State of Florida
Restoration Priorities for Florida's Coral Reef: 2021-2026

January 2021

The purpose of this document is to identify the priorities of the State of Florida (Florida Fish and Wildlife Conservation Commission (FWC) and Florida Department of Environmental Protection (DEP) related to restoration of Florida's Coral Reef (FCR), also known as the Florida Reef Tract. This document is a living document and identifies the State's priorities for the 2021-2026 five-year timeframe, but the most immediate State of Florida priorities for calendar year 2021 have been identified in **purple font** and separately summarized in Appendix 1. This document can be used in support of project development and solicitation activities but is not intended to replace any necessary technical review or public engagement processes.

While the State of Florida recognizes that improving water quality on FCR is important to the success of any restoration activities, those issues are addressed in other documents.

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1. Data Management

The unprecedented challenges facing the FCR have given rise to dynamic research and innovative solutions to address coral disease and coral reef restoration. These activities underscore a need for the efficient collection, storage and wide dissemination of data across the coral restoration community. The State of Florida prioritizes both sustaining and expanding our current data management capabilities to meet the increased needs presented by ongoing coral disease and coral reef restoration activities.

The primary "go-to" for coral-related data management is the FWC Fish and Wildlife Research Institute (FWRI), Information Science and Management Section, and this Section is already operating at capacity. Proactive planning for coral reef restoration data management needs as well as attracting and retaining skilled database programmers and data managers within this Section is a priority.

1.1 Data Management Capacity

Sustaining existing capacity (currently DEP funded), securing programmatic funding that ensures sustained capacity in future years independent of legislative allocations to DEP for coral disease response, and expanding support for database/application (app) programmers and data managers, will be necessary to maintain and expand existing databases/apps that have been developed for coral disease response, as well as modifying and supporting the current database structure and developing new and updated user interfaces to advance restoration priorities. Programmers are those individuals with the skillset to design, develop, test, implement and maintain new and existing enterprise level databases and apps. Data managers are those individuals who coordinate with the coral disease response and restoration communities to ensure end-user (restoration practitioner, scientist, resource manager, etc.) needs are met (data entry, query, reporting, visualization, accessibility, etc.). Data managers also play a higher level role in understanding how different datasets and end-user needs should interact, coordinate with data liaisons to maintain data integrity, as well as develop simple data collection and display solutions (e.g., Data Dashboards, Survey123, Web Mapping Applications, etc.).

1.2 Data Management Needs in Support of Restoration Site Selection

Data management needs specific to the restoration site selection process are identified in Section 4.2.1.

1.3 Data Management Needs in Support of Direct Restoration Activities

Data management needs specific to direct restoration activities are identified in Section 5.1.

2. Gene Banking

Florida's Coral Reef has been experiencing an outbreak of a coral disease termed **Stony Coral Tissue Loss Disease (SCTLD)**. As of December 2020, this lethal disease has significantly impacted coral reefs spanning from Martin County through the Keys to the Marquesas as well as 14 countries throughout the Caribbean. SCTLD has significantly impacted over 20 of the approximately 45 species of Florida's reef-building corals. As this lethal, widespread outbreak continued to progress south through the Keys, managers were faced with the stark reality that gene banking corals was absolutely necessary to ensure coral reef restoration post-outbreak would be possible. The following priorities support ongoing gene banking projects that are essential to meet Florida's long-term coral reef restoration goals.

2.1 Coral Rescue

In response to SCTLD, the DEP in partnership with FWC, National Oceanic and Atmospheric Administration (NOAA), and National Park Service (NPS), developed a coral disease response network consisting of 10 teams, a Steering Committee, and two dedicated staff members. One of these disease response teams is the Florida Coral Rescue Team led by FWC and NOAA Fisheries.

The goal of the Florida Coral Rescue Team is to collect (remove) healthy corals from ahead of the disease boundary and corals that still remain in the disease endemic zone, and hold (gene-bank) such corals in land-based facilities to *prevent* them from becoming infected; to *preserve* genetic diversity; and to *propagate* them for restoration of FCR. These "rescued" corals will serve as the parents (broodstock) of future generations of coral offspring that will be propagated to restore the FCR.

Coral Rescue efforts began in late 2018 by developing a collection plan based on preserving genetic diversity, conducting pilot collections, and developing a public-private partnership with the Association of Zoos and Aquariums (AZA) to gene-bank and care for Rescue corals. AZA was the only entity that had the suite of resources, expertise and professionalism to assist with this daunting conservation challenge. AZA immediately created the Florida Reef Tract Rescue Project and since then has contributed outstanding leadership, structure, and national support for Coral Rescue gene banking.

As of July 2020, over 1800 corals of 20 different species have been gene-banked in 18 different land-based AZA facilities spanning 12 states across the country. These corals were collected from ahead of the disease boundary and represent the genetic diversity that otherwise would have been lost to SCTLD.

Coral Rescue collections have been completed from ahead of the disease boundary but are now moving to the disease endemic zone to collect some of the corals that are remaining to meet collection goals and to incorporate potentially resilient genetics into gene-banking and propagation efforts.

Coral Rescue gene banking is also expanding to non-AZA land-based facilities that meet a comparable level of AZA facility and care standards. Additional AZA and non-AZA facilities both within and outside of Florida are in preparation stages to join Coral Rescue efforts. These newer facilities will be gene banking corals collected from the disease endemic zone.

Support for the long-term operations of Coral Rescue gene banking (holding) facilities, continued development of new holding facilities (AZA and non-AZA), and expansion of existing holding facilities is a priority to:

- House additional Rescue corals.
- Provide additional tank space to spread out Rescue corals currently in holding that are growing faster than expected.
- Modify or expand Rescue coral holding facilities to incorporate other restoration-related activities such as propagation of Rescue corals and rearing of their offspring.

