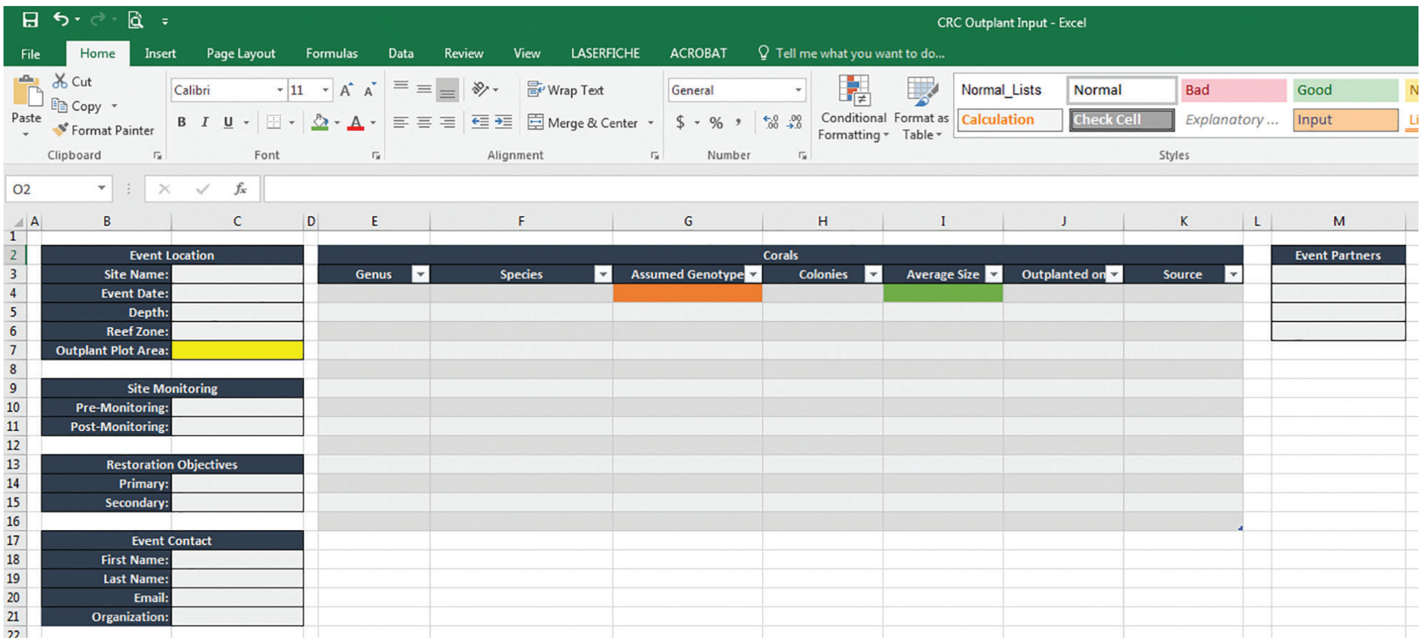

Figure A1.1. CRC Coral Restoration Database spreadsheet for reporting coral outplanting events. The Outplant Plot area from Universal Metric #1: Restored Reef Areal Dimension should be reported in the cell highlighted in yellow for each outplant event. Universal Metric #2: Coral Size-Frequency Distribution should be reported in the cells highlighted in green for each species at the time of outplanting. If multiple colony size are outplanted for each species and genotype, each should be entered on a separate row. Universal Metric #4: Genetic Diversity should be reported in the cells highlighted in orange. If more than one genotype is outplanted per species, each should be entered on a separate row.

Appendix 2: Evaluation Tool for Coral Restoration

The Restoration Evaluation Tool is an adaptation of the original Reef Restoration Program Evaluation Tool developed for restoration activities in the Dominican Republic (Lirman et al., 2017). The objective of this tool is to provide metrics of success for evaluating existing and new restoration projects or programs to assess performance and progress towards restoration goals. Metrics provided within this evaluation tool are designed to evaluate the strength and robustness of each project or program while also identifying specific metrics, which may require adaptive management to improve performance. This tool follows the recovery goals, objectives and criteria outlined with the Recovery Plan for Elkhorn and Staghorn Corals (NOAA National Marine Fisheries Service, 2015) which may also be applied to additional species which are now listed within the ESA or have recently suffered dramatic losses in abundance and cover due to severe bleaching and disease events. Specific goals set forth by the Recovery Plan include increasing the abundance of and protecting the genetic diversity of coral populations throughout their geographical ranges through restoration, restocking, and active management. Therefore, metrics outlined within this evaluation tool focus on best management practices or results from restoration-based research conducted by experts in the field of coral propagation and outplanting. This tool should be used to evaluate the current status of restoration techniques, outline positive attributes of productive projects and programs, and promote the development of successful strategies to achieve population-based recovery for coral reefs. Upon completion, the Evaluation Tool for Coral Restoration will be available online.

Table A2.1 Evaluation Tool Criteria by project, scoring criteria, alignment with Restoration Monitoring Guide goal and associated references. Goals: 1– Ecological Restoration, 2– Socioeconomic, 3– Event-Driven Restoration, 4– Climate Change Adaptation, 5– Research.

Outplanting: Project Scale

#	Evaluation Criteria	Scoring	Goal	References
1	Outplant sites are established based on approved guidelines/Best Management Practices (CRC Field-Based Propagation, Genetics, and Monitoring Working Groups)	if methods followed published manuals/ Guides for site selection and deployment = 1	1, 2, 3, 4, 5	CRC Field-Based Guide, Baums et al., 2019, and Monitoring Guide
2	Outplant site contains/has historical presence of outplanted species (following Guides for site selection)	if outplant species is present or was historically present at site = 1	1, 2, 3, 4, 5	CRC Field-Based Guide
3	Sites are surveyed for reef community structure and species abundance prior to outplanting	if baseline surveys are conducted prior to outplanting = 1	1, 2, 4, 5	CRC Field-Based Guide
4	Environmental parameters are measured at outplant sites to demonstrate that site does not experience large changes in parameters over short periods of time (e.g., minimum measurement of water temperature required, but may also include light, current, sedimentation, turbidity)	if environmental parameters (minimum measurement of water temperature required), are measured/monitored = 1	1, 2, 3, 4, 5	Rogers et al., 2001; Spieler et al., 2001; Baums, 2008; Young et al., 2012, Monitoring Guide (Universal Environmental Metric)
5	Restored Reef Areal Dimension (RRAD) is measured at each outplant site	if project area or restored footprint are measured for each outplant site = 1	1, 2, 3, 4, 5	CRC Field-Based Guide and Monitoring Guide (Universal Metric #1)
6	Restored footprint or area shows no net decrease over time from original project area	if restored footprint or area stays the same or increases from the original project area = 1	1, 2, 3, 4, 5	Monitoring Guide (Universal Metric #1)
7	Outplant sites contain multiple outplanted species	if only one species is outplanted = 0, > 1 species = 1	1 (possibly 2, 3, 4, and 5)	
8	Outplants contain a high degree of potential/possible genotypic diversity (or if genetic info not available, assumed different genotypes based on physical separation of collection sites)	If > 5 potential genotypes per species are outplanted at each restoration site (or >10 for gonochoric species) outplanted= 1	1, 2, 3, 4	Baums, 2008; Drury et al., 2017b (Universal Metric #4)
9	Outplants exhibit positive growth (all species) and/or increases in abundance (branching species only)	if outplants (all species) display positive net change (increase in TLE, % cover, max diameter, % colonies in larger size classes) and/or no net change in abundance = 1	1, 2, 3, 4, 5	Monitoring Guide (Universal Metric #2 and Coral Population Enhancement Metric #1.1)
10	Outplants are tracked (tagged, photographed, mapped, marked, etc.) and monitored for 1st year after outplanting (or requirements for funding/permitting agency)	if outplants are monitored for 1 year = 1	1, 2, 3, 4	Monitoring Guide