2.2 Coral Nurseries

Land-based and in-water coral nurseries are considered *de facto* gene banks as they have been holding coral species that are listed pursuant to the Endangered Species Act (ESA) (*Acropora cervicornis, Acropora palmata, Dendrogyra cylindrus, Orbicella faveolata*) which were already in significant decline prior to the emergence of SCTLD, and more recently have incorporated SCTLD-susceptible species. Maintenance and expansion of land-based and in-water coral nursery operations is a priority for ongoing gene banking activities with a strong emphasis on massive/boulder corals and other disease-susceptible species.

2.3 Research and Development in Support of Coral Husbandry (I.e., coral care) for Gene Banking (i.e., holding) Activities

Land-based

- Training of coral care personnel to address shortage of husbandry expertise to meet the demands for restoration
- Development of species-specific probiotic treatments for health support of corals in holding systems
- Propagation of maintenance animals (e.g., peppermint shrimp, crabs, snails, urchins) for coral holding systems to control macroalgae growth without manual labor
- Analyses of bacterial communities (and other members of the holobiont) during coral care in both the holding system environment and in the corals themselves (e.g., microbiome studies, symbiont studies, endolithic community). This is important for both the long-term care of adult corals and also for sexual recruits during rearing to ensure that they develop an appropriate set of symbiotic organisms to ensure long-term health. Microbial communities in aquaria are strongly influenced by filtration design and husbandry procedures and understanding how this impacts the corals in the aquarium helps to ensure long-term health and potentially the ability to thrive after reintroduction.
- Analyses of the long-term effects of antibiotic and other pharmaceutical treatments - whether the bacterial community remains shifted after treatment or recovers to a condition similar to pre-treatment. A small subset of corals in land-based nurseries have been treated with antibiotics (or repeated antiseptic dips), most notably in *Dichocoenia stokesii*. Questions from coral aquarists and health providers have arisen regarding potential long-term effects of these treatments and whether the bacterial community remains shifted after treatment or recovers to a condition similar to pre-treatment. If a treatment was successful, could this information be used to identify potential pathogens?
- Develop standardized and affordable diagnostic techniques (e.g., water quality, toxicology analyses) for diseased corals in holding that are commercially available to propagation facilities that provide results in a clinically relevant time frame. (i.e. a lab that can process all of the things here in a timely fashion: https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.13431)

In-water

- Development of efficient techniques/best management practices/specialized equipment/symbiotic relationships to clean both corals being held in nurseries and the nursery systems/structures holding them, control competitors (e.g., crabs, snails, urchins, surgeonfish), and control predators (e.g., amphipods, corallivorous snails, fireworms, butterflyfishes, damselfishes, corallivorous parrotfishes). For example, identify ways to attract and hold grazer species of fish at in-water nursery locations (e.g., tangs, wrasse, yellowtail snapper) to facilitate the cleaning of nursery structures and control amphipods.

3. Coral Propagation and Rearing of Recruits

Historically, coral populations are able to recover after disturbances through natural sexual reproduction, resulting in the production of recruits that will replenish depleted reefs. Unfortunately, low coral cover and low coral density significantly reduces the chances that eggs and sperm from different colonies will meet, which prevents natural reproduction and natural recovery. Therefore, reef recovery can be supplemented and accelerated through assisted sexual and asexual reproduction in land-based and in-water propagation facilities (coral nurseries). Asexually reproducing corals through fragmentation has the advantage of quickly increasing coral biomass to provide habitat for reef-associated species and prevent reef substrate erosion but does not contribute to maintaining or increasing genetic diversity because these corals are genetic clones. Assisted sexual reproduction of corals in land-based facilities can also increase coral biomass over a longer time frame but also has the added advantage of maintaining and increasing numbers of genetically unique corals. Additionally, coral larval and juvenile mortality is extremely high in the wild and sexual propagation in land-based controlled environments will increase the amount of stock that would be available for restoration efforts. Coral restoration must incorporate a balanced approach that includes both asexually and sexually propagated corals to increase coral biomass, preserve genetic diversity and decrease juvenile mortality.

3.1 Prioritizing Species to Propagate and Restore

The propagation or restoration of the following priority coral species is needed for restoration of FCR. Additional species and priority levels for each species may be further established through the development of an FCR-specific restoration plan.

<u>Coral Rescue Priority Species</u>

- *Agaricia lamarcki*
- *Colpophyllia natans*
- *Dendrogyra cylindrus*
- *Dichocoenia stokesii*
- *Diploria labyrinthiformis*
- *Eusmilia fastigiata*
- *Favia fragum*
- *Meandrina meandrites*
- *Montastraea cavernosa*
- *Orbicella annularis*
- *Orbicella faveolata*
- *Orbicella franksi*
- *Pseudodiploria strigosa*
- *Madracis auretenra*
- *Mussa angulosa*
- *Mycetophyllia aliciae*
- *Mycetophyllia ferox*

- *Mycetophyllia lamarckiana*
- *Pseudodiploria clivosa*
- *Solenastrea bournoni*

Other Priority Species

- *Acropora cervicornis*
- *Acropora palmata*
- *Oculina diffusa*
- *Porites astreoides*
- *Porites porites*
- *Siderastrea siderea*
- *Stephanocoenia intersepta*

3.2 Genetic Priorities

Genetic information is essential to managing existing restoration efforts, certify whether novel genetic interventions such as genetic rescue or assisted gene flow is necessary and appropriate for restoration efforts moving forward, and to determine resilient traits. The following identifies genetic-related priorities for propagation and restoration activities.

3.2.1. Genetic Management Practices for Coral Propagation

In order to preserve genetic diversity and maintain the genetic integrity of Florida's wild coral populations, FWC oversees genetic management for coral restoration-related activities. Activities in need of FWC authorization undergo a genetic risk-assessment process based on a genetic management plan and must conform to standards and guidelines detailed in this plan. For FWC authorization, best management practices and procedures contained in the genetic management plan are designed to maintain natural genetic structure and diversity, local adaptation (if any), and genetic effective populations sizes above a threshold at which inbreeding becomes a concern. Coral restoration practitioners seeking to propagate corals including selectively propagate and/or proliferate any specific genotypes or phenotypic traits, characteristics or physical/ physiological/behavioral qualities through sexual or asexual propagative means, must have an FWC-approved need and approach consistent with the genetic management plan. FWC is developing "Genetic Management Practices for Coral Propagation" to assist restoration practitioners with developing a genetic management approach for propagation activities so that the activities will be consistent with the FWC genetic management plan.

3.2.2 Coral Rescue Genetic Priorities

Genetic data are already being collected and analyzed for all 20 species included within the Coral Rescue gene banking project. The actions that are not currently supported and need to be conducted are:

- Genotyping of all corals of Coral Rescue species being held in land-based and in-water coral nurseries.
- *Dendrogyra cylindrus* (DCYL)
  In addition to existing forms of restoration, genetic rescue appears to be a necessary and appropriate form of restoration intervention for DCYL. The following is needed to confirm this hypothesis:
    - Develop genetic markers for genotyping and use these standardized markers to:
        - Genotype all DCYL in nurseries;

        - Examine genomic data for early signals of inbreeding (i.e., runs of homozygosity, identity disequilibrium due to selfing);
        - Determine levels of genetic connectivity and spatial genetic structure for populations across the species range;
        - Develop SNP-based laboratory methods for parentage-offspring assignment to assist captive propagation and rearing efforts.

3.2.3 Other Species Genetic Priorities

- *Acropora palmata* (APAL)
  In addition to existing forms of restoration, genetic rescue appears to be a necessary and appropriate form of restoration intervention for APAL. The following is needed to confirm this hypothesis:
    - Convert available genomic (SNP) data from Penn State University (PSU) to a standardized cost-efficient genotyping assay for genet ID (i.e., SNP mining PSU data to develop genetic markers for genotyping), and use these standardized markers to:
        - Genotype all APAL in nurseries that have not already been genotyped in STAGdb;
        - Develop contemporaneous estimates of genetic effective population sizes (adopting meta-population dynamics) and mean levels of relatedness within the FCR population (including nursery stocks);
        - Examine genomic data for early signals of inbreeding (i.e., runs of homozygosity, identity disequilibrium due to selfing);
        - Determine levels of genetic connectivity and spatial genetic structure for additional populations across the species range with samples in holding with the Iliana Baums, PSU lab;
        - Identify seascape structure to further identify areas and factors of local adaptation.

- *Acropora cervicornis* (ACER)
  In addition to existing forms of restoration, genetic rescue appears to be a necessary and appropriate form of intervention. Assisted gene flow may be a possible form of intervention for ACER following genetic rescue. The following is needed to confirm these hypotheses:
    - Convert available genomic (SNP) data from Penn State University (PSU) to a standardized cost-efficient genotyping assay for genet ID (i.e., SNP mining PSU data to develop genetic markers for genotyping), and use these standardized markers to:
        - Genotype all ACER in nurseries that have not already been genotyped in STAGdb;
        - Develop contemporaneous estimates of genetic effective population sizes (adopting meta-population dynamics) and mean levels of relatedness within the FCR population (including nursery stocks);
        - Examine genomic data for early signals of inbreeding (i.e., runs of homozygosity, identity disequilibrium due to selfing);
        - Determine levels of genetic connectivity and spatial genetic structure for additional populations across the species range with samples in holding with the Iliana Baums, PSU lab;
        - Identify seascape structure to further identify areas and factors of local adaptation.

- *Millepora complanata* (MCOM)
  In the absence of data for MCOM, it appears that genetic rescue may become a necessary and appropriate form of intervention for this species of hermatypic hydrozoan (I.e., reef-building fire coral). The following is needed to further explore this hypothesis:
  - SNP marker development and use the markers to:
    - Genotype all MCOM in nurseries;
    - Genetically estimate genet numbers and distributions within FCR population(s) (including any nursery stocks); includes spatial estimates of Ng/N ratios;
    - Develop contemporaneous estimates of genetic effective population sizes (adopting meta-population dynamics);
    - Examine genomic data for early signals of inbreeding (i.e., runs of homozygosity);
    - Determine levels of genetic connectivity and spatial genetic structure for populations across the species range;
    - Identify seascape structure to further identify areas and factors of local adaptation.

- *Oculina diffusa, Porites astreoides, Porites porites, Siderastrea radians, Siderastrea siderea* and *Stephanocoenia intersepta*
  Reproductive interventions (sexual and/or asexual propagation) may be necessary for these species but in the absence of genetic data, it is currently not known whether other forms of intervention such as genetic rescue or assisted gene flow may be necessary. The following is needed:
  - SNP marker development and use the markers to:
    - Genotype all corals of these species in nurseries;
    - Genetically estimate genet numbers and distributions within FCR population(s) (including any nursery stocks); includes spatial estimates of Ng/N ratios;
    - Develop contemporaneous estimates of genetic effective population sizes (adopting meta-population dynamics);
    - Examine genomic data for early signals of inbreeding (i.e., runs of homozygosity);
    - Determine levels of genetic connectivity and spatial genetic structure for populations across the species range;
    - Identify seascape structure to further identify areas and factors of local adaptation.