Table A2.1 Continued... Goals: 1– Ecological Restoration, 2– Socioeconomic, 3– Event-Driven Restoration, 4– Climate Change Adaptation, 5– Research.

Outplanting: Project Scale

#	Evaluation Criteria	Scoring	Goal	References
11	Representative photos are taken prior to, after, and during each monitoring event to document changes to overall abundance, coral cover, and/or reef structure (or requirements for funding/permitting agency)	if photos are collected, catalogued and maintained prior to outplanting, after outplanting, and during each monitoring event = 1	1, 2, 3, 4	Monitoring Guide
12	Outplants exhibit high coral survivorship within 1st year resulting in positive change in abundance of each outplanted species at outplant site over time	if >80% of outplants survive during first year after outplanting = 1	1, 2, 3, 4, 5	Rinkevich, 1995; Schopmeyer et al., 2017; Goergen and Gilliam, 2018 Monitoring Guide (Universal Metric #2 and #3; Coral Population Enhancement Metric #1.3)
13	Restored corals maintain a high percent of live tissue per coral (outside of acute events) during 1st year	if mean live tissue per colony (recent partial mortality) >80% = 1	1, 2, 3, 4, 5	Lirman et al., 2014 Monitoring Guide (Universal Metric #3; Coral Population Enhancement Metric #1.3)
14	Outplants exhibit low tissue loss (< 5% of outplants) from bleaching	if less than 5% of outplants exhibit tissue loss from bleaching = 1	1	CRC Field-Based Guide; Monitoring Guide (Coral Population Enhancement Metric #1.3)
15	Outplants exhibit low prevalence (<10%) of disease within the 1st year (outside of acute events)	if annual disease prevalence of outplants < 10% = 1	1	Harvell et al., 2007; Myers and Raymundo, 2009; Ruiz-Moreno et al., 2012; Pollock et al., 2014; Vega Thurber et al., 2014 Monitoring Guide (Coral Population Enhancement Metric #1.3)
16	Outplants exhibit low abundance and impacts of coral predators	if annual predation prevalence is < 5% = 1	1, 2, 3, 4	Goergen and Gilliam, 2018 Monitoring Guide (Coral Population Enhancement Metric #1.3)
17	Outplants exhibit limited competition by algae and other competitors (e.g., hydroids, sponges, damselfish)	if annual competition mortality prevalence is <5% = 1	1, 2, 3, 4	Bruckner per obs.; Monitoring Guide (Coral Population Enhancement Metric #1.3)
18	Outplants experience low levels of physical damage (unnatural colony fragmentation, breakage, and/or dislodgement)	if physical damage to outplants is < or equal to wild colonies (e.g., dislodgement, extreme breakage, fragmentation due to anchor drags, boat strikes, divers) = 1	1, 2, 3, 4	Monitoring Guide (Coral Population Enhancement Metric #1.3)
19	Outplants (all species) reach sexual maturity	if annual surveys or observations are conducted to determine that outplants reach sexual maturity via observing sexual reproduction/gamete production within branches/tissue, histological sampling, in situ spawning observations of outplants, and/or colonies reach size of sexual maturity = 1	1 (possibly 3)	Soong, 1992; Chamberland et al., 2016; Calle-Triviño et al., 2018 Monitoring Guide (Coral Population Enhancement Metric #1.2)
20	Outplants increase reef height/rugosity of site (branching species only)	if outplants increase reef height/rugosity of reef site as determined by pre- and post-outplanting measurements = 1	1, 4	Alvarez-Filip et al., 2011; Graham and Nash, 2012
21	Outplants improve ecological value of reef/provide habitat for reef fish	if outplants increase net abundance of reef organisms (in particular reef fish) as determined by pre- and post-outplanting surveys = 1	1, 2, 3	Lirman, 1999; Cabaitan et al., 2008; Ferse, 2008
22	Outplants improve ecological value of reef/provide habitat for invertebrates (non-corallivorous)	if outplants increase net abundance of invertebrate reef organisms as determined by pre- and post-outplanting surveys = 1	1, 3	
23	Outplants exhibit high annual coral survivorship/abundance during years 2-5	if annual outplant survival >65% OR if >65% of colonies are present at site through year 5 = 1	1, 2, 4	Schopmeyer et al., 2017; Goergen and Gilliam, 2018 Monitoring Guide (Coral Population Enhancement Metric #1.3)
24	Outplants exhibit high coral survivorship/abundance >5 years	if annual outplant survival >50% OR if >50% of colonies are present at site = 1	1, 2, 4	Goergen and Gilliam, 2018
25	Benthic composition of outplant sites are surveyed long-term (>5 years) and outplant species exhibit positive change in abundance (may include recruitment of outplant species at restoration site) and growth as compared to baseline surveys	if benthic composition is surveyed annually and exhibit positive change when compared to baseline surveys = 1	1, 2, 3, 4, 5	
26	Increased monitoring during times of stress (storms, disease events, etc.) or after impact events (coastal construction, dredging projects, etc.)	if additional monitoring events are conducted during or immediately after stress events to document impact on outplant condition and survival = 1	1, 2, 3, 4	

Table A2.1 Continued... Goals: 1– Ecological Restoration, 2– Socioeconomic, 3– Event-Driven Restoration, 4– Climate Change Adaptation, 5– Research.