3.2.4 Identification of Resilient Traits Genetic Priorities

Overall question: *What is the role of environmental history vs. coral genetics in determining coral resilience?* This general question underpins many of the specific restoration research questions that need to be addressed and are listed in the various thematic areas below.

- What is the role of genetic variation in determining coral resilience?
  - Identification of "resilient" coral genotypes
    - Phenotyping of coral genotypes (ranking, tradeoffs, etc.)
    - Genetic correlates of resilience (GWAS)
    - Coral biomarker development and validation
    - Develop high-throughput assays for testing large numbers of recruits for traits of "resilience"

    - How do "resilient" algal or bacterial partners further modify coral resilience? Under what circumstances do these partners change? Addressing these questions is an active area of research but could have immediate restoration implications. Differences in algal symbionts are well known as being one of the strongest predictors of bleaching variability, in Florida and elsewhere. Moreover, there is mounting evidence for the role of algal symbionts in modulating disease resistance, including recent work showing that some algal symbionts, such as Durusdinium, may impart resilience to SCTLD. Although these symbionts can change in response to the environment, changing environmental conditions mean that these symbionts may be relatively stable in many outplanting scenarios in Florida. In fact, reefs that have been devastated by bleaching and disease since 2014 are showing symbiont shifts in favor of Durusdinium that may be long-lived at this point. Future restoration efforts may need to leverage this finding by, for example, not outplanting corals with disease-susceptible symbionts that potentially fuel new outbreaks.

- How does the environment modulate genetic variation to drive phenotypic variation?
    - What are the Genotype x Environment (GxE) interactions driving coral phenotypes?
    - What is the role of pre-exposure (stress hardening) in determining coral resilience?
        - What is the effectiveness of different pre-exposure approaches? What are the tradeoffs and longevity of these approaches?
        - What are the underlying mechanisms (reversible changes in gene expression, epigenetic modifications, and/or holobiomic shifts)?

3.3 Propagation and Rearing Infrastructure

Land-based and in-water facilities both in-state and out-of-state are needed to hold broodstock corals, use such broodstock corals to conduct sexual and asexual propagation activities, and rear the coral offspring. Rearing activities may occur in separate facilities from broodstock holding and propagation activities. Propagation activities may occur in the following manners:

<u>Sexual Propagation</u>

- Land-based propagation via induced spawning systems → gamete collection → assisted fertilization → settlement → rearing
- Land-based propagation via mimicking of natural conditions to promote spawning → gamete collection → assisted fertilization → settlement → rearing
- Gamete collection (from wild corals, corals in spawning hubs, or corals in land-based or in-water holding) → assisted fertilization (land-based) → settlement (land-based) → rearing in land-based or in-water nursery, or directly outplanting within short term after settlement

<u>Asexual Propagation</u>

- Fragmentation/microfragmentation

Priorities for propagation and rearing infrastructure are to ensure current land-based facilities conducting sexual propagation and rearing activities have what they need to continue running their operations for 3 years, and the development of additional land-based sexual propagation and rearing facilities.

3.4 Cryopreservation

Sperm (and eggs, larvae and nanofragments as technology advances) of corals need to be cryopreserved to address spawning asynchrony, facilitate genetic rescue/assisted gene flow, and provide propagation flexibility to maximize genetic diversity. The priorities for cryopreservation are as follows:

- Equipment and training for operational (in field and on land) sperm collection and freezing
- Archival facility (separate from operational activities)
- Establishment of a 5-person cryopreservation team that is trained in cryopreservation techniques and can be deployed along the FCR during spawning seasons to facilitate cryopreservation of biological material for short term (operational) and long term (archival) coral propagation activities. A database would need to be developed (or added into an existing database) and the team would also be responsible for sampling, database management and coordination with the Coral Restoration Consortium (CRC) Cryopreservation Working Group

3.5 Research and Development in Support of Land-based and In-water Coral Propagation and Rearing

- Identification of optimal size to move coral recruits from land-based rearing nurseries to in-water rearing nurseries or directly to restoration sites, to maximize survival and minimize in-water maintenance
- Development of species-specific probiotic treatments for health support of corals to "boost" coral recruits (sexual and asexual) prior to being moved into open water or onto restoration sites
- Identification of appropriate grow out substrate types and sizes (e.g., tiles, discs, plugs, tetrapods) for rearing coral recruits on land so that these substrates can later be affixed to in-water nursery structures for additional grow out in-water. This will need to take into consideration coral recruit size when transferred from land-based to in-water rearing nurseries (see priority directly above) and in-water maintenance needs.
- Investigation of both land-based and in-water fragmenting methodologies with regards to tissue loss, attachment failure, disease susceptibility, and time spent executing the activity to improve efficiencies and survival.
- Development of efficient techniques/best management practices/specialized equipment/symbiotic relationships to clean nursery systems/structures and coral recruits, control of competitors (e.g., crabs, snails, urchins, surgeonfish), and control predators (e.g., amphipods, corallivorous snails, fireworms, butterflyfishes, damselfishes, corallivorous parrotfishes). For example, identify ways to attract and hold grazer species of fish at in-water nursery locations (e.g., tangs, wrasse, yellowtail snapper) to facilitate the cleaning of nursery structures and control amphipods.
- Study(ies) to determine differences of survival between asexually and sexually propagated colonies reared both in-water and land-based.
- Optimization of propagation techniques for land-based, mass-scale production
    - Identification of expected spawning time for each species with regional considerations; development of a Florida spawn prediction calendar.
    - Refine settlement methods to provide consistent settlement percentages to include identification of chemical cues, surface texture, water flow, etc.
    - Optimization post-settlement rearing techniques to ensure consistent post-settlement survival rates (including light levels, food, symbionts, and microbiome throughout development)