Education and Outreach: Project Scale

#	Evaluation Criteria	Scoring	Goal	References
1	Volunteer restoration participants have an increased awareness about the status of coral reefs and the need for coral reef restoration	if a pre- and post-participation survey is conducted and shows increased awareness by participants = 1	2	Monitoring Guide
2	Corals outplanted as part of educational, stewardship, or capacity building restoration programs have similar condition and survival to other local restoration programs	if corals outplanted as part of educational, stewardship, or capacity building programs show positive growth and survivorship over time = 1	2	Monitoring Guide
3	The satisfaction of reef-users to coral reef conditions or their experience on coral reefs is increased after restoration activities	if the satisfaction of reef-users post-restoration is increased = 1	2	Monitoring Guide
4	Program has established an outreach and community engagement strategy that includes volunteer training standards	if the program meets it's training and outreach plan = 1	1	CRC Field-Based Guide; Monitoring Guide (Coral Population Enhancement Metric #1.3)

Event-Driven Restoration: Project Scale

#	Evaluation Criteria	Scoring	Goal	References
1	Benthic surveys are conducted post-event to determine: 1) the extent of the damage to the reef structure and ecological function and 2) if coral restoration through triage or outplanting is feasible	if post-event surveys are conducted and data is analyzed to determine if restoration is feasible/required = 1	3	Monitoring Guide
2	Event-Driven Restoration is monitored according to relevant metrics	if Event-Driven Restoration monitoring is conducted using relevant outplanting metrics = 1	3	Monitoring Guide

Program Scale

#	Evaluation Criteria	Scoring	Goal	References
1	Program has successful scores from project level metrics (> 75%)	if mean project scores >75% = 1	1, 2, 3, 4, 5	
2	Includes multiple projects (nurseries and outplant sites) locations to mitigate threats from large-scale disturbances (e.g., hurricanes, disease outbreaks)	if program has > 1 Project = 1	1, 2, 4, 5	
3	Has genotypic redundancy (exchange of genotypes among all projects) within nurseries and outplant sites	if each project conducted by a program has multiple (> 5) genotypic representatives from other projects/programs = 1	1, 2, 3, 4	
4	Has defined goal(s) and clear metrics of success (e.g., number of nursery or outplanted corals, evidence of sexual reproduction)	if there is a SOP to track success = 1	1, 2, 3, 4, 5	
5	Consistently meets or exceeds suggested metrics of restoration success from project level metrics (>75%)	if ALL individual project scores >75% = 1	1, 2, 3, 4, 5	
6	Supports wider conservation, management (MPAs, no-take zones, etc.), and restoration actions	if restoration is more than just one of the conservation tools implemented = 1	1, 2, 4	
7	Program has appropriate exit strategies for nursery stock/ monitoring	if program has the ability to outplant remaining nursery stock and complete required monitoring = 1	1, 2, 3, 4, 5	
8	Program has a response plan to minimize and address stress events (as suggested in Guides)	if program has a response plan to stress events = 1	1, 2, 3, 4, 5	
9	Monitoring of all programs includes recommended data, methods and frequency outlined within the Monitoring Guide's Universal Metrics	if monitoring data is collected per the CRC Monitoring and Field-Based Guides = 1	1, 2, 3, 4, 5	
10	Includes long-term monitoring to determine success/ecological function	if program conducts monitoring for more than 1 year after outplanting = 1	1, 3, 4	
11	Shows financial robustness and stability	if program has a > 3 year financial plan = 1	1, 2, 4	
12	Program can be managed and maintained by the staff and/or resources locally available	if nursery structures or corals are properly maintained and gross mortality is not observed due to neglect (i.e., colonies fallen in sand, dislodged colonies, colonies overgrown by competing organisms, broken structures, abrasion) = 1	1, 2, 3, 4, 5	

Table A2.1. Continued... Goals: 1– Ecological Restoration, 2– Socioeconomic, 3– Event-Driven Restoration, 4– Climate Change Adaptation, 5– Research.

Regional Scale

#	Evaluation Criteria	Scoring	Goal	References
1	Programs within region have successful scores from program level metrics (>75%)	if mean program score >75% = 1	1, 2, 3, 4, 5	
2	Region has a strategic plan for restoration goals and objectives linked to coral recovery plans	if the region has a strategic plan with abundance and geographic coverage goals = 1	1, 3, 4	Recovery Plans; Monitoring Guide
3	Region defines clear metrics of success based on monitoring Guides (e.g., number of nursery or outplanted corals, evidence of sexual reproduction)	if there is a SOP based on Guides to track success = 1	1, 2, 3, 4, 5	Monitoring Guide
4	Regions have genotypic redundancy within projects/programs (>5)	if each program within a region has multiple (> 5) genotypic representatives from other projects/programs = 1	1, 2, 3, 4	
5	Programs are increasing functional capacity of the region by deploying projects strategically to mitigate threats from large-scale disturbances (e.g., hurricanes, disease outbreaks)	If > 1 Program within a region to reduce threats = 1	1, 2, 4, 5	
6	Programs are increasing functional capacity of the region by deploying projects strategically to enhance spatial coverage of restoration efforts (e.g., increase local coral, expand current population coverage, increase community education/involvement)	If > 1 Program within a region = 1	1, 4	
7	Programs communicate/collaborate with broader regional coral restoration community (e.g., create regional restoration plan, share ideas, information, data, successes/failures)	Restoration data are freely shared and/or centrally archived = 1	1, 2, 4	
8	Regional restoration efforts can be scaled up as needed	If additional candidate projects are planned or waiting to be deployed = 1	1, 3, 4	
9	Regional restoration efforts can be scaled down as needed	If exit strategies exist as defined by Guides = 1	1, 2, 3, 4	
10	Supports wider regional conservation, management, and restoration actions	If restoration is more than one of the conservation tools implemented = 1	1, 2, 4	
11	Programs within region show financial robustness and stability	If Programs within the Region have > 2 year management plan = 1	1, 2, 4	

Appendix 3: Guides and Website References

Coral Restoration Consortium Working Group Pages and Products:

Monitoring Working Group

crc.reefresilience.org/working-groups/monitoring/

Coral Restoration Database

To submit data from the Universal Metrics and select Goal-Based Performance Metrics to the Coral Restoration Database contact: Alison Moulding (alison.moulding@noaa.gov)

An interactive map of coral nursery and outplant locations and corresponding site information can be found here: https://bit.ly/CRCRestorationMap

Evaluation Tool

Evaluate your project, program, or region using the Evaluation Tool. Online tool under development. Contact Stephanie Schopmeyer (stephanie.schopmeyer@myfwc.com)

Webinar

Photomosaics as a Tool for Monitoring Coral Restoration Success:
crc.reefresilience.org/photomosaics-as-a-tool-for-monitoring-coral-restoration-success/

Field-Based Propagation Working Group

crc.reefresilience.org/working-groups/field-based-propagation/

Guide to Field-Based Coral Reef Restoration

Goergen EA, Johnson M, Lustic C, Griffin S, Levy J, Moulding A, Ross A. In Review. Guide to coral reef restoration: Methods to optimize efficiency and scale. Coral Restoration Consortium. 165 pp.
crc.reefresilience.org/working-groups/field-based-propagation/

Restoration Facebook Page

Coral Restoration Coordination–Caribbean www.facebook.com/groups/Coral.Nursery/

Larval Propagation Working Group

crc.reefresilience.org/working-groups/larval-propagation/

Prediction Calendar

crc.reefresilience.org/wp-content/uploads/2019/06/Coral-Spawning-Predictions-Dominican-Republic-2019.pdf
crc.reefresilience.org/wp-content/uploads/2019/06/Coral-Spawning-Predictions-Southern-Caribbean-2019.pdf
crc.reefresilience.org/wp-content/uploads/2019/07/Coral-Spawning-Prediction-Calendar_Mexico-2019.pdf

Reporting Guidance

crc.reefresilience.org/wp-content/uploads/2019/06/Spawning-Monitoring-Guidelines.pdf
crc.reefresilience.org/wp-content/uploads/2019/06/Coral_spawning_data_TEMPLATE.xlsx

Webinar

reefresilience.org/caribbean-coral-restoration-coral-spawning-research-larval-propagation/

Facebook Group

Coral Spawning Research: www.facebook.com/groups/270783472935805/

Genetics Working Group

crc.reefresilience.org/working-groups/genetics/

Publication

Baums, I. B., Baker, A. C., Davies, S. W., Grottoli, A. G., Kenkel, C. D., Kitchen, S. A., Kuffner, I. B., LaJeunesse, T. C., Matz, M. V., Miller, M. W., Parkinson, J. E., and Shantz, A. A.. 2019. Considerations for maximizing the adaptive potential of restored coral populations in the western Atlantic. Ecological Applications 29 (8):e01978.

Database

To submit data the user will submit coral tissue to a service provider that will in turn return the raw genotype data to the user in 4-6 weeks. Then, the user will upload the raw data along with metadata for each sample including collection site information (GPS coordinates, depth, where is the colony such as apical tip, mid-branch or base), phenotype data if available, and collector information. In the future, we hope to link our data with other databases that contain field surveys and ecological data using a common database registry key.

Database login: https://coralsnp.science.psu.edu/galaxy/

Database reports page: https://coralsnp.science.psu.edu/reports, provides a web interface of the database to explore the various data tables we currently store and current samples we have genotyped.

Web-based guides and resources referenced by chapter:

Chapter 2

Guide to Field-Based Coral Reef Restoration

Goergen EA, Johnson M, Lustic C, Griffin S, Levy J, Moulding A, Ross A. In Review. Guide to coral reef restoration: Methods to optimize efficiency and scale. Coral Restoration Consortium. 165 pp.
crc.reefresilience.org/working-groups/field-based-propagation/

Chapter 4

Guide to Field-Based Coral Reef Restoration

Goergen EA, Johnson M, Lustic C, Griffin S, Levy J, Moulding A, Ross A. In Review. Guide to coral reef restoration: Methods to optimize efficiency and scale. Coral Restoration Consortium. 165 pp.
crc.reefresilience.org/working-groups/field-based-propagation/

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https://bit.ly/CRCRestorationMap

Evaluation Tool

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Chapter 5

Webinar

Photomosaics as a Tool for Monitoring Coral Restoration Success
crc.reefresilience.org/photomosaics-as-a-tool-for-monitoring-coral-restoration-success/

Coral Restoration Database

To submit data from the Universal Metrics and select Goal-Based Performance Metrics to the Coral Restoration Database contact: Alison Moulding (alison.moulding@noaa.gov)

An interactive map of coral nursery and outplant locations and corresponding site information can be found here: https://bit.ly/CRCRestorationMap

Evaluation Tool

Evaluate your project, program, or region using the Evaluation Tool. Online tool under development. Contact Stephanie Schopmeyer (stephanie.schopmeyer@myfwc.com)

Genetic Databases

Genetics Working Group Database

Database login: https://coralsnp.science.psu.edu/galaxy/

Database reports page: https://coralsnp.science.psu.edu/reports, provides a web interface of the database to explore the various data tables we currently store and current samples we have genotyped.

Chapter 6

Coral Restoration Database

To submit data from the Universal Metrics and select Goal-Based Performance Metrics to the Coral Restoration Database contact: Alison Moulding (alison.moulding@noaa.gov)

An interactive map of coral nursery and outplant locations and corresponding site information can be found here: https://bit.ly/CRCRestorationMap

Evaluation Tool

Evaluate your project, program, or region using the Evaluation Tool. Online tool under development. Contact Stephanie Schopmeyer (stephanie.schopmeyer@myfwc.com)

Chapter 7

Long-Term Monitoring Project Examples:

Australian Institute of Marine Science (AIMS) Long-Term Coral Reef Monitoring Program (LTMP)
www.aims.gov.au/docs/research/monitoring/reef/reef-monitoring.html

Atlantic Gulf Rapid Reef Assessment (AGRRA)
www.agrra.org/

Coral Reef Evaluation and Monitoring Program (CREMP)
myfwc.com/research/habitat/coral/cremp/

Global Coral Reef Monitoring Network (GCRMN)
gcrmn.net/

Great Barrier Reef Marine Park Authority Marine Monitoring Program (MMP)
www.gbrmpa.gov.au/our-work/our-programs-and-projects/reef-2050-marine-monitoring-program

NOAA's National Coral Reef Monitoring Program (NCRMP)
coastalscience.noaa.gov/project/national-coral-reef-monitoring-program-biological-socioeconomic/

Larval Ecology Working Group:

crc.reefresilience.org/working-groups/larval-propagation/

Bleaching and Disease Reporting:

NOAA's Coral Reef Watch for all locations
coralreefwatch.noaa.gov

Coral Watch for all locations
Coralwatch.org

BleachWatch for Florida Keys National Marine Sanctuary and Dry Tortugas National Park
mote.org/bleachwatch

SEAFAN for South Florida
floridadep.gov/rcp/coral/content/bleachwatch
floridadep.gov/rcp/coral/content/stony-coral-tissue-loss-disease-response

Eyes on the Reef for Hawaii
eorhawaii.org/

Philippine Coral Bleaching Watch
Application on Googleplay or form.jotform.me/61241912098454

Reef Connect BleachWatch for the United States Virgin Islands
www.reefconnect.org/bleachwatch/