   - Develop and refine methods of rearing rear large quantities of coral larvae of several species simultaneously
   - How to measure adult and newly settled/juvenile corals – guidelines for measuring corals of all morphology types needs to be established for data consistency across facilities (live tissue area?)
   - Induced spawning system equipment development – develop a commercial-scale programming and control system that is capable of handling multiple large-volume aquarium systems
- Can broodstock corals be sourced for propagation from particular environments that select for climate and/or disease resilience?
   - Inshore vs offshore source sites, small-scale thermal gradients etc.
   - Is there a difference in SCTLD-resistance between large adults that were there before the disease, and smaller juveniles that have recruited since the disease?

4. Restoration Planning

Planning for restoration of FCR requires the development of a strategy, data management, and information and data tools to support appropriate site selection. The following priorities address these needs.

4.1 Restoration Strategy Development

The State of Florida (DEP and FWC) in partnership with NOAA (i.e., NOAA Fisheries, Florida Keys National Marine Sanctuary, Coral Reef Conservation Program) and the National Park Service should develop a comprehensive restoration strategy for Florida's Coral Reef. This will require a restoration strategy coordinator position and facilitation assistance for restoration plan development provided by, preferably, an entity outside of these managing agencies. The goal is not to reinvent the wheel, but to build off of existing restoration planning documents such as:

- "Developing a Comprehensive Strategy for Coral Restoration for Florida" (2014)
- "Restoring Seven Iconic Reefs, A Mission to Recover the Coral Reefs of the Florida Keys" (2019)
- "Reef Managers Guide to Coral Restoration Planning and Design" (2020)

4.2 Restoration Site Selection

A large part of restoration planning includes the selection of sites to be restored. Restoration site selection significantly drives other parts of restoration plan development such as the identification of coral species that are appropriate for restoration site parameters (e.g., habitat, depth, water flow), prioritizing the species of coral that need to be propagated based on restoration site parameters, identifying restoration site parameters to acclimate coral offspring to before they are outplanted to a restoration site, and the siting of spawning hubs (see Section 5.7 Spawning Hubs). Site selection should include ecological service considerations to ensure a balance between sites that are restored for shoreline protection, fisheries habitat, tourism, etc. Site selection must also consider restoration economics – in other words, the cost of conducting restoration at specific sites due to time, equipment, personnel and other resources necessary to restore a specific site.

Since so many parts of restoration planning are dependent on restoration site selection, priority is being assigned to the following activities that will develop the data and information required but is not yet available for the selection of restoration sites.

4.2.1 Data Management Needs in Support of Restoration Site Selection

A decision support tool (DST) is needed to guide and inform the coral restoration site selection process. A DST will provide a collaborative and interactive platform for visualization of relevant data, restoration targets and site selection options for identifying suitable restoration sites that consider local knowledge, expert opinion and the best available data. There are several biotic and abiotic datasets that should inform the restoration site selection process, but existing data will need to be processed for incorporation into a DST.

4.2.2 Larval Connectivity and Disease Risk Assessment Modeling

To restore the entirety of the FCR, direct restoration efforts (see Section 5) must be successful in re-establishing the natural processes of reef recovery, namely larval dispersal and recruitment. Larval connectivity modeling is needed to identify reefs that when directly restored, can provide spillover effects to naturally restore other areas of the FCR without direct restoration. This modeling is essential to the decision-making process for selecting restoration sites to more effectively maximize the spatial impact of coral reef restoration actions, while minimizing restoration costs and effort.

Additionally, the modeling approach should also incorporate a risk assessment for Stony Coral Tissue Loss Disease (SCTLD) transmission to simultaneously identify potential reef restoration areas that have low levels of SCTLD transmission risk.

The scope of larval connectivity and disease risk assessment modeling should be the entire FCR inclusive of existing and already planned for locations of concentrated coral restoration activity. For example, Molasses Reef and other reefs in the Florida Keys have already experienced substantial *Acropora spp.* restoration. Additionally, Mission: Iconic Reefs plans to fully restore important coral and grazer populations to seven iconic reefs within the Florida Keys National Marine Sanctuary. One component of modeling should be to ascertain the likelihood that these locations are important sources of larvae for the FCR.

Larval connectivity and disease risk assessment modeling should be proposed as a multi-year, cross disciplinary collaborative project wherein subsequent years, a more robust model will be developed that builds on the previous model. This will allow managers to shift priority restoration areas and practitioners to continue working using the best available knowledge.

Modeling methodology cannot be strictly based on passive particle dispersal and must have high temporal and spatial resolution to identify restoration areas at individual reef-scales (e.g., 100 m). The model framework must consider species-specific larval attributes (e.g., duration of the pelagic larval stage, larval distribution throughout the water column, weight, buoyancy, swimming capabilities, competency), environmental covariates relevant to dispersal, and account for variability in potential connectivity by incorporating multiple years of hydrodynamic simulations. In the absence of explicit understanding of species-specific larval attributes, modeling should incorporate the attributes of similar species from other geographic regions or utilize a range of larval-behavioral attributes to determine which, if any, have a key impact on dispersal outcomes. The end product will identify potential restoration areas with high larval spillover potential and low disease risk and communicate model error and validity from in situ observations, as appropriate.