BleachWatch Egypt
https://www.hepca.org/projects/project/140

Eye on the Reef for Great Barrier Reef
Application or www.gbrmpa.gov.au/our-work/our-programs-and-projects/eye-on-the-reef

Restoration Facebook Page
Coral Restoration Coordination–Caribbean www.facebook.com/groups/Coral.Nursery/

Webinar
Photomosaics as a Tool for Monitoring Coral Restoration Success
crc.reefresilience.org/photomosaics-as-a-tool-for-monitoring-coral-restoration-success/

Chapter 8

European Tourism Indicator System
ec.europa.eu/growth/sectors/tourism/offer/sustainable/indicators_en

NOAA's National Coral Reef Monitoring Program Socioeconomic Survey: CORE Questions Template
www.coris.noaa.gov/monitoring/resources/ncrmp_soc_core_survey_module_public.pdf

Cornell Lab's User's Guide for Evaluating Learning Outcomes in Citizen Science
www.birds.cornell.edu/citizenscience/wp-content/uploads/2018/10/USERS-GUIDE_linked.pdf

Chapter 9

Long-Term Monitoring Project Examples:

Australian Institute of Marine Science (AIMS) Long-Term Coral Reef Monitoring Program (LTMP)
www.aims.gov.au/docs/research/monitoring/reef/reef-monitoring.html

Atlantic Gulf Rapid Reef Assessment (AGRRA)
www.agrra.org/

Coral Reef Evaluation and Monitoring Program (CREMP)
myfwc.com/research/habitat/coral/cremp/

Global Coral Reef Monitoring Network (GCRMN)
gcrmn.net/

Great Barrier Reef Marine Park Authority Marine Monitoring Program (MMP)
www.gbrmpa.gov.au/our-work/our-programs-and-projects/reef-2050-marine-monitoring-program

NOAA's National Coral Reef Monitoring Program (NCRMP)
coastalscience.noaa.gov/project/national-coral-reef-monitoring-program-biological-socioeconomic/

Decontamination protocols related to Stony Coral Tissue Loss Disease
https://floridakeys.noaa.gov/coral-disease/citizen-participation.html

Appendix 4: Standard Operating Procedures for Data Collection with Mosaics

Imagery combined in a mosaic format, also called Structure From Motion, is a powerful tool to support visualization, benthic analyses, and a permanent record of the site. Structure From Motion technology, capacity, and analyses are a rapidly evolving field of applied research. For an overview of this methodology, refer to the CRC Monitoring Working Group's photomosaic webinar (website provided in Appendix 3).

Standard operating procedures currently vary between groups and organizations. Some examples are listed below.

Organization	Website
Coral Restoration Foundation	www.coralrestoration.org/white-paper-photomosaic-manual
Scripps Institution of Oceanography	http://crc.reefresilience.org/wp-content/uploads/2019/07/SIO_Mosaic_SOP_V2_2019-06-18.pdf http://crc.reefresilience.org/wp-content/uploads/2019/07/SIO_Mosaic_SOP_V3_SingleRig_20190320.pdf
University of Miami	web2.physics.miami.edu/~agleason/index.shtml

In the project planning phase prior to project implementation, we recommend that restoration practitioners, scientists, and managers carefully consider whether photomosaics are a good fit for monitoring goals and for program capacity. As with many technologies, this approach does have technological and financial constraints, and costs vary. Technological infrastructure requirements are affiliated with image acquisition, and the quality of underwater camera systems will affect image quality. Additional requirements relate to software and computational power for image processing, visualization, and analyses. Furthermore, the file sizes of large area imagery can be significant, so high-capacity long-term data storage needs are an additional consideration.

Appendix 5: Example Spawning Prediction Calendar and Datasheets

Included here is an example of a 2019 spawning prediction calendar for the Southern Caribbean (Figure A5.1). Each year this and prediction calendars for other regions are created by the CRC Larval Propagation working group using data submitted to the CRC coral spawning database and available literature. For the best prediction times for your region visit the CRC Larval Propagation website (Appendix 3) each year.

The next two figures are example datasheets for in situ coral spawning observations. Figure A5.2 should be used when recording spawning data per species and Figure A5.3 should be used when reporting data per genotype or colony per species.

2019 Coral Spawning Predictions for the Southern Caribbean

June

		Days AFM:											10	11	12	13
		Calendar Date:											27-Jun	28-Jun	29-Jun	30-Jun
		Sunset Time:											19:03	19:03	19:04	19:04
Latin name	Common Name	Spawning Window														
Diploria labyrinthiformis *	Grooved Brain Coral	60-0 min BS												17:55-19:10		

*Consecutive monthly spawning events have been observed from May to October in Curaçao, Bonaire, the Dominican Republic, and Mexico. It is unknown if this occurs accross the entire region. New observations are encouraged!

July

		Days AFM:	0	1	2	3	4	5	6	7	8	9	10	11	12	13
		Calendar Date:	16-Jul	17-Jul	18-Jul	19-Jul	20-Jul	21-Jul	22-Jul	23-Jul	24-Jul	25-Jul	26-Jul	27-Jul	28-Jul	29-Jul
		Sunset Time:	19:04	19:04	19:04	19:04	19:04	19:04	19:03	19:03	19:03	19:03	19:03	19:02	19:02	19:02
Latin name	Common Name	Spawning Window														
Dendrogyra cylindrus	Pillar Coral	105-155 min AS	?	?	?	20:45-21:45										
Montastraea cavernosa	Great Star Coral	15-165 min AS				?	?	?	19:15-21:55							
Colpophyllia natans	Boulder Brain Coral	35-110 min AS							19:30-21:00							
Pseudodiplora strigosa (Early group)	Symmetrical Brain Coral	40-60 min AS							19:40-20:05							
Pseudodiplora strigosa (Late group)	Symmetrical Brain Coral	220-270 min AS							22:40-23:40							
Diploria labyrinthiformis *	Grooved Brain Coral	60-0 min BS												17:55-19:05		

August

		Days AFM:	0	1	2	3	4	5	6	7	8	9	10	11	12	13
		Calendar Date:	15-Aug	16-Aug	17-Aug	18-Aug	19-Aug	20-Aug	21-Aug	22-Aug	23-Aug	24-Aug	26-Jul	27-Jul	28-Jul	29-Jul
		Sunset Time:	18:55	18:55	18:54	18:54	18:53	18:53	18:52	18:52	18:51	18:51	18:50	18:49	18:49	18:48
Latin name	Common Name	Spawning Window														
Acropora palmata	Elkhorn Coral	140-190 min AS	21:10-22:10 (Spawning could happen any of these days: This species is highly unpredictable in the Southern Caribbean)													
Acropora cervicornis	Staghorn Coral	150-190 min AS			21:20-22:10											
Dendrogyra cylindrus	Pillar Coral	105-155 min AS	?			20:35-21:35										
Montastraea cavernosa	Great Star Coral	15-165 min AS				?	?	?	19:05-21:40							
Colpophyllia natans	Boulder Brain Coral	35-110 min AS							18:50-20:50							
Pseudodiploria strigosa (Early group)	Symmetrical Brain Coral	40-60 min AS							19:30-19:55							
Pseudodiploria strigosa (Late group)	Symmetrical Brain Coral	220-270 min AS							22:25-23:35							
Diploria labyrinthiformis *	Grooved Brain Coral	60-0 min BS												17:45-18:55		