4.2.3 What We Know (and don't know) About Corals – Intern/Grad Student Project

In order to select the appropriate coral species to restore a site, managers and restoration practitioners require basic information of coral species range, habitat needs, age of sexual maturity, spawning time of year, etc. Information on attributes of coral larvae are also needed to provide data inputs for larval connectivity modeling to select restoration sites.

The concept of this project is to engage the next generation of coral scientists by assembling a collaborative group of interns/grad students from across research and academic institutions to conduct data mining of relevant literature (including grey literature) and relevant anecdotal information; centralize all of this data and information, and make it available to managers and restoration practitioners to utilize for restoration strategy development (see Section 4.1) and direct restoration activities (see Section 5). By identifying what is known, centralizing this knowledge and providing it for restoration planning and directed restoration efforts, the data gaps for what is not known will also become apparent which will help to direct research efforts to address these data gaps. This group should be led by a non-intern Principle Investigator or Co-Principle Investigators to oversee and direct the group's efforts.

4.2.4 United States Geological Service (USGS) Seafloor Elevation Change Mapping and Modeling

Declining coral reef ecosystem health has caused substantial, regional-scale erosion of reefs and the shallow coastal seafloor surrounding them as coral production/growth has been outpaced by reef erosion. The resulting loss of seafloor elevation, combined with sea level rise, has already increased water depths to levels not expected until near the year 2100 (Yates et al. 2017). Projections of vertical-reef-growth potential indicate significant reef submergence along the FCR by 2100 (Perry et al. 2018), reducing the ability of reefs to serve as natural barriers that protect against coastal hazards such as storms and erosion. Thus, decreasing coral health, growth, and abundance has exacerbated the potential impact of storms on coral reefs, and has placed coastal ecosystems, human populations, and infrastructure at accelerated risk from coastal hazards, illustrating the urgency for successful coral reef restoration. High-resolution, seafloor elevation-change data and models are essential for targeting appropriate coral restoration locations and improving success of coral restoration activities. Specifically, these data will assist with: 1) identifying restoration locations where seafloor elevation has remained stable and suitable for coral restoration to improve the likelihood of long-term coral outplant success, 2) identifying locations where seafloor elevation is unstable and potentially unsuitable for coral restoration, and 3) planning for alternative restoration approaches (i.e., geo-engineering, seagrass restoration) to help stabilize the seafloor for coral reef restoration. USGS has already been funded to complete mapping and modeling of seafloor elevation-change and stability for the Florida Keys from Key West to Miami Beach. The remainder of the FCR from Miami Beach through St. Lucie Inlet needs to be completed.

5. Direct Restoration Activities

The decline of coral reefs worldwide over the past several decades has been particularly devastating in the Caribbean where reefs have sustained massive losses of important reef-building species such as *Acropora* and *Orbicella* spp. (Gardner et al., 2003; Hoegh-Guldberg et al., 2007). These declines have been driven by disease and other stressors including the loss of grazers, increased storm damage, and temperature anomalies (Aronson & Precht, 2001). The loss of reef-building species has contributed to decreases in reef structure and function, reef growth, fisheries habitat, coastal buffering, and biodiversity (Bruckner, 2002; Alvarez-Filip et al., 2009). In order to recover these key ecosystem services, direct biological restoration activities in this section includes coral propagation, outplanting, and spawning hub creation and are now considered essential components of coral conservation and management plans. Direct biological restoration focuses on propagating target corals for species recovery where nursery-reared corals are outplanted to bridge spatial gaps between existing populations (Griffin et al. 2012, 2015), for enhancing coral cover and abundance, for supplementing genetic and genotypic diversity (Lirman and Schopmeyer 2016), and for promoting natural recovery through the creation of sexually reproductive populations (Baums 2008). Physical or hardbottom restoration in response to groundings and hurricanes is also critical but is not included in this document.

5.1. Data Management Needs in Support of Direct Restoration Activities

Site-specific and higher resolution data than what currently exists will be needed to inform direct restoration outplanting approaches and to establish baseline conditions for restoration monitoring prior to direct restoration activities occurring. This need should be guided by restoration expertise and include the identification and utilization of appropriate technology to produce high resolution, site-specific data. Examples of technology that could be considered are Structure from Motion to provide topographic imagery or photo mosaics to document community structure.

Additional direct restoration data management needs also include the development of a monitoring database, data entry tools and reporting tools that can accommodate a distributed network of monitoring partners, secured access and large quantities of high resolution in situ photographs.

5.2 Scaling Up Direct Restoration of Disease-Susceptible Coral Species

Direct restoration of the FCR is not limited to disease-susceptible corals, but half of the coral species on the FCR are susceptible to SCTLD and have been significantly impacted by this disease. In order to appropriately assess the potential risks associated with conducting large-scale direct restoration of this group of disease-susceptible coral species, a study has been developed to examine the potential disease risks related to outplanting these coral species. This study will be the largest scale multi species outplant study to date. It is designed to outplant three species of SCTLD-susceptible coral species across the FCR and monitor them and the nearby natural communities for an extended timeframe. Outplant monitoring will be sufficiently robust to detect tissue loss and mortality caused by disease relative to other causal factors such as coral predation and bleaching. Reef monitoring has been designed to detect changes in the incidence of active SCTLD. To execute this study, coordinated actions among all the regional coral reef restoration practitioners and science partners will occur.

5.3 Enhancing Direct Restoration Success

5.3.1 Outplant Design

Studies are needed to determine optimal size, number, genotype and placement of corals to enhance direct restoration outcomes. While much effort has been dedicated to outplanting as a means to restore Florida's Coral Reef, little is known regarding how colony size, numbers of fragments per genotype planted in each cluster, or spacing of those fragments affects survival, fusion and growth to a reproductively mature colony. Study methodologies should account for spatiotemporal variations in environmental conditions across the reef tract and long-term health of outplanted coral colonies.

5.3.2 Predation Control

A significant barrier to successful direct restoration efforts is predation on newly outplanted corals. Recent restoration outplanting efforts in Miami-Dade County suffered 90% mortality due to predation from parrotfish within weeks of corals being outplanted, and outplanting efforts in other locations have suffered losses in varying degrees. Outplant methods, tools, technology, etc. focused on limiting predation must be developed to provide restoration efforts with the opportunity to succeed.

5.4 Acclimation

It may be necessary to develop acclimation procedures to be employed prior to introducing corals to in-water nurseries or outplanting corals to restoration sites that were propagated and/or reared in land-based facilities. This process would be dependent on the identification of restoration sites (see Section 4.2) so that restoration site-specific conditions could be mimicked and gradually introduced in to rearing system parameters.

5.5 Maintenance

It is a priority to develop efficient in-water techniques/best management practices/specialized equipment/symbiotic relationships to protect relocated or outplanted corals from competitors and predators to increase survival. Volunteerism (e.g., FWC Coral Crew) and voluntourism (as identified in Mission: Iconic Reefs) should be explored to assist with maintenance activities.

5.6 Optimization of Restoration Sites to Promote Natural Larval Settlement

A complex suite of factors affect settlement for corals and other reef-obligate species. The loss of coral cover, plus the general shift from scleractinian corals to non- coral species on reefs, including increased abundance of foliose algae, turf algae, cyanobacteria, *Palythoa*, hydrozoan corals, and certain gorgonians has fundamentally altered the physical and chemical nature of Florida's reefs. Research suggests that coral and fish larvae can detect and utilize physical and chemical cues that emanate from reefs, and typically respond positively to chemical cues from reefs that exhibit higher coral structure and low algal abundance and negatively to reefs with few corals and high algal abundance. Managing and preparing reefs to facilitate the production of cues that attract, rather than repel, recruiting corals and other reef-associated species will become an important component of a comprehensive restoration strategy. The following topics are priorities for investigating ways to promote natural larval settlement on coral reefs.

- Appropriate restoration site selection to facilitate natural larval settlement (see Section 4.2).
- Site preparation - development of efficient restoration and spillover site cleaning techniques/best management practices/equipment for algae, coral competitor and predator control. These actions should consider potential positive ecosystem functions of algae, competitors and predators as well as negative effects.
- Identification of chemical ques (e.g., crustose coralline algae (CCA)) for larval settlement
- Identification of "good" CCA species that promote successful recruitment, either via attracting larvae or allowing for settlement and growth of corals, followed by research to measure the abundance and distribution of CCA species preferred for coral recruitment.

- Improving substrate condition through addition of herbivores.
- Working with sound and coral reefs to mimic healthy reefs thus promoting coral larval settlement and improving fish community development – examples of supporting literature for this approach are:
    - Habitat quality affects sound production and likely distance of detection on coral reefs (Piercy et al 2014)
    - Acoustic enrichment can enhance fish community development on degraded coral reef habitat (Gordon et al 2019)

5.7 Spawning Hubs

Spawning hubs are specific locations where corals are centralized through relocation and/or outplanting. The establishment of a spawning hub serves several restoration purposes: 1) contribute to natural restoration processes by increasing the likelihood that eggs and sperm from coral colonies will come into contact with each other during spawning events resulting in larvae; and 2) facilitate the collection of gametes by restoration practitioners for propagation purposes.

Spawning hubs can serve as a valuable restoration tool, especially in aiding assisted fertilization activities for propagation. However, hubs must be correctly sited within an appropriately selected restoration site along the FCR to contribute to natural restoration processes through successful settlement of coral larvae produced by the hubs. To achieve successful larval settlement, restoration sites must first be appropriately selected based in large part on larval connectivity (see Section 4.2.2). Once restoration sites are appropriately selected with larval connectivity as a consideration, creation of spawning hubs are a priority activity for coral reef restoration.

5.8 Monitoring of Direct Restoration Activities

Monitoring of restoration actions whose primary purpose is to increase coral abundance at a reef site should be robust and long-term. In particular, the goal of such monitoring should be to best track the long-term outcome of a restoration action or multiple restoration actions at that location. Ideally, such monitoring will be conducted at regular intervals and be completed identically across all locations that are restored pursuant to a restoration strategy developed for the Florida's Coral Reef (see Section 4.1). Such monitoring could be accomplished by the entity that conducts the restoration action or by an independent monitoring team. Those data could then reside at a central location (see Section 5.1) and, in addition to regular overarching and site/region specific reports that delineates change of the measured variables through time completed by an independent monitoring team, these data should be accessible for analysis. A recent document, "Coral reef restoration monitoring guide: Methods to evaluate restoration success from local to ecosystem scales", provides guidance for such monitoring, and could be used by a team of scientists and managers as the starting point to develop a restoration monitoring plan in support of a restoration strategy developed for the Florida's Coral Reef.

Restorations actions that have a specific purpose (e.g. establishment of a spawning hub; a restoration action specifically designed to answer questions regarding short or long-term outcomes of selected coral traits) should in addition to the overarching monitoring have project specific monitoring as part of the project plan. The details of such monitoring will be unique to each project. If there are useful data that could be gleaned from such a study whose collection will require longer-term detailed monitoring beyond the scope of the team that initiated the project, such monitoring should be considered for inclusion for an independent monitoring team mission. Data collected by the independent team should then be accessible to all.