September

		Days AFM:	0	1	2	3	4	5	6	7	8	9	10	11	12	13
		Calendar Date:	13-Sep	14-Sep	15-Sep	16-Sep	17-Sep	18-Sep	19-Sep	20-Sep	21-Sep	22-Sep	23-Sep	24-Sep	25-Sep	26-Sep
		Sunset Time:	18:37	18:36	18:36	18:35	18:34	18:33	18:33	18:32	18:31	18:31	18:30	18:29	18:29	18:28
Latin name	Common name	Spawning Window														
Dendrogyra cylindrus	Pillar Coral	105-155 min AS	?			20:15-21:15										
Siderastrea siderea	Massive Starlet Coral	210-280 min AS					22:00-23:15									
Montastraea cavernosa	Great Star Coral	15-165 min AS							18:45-21:25							
Montastraea/Orbicella annularis	Lobed/Boulder Star Coral	195-250 min AS							21:40-22:50							
Montastraea/Orbicella faveolata	Mountainous Star Coral	195-250 min AS							21:40-22:50							
Montastraea/Orbicella franksi	Boulder Star Coral	90-150 min AS							20:00-21:05							
Colpophyllia natans	Boulder Brain Coral	35-110 min AS							19:05-20:30							
Pseudodiploria strigosa (Early group)	Symmetrical Brain Coral	40-60 min AS							19:05-19:35							
Pseudodiploria strigosa (Late group)	Symmetrical Brain Coral	220-270 min AS							22:10-23:05							
Pseudodiploria clivosa	Knobby Brain Coral	210-255 min AS								22:00-22:55						
Stephanocoenia intersepta	Blushing Star Coral	170-205 min AS				?	21:15-22:05									
Dichocoenia stokesii	Pineapple Coral	90-170 min AS		?	?		20:00-21:25 (Spawns more than 20 nights in a row, expected through Oct 7 or later)									
Eusmilia fastigiata	Smooth Flower Coral	75-140 min AS							19:20-00:00							
Meandrina meandrites	Maze Coral	10-70 min AS			?	?		18:40-19:50 (Spawns many different nights in this range, expected through Oct 3 or later)								
Madracis senaria	Ten-Ray Star Coral	all night				all night										
Agaricia humilis/Agaricia agaricites	Lettuce Coral	all night				all night										
Diploria labyrinthiformis *	Grooved Brain Coral	60-0 min BS												17:25-18:35		

October

		Days AFM:	0	1	2	3	4	5	6	7	8	9	10	11	12	13
		Calendar Date:	14-Oct	15-Oct	16-Oct	17-Oct	18-Oct	19-Oct	20-Oct	21-Oct	22-Oct	23-Oct	24-Oct	25-Oct	26-Oct	27-Oct
		Sunset Time:	18:17	18:17	18:16	18:16	18:15	18:15	18:14	18:14	18:13	18:13	18:13	18:12	18:12	18:28
Latin name	Common Name	Spawning Window														
Dendrogyra cylindrus	Pillar Coral	105-155 min AS	?	?	?	20:05-20:55										
Siderastrea siderea	Massive Starlet Coral	210-280 min AS						21:40-23:00								
Montastraea cavernosa	Great Star Coral	15-165 min AS				?			18:25-21:05							
Montastraea/Orbicella annularis	Lobed/Boulder Star Coral	195-250 min AS							21:25-22:30							
Montastraea/Orbicella faveolata	Mountainous Star Coral	195-250 min AS							21:25-22:30							
Montastraea/Orbicella franksi	Boulder Star Coral	90-150 min AS							19:40-20:50							
Colpophyllia natans	Boulder Brain Coral	35-110 min AS							18:35-20:10							
Pseudodiploria strigosa (Early group)	Symmetrical Brain Coral	40-60 min AS							18:50-19:20							
Pseudodiploria strigosa (Late group)	Symmetrical Brain Coral	220-270 min AS							21:50-22:50							
Pseudodiploria clivosa	Knobby Brain Coral	210-255 min AS								21:40-22:35						
Stephanocoenia intersepta	Blushing Star Coral	170-205 min AS				?	21:00-21:45									
Dichocoenia stokesii	Pineapple Coral	90-170 min AS		?	?		19:40-21:10 (Spawns more than 20 nights in a row, expected through Nov 6 or later)									
Eusmilia fastigiata	Smooth Flower Coral	75-140 min AS							19:00-00:00							
Meandrina meandrites	Maze Coral	10-70 min AS			?	?		18:20-19:30 (Spawns many different nights in this range, expected through Nov 2 or later)								
Madracis senaria	Ten-Ray Star Coral					all night										
Agaricia humilis/Agaricia agaricites	Lettuce Coral					all night										
Diploria labyrinthiformis *	Grooved Brain Coral	60-0 min BS												17:05-18:15		

August, September, and/or October

		Days AFM:	0	1	2	3	4	5	6	7	8	9	10	11	12	13
		Calendar Date:	See tables above for calendar dates in August, September, and October													
Latin name	Common Name															
Neofibularia nolitangere	Touch-Me-Not Sponge					14:00-17:00										
Plexaura homomalla	Black Sea Rod						19:00-23:00									
Pseudopterogorgia spp.	Sea Plume						20:00-23:00									
Plexaura, Pseudoplexaura, Eunicia	Sea Rod						starting at 19:00									
Diadema antilliarum	Long-Spined Sea Urchin		12:00-21:00, every day													
Holothuria mexicana	Donkeydung Sea Cucumber		12:00-18:00, every afternoon													
Ophiuroidea	Brittle Sea Star/Serpent Star		19:30-23:00, every night													
Hermodice carunculata	Fire Worm		12:00-19:00, every afternoon													
Spirobranchus giganteus	Christmas Tree Worm		21:00-22:30, every night													

Legend:

Days AFM: Days After the Full Moon

min BS = Minutes Before Sunset

min AS = Minutes After Sunset

Gray with ?: Spawning is unlikely but possible (This species is understudied for these dates and times. Additional observations during these windows are highly encouraged!)

Pale Yellow: Spawning is possible

Bright Orange: Spawning is likely

Red: Spawning is very likely

To Observe Spawning

- Make multiple dives
- Dive in a place with high coral cover
- Enter the water at least 15 min before predicted times
- Do not dive deeper than 50 ft to maximize bottom time
- Use a moderately bright dive light
- Scan the water column for clouds of spawn

CARMABI

Notes

Your observations help coral research! Please report your spawning observations (including species, date, time, location, and pictures if possible) to carmabilog@gmail.com. If you would like to become a regular contributor to the Coral Restoration Consortium coral spawning database, please contact v.chamberland@secore.org

These predictions are based on observations from previous years: They do not guarantee that spawning will occur during these times.

Spawning times vary montly based on local sunset times. To look up your local sunset times, visit www.sunandmoon.com.

Thank you to everyone who has collected and contributed spawning information over the past 25+ years! We wish you a safe and productive spawning season!

Figure A5.1. 2019 coral spawning prediction for the southern Caribbean

Spawning Monitoring (per species)

Date: ______________________
Country: ______________________
Site: ______________________
Depth range: ______________________
Area (m^2): ______________________
Observer(s): ______________________
____

# of days AFM: ______________________
Sunset time: ______________________
Focal species monitored: ______________________
Other species monitored: ______________________
Monitoring start: ______________________
Monitoring stop: ______________________
Additional notes: ______________________

Hermaphrodite species	# of colonies monitored	# of colonies that spawned	Time setting started	Time spawning started	Time spawning stopped	Individual spawning times per colony (if available)									
Gonochore species	# of colonies monitored	# of colonies that spawned	Time setting started	Time spawning started	Time spawning stopped	Individual spawning times per colony (if available)									
MALE	(total)														
FEMALE															
MALE															
FEMALE															
MALE															
FEMALE															
MALE															
FEMALE															

Figure A5.2. Example in situ datasheet for spawning observations by species

Spawning monitoring (per genotype/colony)

Date: ______________________
Country: ______________________
Site: ______________________
Depth range: ______________________
Area (m^2): ______________________
Observer(s): ______________________
____

# of days AFM: ______________________
Sunset time: ______________________
Species monitored: ______________________
Monitoring start: ______________________
Monitoring stop: ______________________
Additional notes: ______________________
____

Genotype/colony ID	Sex (if gonochore)	Time setting started	Time spawning started	Time spawning stopped

Figure A5.3. Example in situ datasheet for spawning observations by genotype and colony per species

Appendix 6: Coral Restoration Participant Survey

Below are a few examples of surveys used by Rescue a Reef citizen science program and Coral Restoration Foundation to assess volunteer participation and educational impacts.

Rescue a Reef Questionnaire (post-expedition only) from Hesley et al. (2017).

Citizen Scientist Survey

Q1 Thank you for contributing to the evaluation of our program. We greatly appreciate it! Please find our short citizen science survey below and answer the questions to the best of your ability.

Q2 What is your age range?

- ◯ 18 - 24 years old (1)
- ◯ 25 - 34 years old (2)
- ◯ 35 - 44 years old (3)
- ◯ 45 years or older (4)

Q3 Are you a current resident of South Florida?

- ◯ Yes (1)
- ◯ No (2)
- ◯ Seasonal (3)
- ◯ Other (4)

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Rescue a Reef Questionnaire (post-expedition only) from Hesley et al. (2017).

Q4 What is your highest level of education?

- ◯ High school graduate, diploma, or equivalent (1)
- ◯ Some college credit, no degree (2)
- ◯ Associate degree (3)
- ◯ Bachelor's degree (4)
- ◯ Master's degree (5)
- ◯ Professional degree (6)
- ◯ Doctorate degree (7)

Q5 How many dives have you completed to date?

- ◯ N/A (1)
- ◯ 1 - 10 (2)
- ◯ 11 - 25 (3)
- ◯ 26 - 50 (4)
- ◯ 50+ (5)

Q31 Did you participate as a diver or snorkeler?

- ◯ SCUBA Diver (1)
- ◯ Snorkeler (2)

Page Break

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Rescue a Reef Questionnaire (post-expedition only) from Hesley et al. (2017).

Q6
Individual perception (BEFORE)
To the best of your ability, please answer the following questions honestly regarding your knowledge BEFORE engaging our Rescue a Reef team.

Q7 What was your impression of the status of coral reefs in Florida?

	Degraded			Pristine	
	1	2	3	4	5
Coral reef status ()					

Q8 How knowledgeable were you on coral reef ecology?

	Not very			Very	
	1	2	3	4	5
Knowledge level ()					

Q9 How knowledgeable were you on coral reef restoration?

	Not very			Very	
	1	2	3	4	5
Knowledge level ()					

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Rescue a Reef Questionnaire (post-expedition only) from Hesley et al. (2017).

Q10 How important did you feel active coral restoration was for the future of coral reefs?

	Not very			Very	
	1	2	3	4	5
Importance ()					

Page Break

Q11
Individual perception (AFTER)
To the best of your ability, please answer the following questions honestly regarding your knowledge AFTER engaging our Rescue a Reef team.

Q12 What is your impression of the status of coral reefs in Florida?

	Degraded			Pristine	
	1	2	3	4	5
Coral reef status ()					

Q13 How knowledgeable are you on coral reef ecology?

	Not very			Very	
	1	2	3	4	5
Knowledge level ()					

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Rescue a Reef Questionnaire (post-expedition only) from Hesley et al. (2017).

Q14 How knowledgeable are you on coral reef restoration?

	Not very			Very	
	1	2	3	4	5
Knowledge level ()					

Q15 How important do you feel active coral restoration is for the future of coral reefs?

	Not very			Very	
	1	2	3	4	5
Knowledge level ()					

Q16 What are the largest issues you feel are facing coral reefs? (Please list 2-3 if possible)

____

____

____

____

____

Page Break

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Rescue a Reef Questionnaire (post-expedition only) from Hesley et al. (2017).

Q17
How did you hear about Rescue a Reef? (check all that apply)

- ☐ Web search (1)
- ☐ Social media (2)
- ☐ Email (3)
- ☐ Word of mouth (4)
- ☐ Event (5)
- ☐ Other (6) ____

Q18
Why did you become involved with Rescue a Reef?

____

____

____

____

____

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Rescue a Reef Questionnaire (post-expedition only) from Hesley et al. (2017).

Q19
How likely are you to support Rescue a Reef in additional ways?
(i.e. volunteering, donating, advocating, etc.)

	Not very				Very
	1	2	3	4	5
Likeliness ()					

Q20
Overall, how satisfied are you with your Rescue a Reef experience?

	Not very				Very
	1	2	3	4	5
Satisfaction level ()					

Q21 In your opinion, what are potential tools to help conserve and/or recover coral reef populations? (Please list 2-3 if possible)

Page 7 of 8

Rescue a Reef Questionnaire (post-expedition only) from Hesley et al. (2017).

Q22
Please list an interesting fact you learned through Rescue a Reef.

Q23
Please share at least one way we can improve our program.

End of Block: Default Question Block

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Coral Restoration Foundation Questionnaire

Getting Involved Survey

First Name:
Last Name:
What email do you prefer we contact you at?

Q1: How did you learn about the Coral Restoration Foundation™?

- I found you searching the internet
- A friend told me about you
- A brochure I found
- Social Media like Facebook or Instagram
- I get Coral Chronicles and love it
- I participated in the past and can't wait to do it again
- Other

Q2: What expectations do you have for your time with us?

- I want to give back and make a difference
- Science is my THING
- I want to learn about restoration techniques
- To be a better diver
- To learn and have a new experience
- Other

Q3: Do you live in Florida?

- Yes, I do live in Florida
- No, I do NOT live in Florida
- No, but I do visit the Keys for three weeks or more at a time

Q4: Are you SCUBA certified?

- Yes, I am SCUBA certified
- I am not SCUBA certified, but I plan to be
- No, but I love snorkeling and land work

Q5: If a diver, what kind of boats have you spent the most time on?

- Boats? I like shore diving!
- 30 feet or smaller
- The average dive boat
- Liveaboards
- I am not a SCUBA diver

CORAL RESTORATION FOUNDATION

Coral Restoration Foundation Questionnaire

Q6: If a diver, about how many dives have you logged?

- Less than 30 dives
- 30-50 dives
- 50-100 dives
- 101 dives and still going
- I'm not a SCUBA diver

Q7: How much time do you have to spend with us?

- Just a day or two through the year
- Several times per month, all year round
- I can be there three weeks or longer
- I'm a weekend warrior

Q8: What age range are you?

- 17 and under
- 18-35
- 36-60
- 61 and over

Q9: What do you find inspiring about Coral Restoration Foundation™ and why do you want to join our mission?

Q10: Do you want to sign up for Coral Chronicles?

- Yes, I want to keep up with all your exciting progress!
- No, I'm not interested in learning more about CRF™

Verification: I'm not a robot

CORAL RESTORATION FOUNDATION

Coral Restoration Foundation Questionnaire

Post-Dive Program Survey: This is an anonymous survey sent out to participants post-program. It is meant to track how people "found" the program opportunity and how their experience was rated.

Q1: How did you learn about Coral Restoration Foundation™ and the Restoration Adventure dive programs?

- Social Media (ie Facebook, Instagram, Twitter)
- Coral Chronicles
- A friend told me
- DEMA
- Visiting the Exploration Center
- Other (please specify)

Q2: How would you rate your overall experience on the Restoration Adventure dive program with CRF™?

★ Terrible – I didn't enjoy the experience at all and couldn't wait for it to end
★★ OK – too many moving parts and I felt overwhelmed
★★★ Good – once I arrived it was easy sailing
★★★★ Great – a walk in the "underwater" park! Sign me up for another!

Q3: How did you feel at the end of the experience?

★ It was hot, difficult, boring, I threw up four times on the boat and was happy to leave
★★ Cool program but too physically or logistically difficult for me to bother with again
★★★ You'll see me again, I had fun!
★★★★ Excited! Inspired! Felt like I made a small, but positive impact!

Q4: How likely are you to participate in another Restoration Adventure or program with us?

- Um, no
- Maybe in a year or two
- I'm not scheduling it now, but it's likely!
- Can we plan it right now?

Q5: Any final constructive Comments to help us improve or shout-out to someone in particular?

Q6: This survey is anonymous! If you would like to identify yourself or the program that you participated in, please do so below.

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Coral Restoration Foundation Questionnaire

New Volunteer Feedback

Q1: Did the land presentation:

- Tell you what you wanted to know?
- Tell you what to expect from volunteering?
- Explain the scheduling process?
- Provide interesting information?

Answer options:

- What?
- Not really…
- It was OK
- It was everything I needed

Q2: Did the hands-on land practice:

- Give a good understanding of what to expect underwater?
- Tell you what to expect underwater?
- Explain the restoration logic and process?
- Provide sufficient information?

Answer options:

- What?
- Not really…
- It was OK
- It was everything I needed

Q3: Did the in-water practice:

- Give a good understanding of restoration work?
- Make you smile?
- Explain the restoration logic and process?
- Prepare you for the "real" working dives?

Answer options:

- What?
- Not really…
- It was OK
- It was everything I needed

Coral Restoration Foundation Questionnaire

Q4: How was signing up with the Doodle?

- No idea what's going on there
- Confusing at first but now it's OK
- It's OK
- I think it's easy

Q5: Once you signed up, how was the communication for your volunteer day?

- Filling in the Doodle
- Receiving a schedule
- Communication by text message
- Was sufficient information received?

Answer options:

- What communication?
- I received spotty communication
- Communication was OK
- I knew exactly what to do

Q6: Anything you like to add/suggest?

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Coral Restoration Foundation Questionnaire

End of Year Volunteer Feedback

Q1: Are you a new volunteer in the XXXX year?

- Yes – I started this XXXX year!
- No – I'm a seasoned volunteer!

Q2: How was your land orientation?

★ It didn't give me the information I needed at the time
★★ It was OK
★★★ The land orientation gave me all the information I could have wanted at the time!

Q3: How was your in-water orientation?

★ It lacked some skill components I needed for my first "real" volunteer day.
★★ It was OK
★★★ It provided me with all the in-water skills I needed for my first "real" volunteer day!
★★★★ N/A I was a land volunteer and the in-water didn't apply to me.

Q4: Did you see any changes throughout your volunteer experience in 2018?

★ I definitely saw some negative changes this year.
★★ No changes really.
★★★ I definitely saw some positive changes this year.
★★★★ N/A

Q5: How often do you feel you do the activity you signed up to do (half day/full day/dive program/etc)?

- 0-25%
- 26-50%
- 51-75%
- 76-100%

Q6: Does it deter you from volunteering again if you do not do the activity you signed up for?

- Definitely – I hesitate to sign up if I don't know what I'm doing
- Sometimes
- Never – keep calm and volunteer on!

Q7: Do you feel you "made a difference" while volunteering with CRF?

- No, I definitely don't feel I "made a difference"
- Maybe? Hard to say!
- Absolutely! I feel great every time I end a volunteer day :D

Q8: What is/was the best part of your volunteer experience?

Q9: What can we improve on?

CORAL RESTORATION FOUNDATION

NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

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