Monitoring should be a regular program component of any comprehensive state coral reef restoration strategy and appropriately funded long-term. Where possible, the use of innovative technology and techniques to increase the efficiency and resolution of monitoring efforts is encouraged.

6. Restoration of Coral Reef Ecosystem Functions

While direct coral restoration is the most expansive need for coral reef restoration, an equally essential need is to restore coral reef ecosystem function. At present, the knowledge and techniques required to conduct such restoration are in their infancy. Resources should be directed towards development and implementation of the following activities to address this essential restoration component for FCR.

6.1 Propagation of Reef-Associated Species

Successful restoration of the FCR will require directed efforts to aid in the recovery of coral reef-associated species that are essential to coral reef ecosystem function. Many of these species regulate ecosystems through their trophic activities directly on reefs. For example, recovering robust populations of certain herbivores that dwell on reefs will reduce the presence of species that impede coral recruitment and will assist the re-establishment of substrate conditions that increase the probability of successful coral larval settlement from strategically located coral outplant sites. Additionally, there is at least one species that is a known predator on coral-eating snails. Addressing these types of relationships could increase coral outplant survivorship. There are also coral reef-associated species that are rare, and when abundant, were likely to provide important contributions for a fully functioning ecosystem. Finally, restoration of key structural components of the entire coral reef ecosystem especially sponges in shallow-water hardbottom, will aid in the overall reef seascape management.

Restoration approaches for coral reef-associated species should mirror management standards for coral restoration activities with respect to genetics and health. For mobile species such as long-spined urchins, considerable manipulative research will be needed, such as understanding and developing shelter that ensures their survival until such time as coral restoration activities will be sufficient to serve in that function. The priority species and species groups are:

- Herbivores
  - *Diadema antillarum* – long-spined urchin
  - *Maguimithrax spinosissimus* – Caribbean king crab
- Coralivorous predators
  - *Thais deltoida* – deltoid rock snail
- Sponges
  - Shallow-water sponges – multiple species
  - *Xestospongia muta* – giant barrel sponge
- Octocorals
  - *Gorgonia flabellum* – Venus sea fan
  - *Gorgonia ventalina* – common sea fan

6.2 Seafloor Stabilization

Priority is being given to actions that will stabilize the seafloor (i.e., geo-engineering) to prevent erosion such as seagrass restoration, structures specifically designed to address restoration needs (e.g., artificial reefs), and restorative aquaculture.

6.3 Novel and Outside-the-box

Explore ways to mitigate ocean acidification at restoration sites to help corals grow stronger and bigger such as the use of strategically placed olivine sand to pull CO2 from the air. This approach has the potential to decrease ocean acidification and increase HCO_3 availability. This is a climate change mitigation approach similar to cloud brightening for the Great Barrier Reef, but would increase benefits one step further with availability of HCO_3 for uptake by corals and other reef-associated invertebrates: https://projectvesta.org/

Appendix I: State of Florida Restoration Priorities for Florida's Coral Reef - Calendar Year 2021

IMMEDIATE PRIORITY (2021)

References in purple font indicate the related sections in the 2021-2026 document.

1. **Data Management**
   a. Sustain existing data management capacity and future capacity expansion for the FWC Fish and Wildlife Research Institute (FWRI), Information Science and Management Section. (**1.1**)
   b. Develop a decision support tool for restoration site selection. (**4.2.1**)
   c. Data management needs in support of direct restoration activities. (**5.1**)

2. **Gene Banking**
   a. Support for ongoing Coral Rescue gene banking activities within the AZA network or with equivalent standard of care facilities outside of the AZA network, addition of new facilities, and facility expansions to provide for ongoing endemic coral collections, additional holding space for corals already in holding as they are growing, and redistribution of corals already in holding to minimize risks. (**2.1**)
   b. Maintenance and expansion of land-based and in-water coral nursery operations is a priority for ongoing gene banking activities with a strong emphasis on massive/boulder corals and other disease-susceptible species. (**2.2**)
   c. Training of coral care personnel to address shortage of husbandry expertise to meet the demands for restoration. (**2.3**)
   d. Development of species-specific probiotic treatments for health support of corals in holding systems. (**2.3**)
   e. Development of efficient techniques/best management practices/specialized equipment/symbiotic relationships to clean both corals being held in nurseries and the nursery systems/structures holding them, control competitors (e.g., crabs, snails, urchins, surgeonfish), and control predators (e.g., amphipods, corallivorous snails, fireworms, butterflyfishes, damselfishes, corallivorous parrotfishes). (**2.3**)

3. **Coral Propagation and Rearing of Recruits**
   a. Develop Genetic Management Practices for coral propagation activities (**3.2.1**)
   b. Propagation Genetics (**3.2.2 and 3.2.3**)
      - Develop genetic markers for all priority species
      - Genotype all corals of priority species in all coral nurseries
   c. Infrastructure - Ensure current land-based facilities conducting sexual propagation and rearing activities have what they need to continue running their operations for 3 years, and the development of additional land-based sexual propagation and rearing facilities (additional 1-2 facilities). (**3.3**)
   d. Cryopreservation – Provide equipment and training for operational (in field and on land) sperm collection and freezing. (**3.4**)
   e. Research and Development in Support of Coral Propagation and Rearing (land-based and in-water). (**3.5**)
      - Identification of optimal size to move coral recruits from land-based rearing nurseries to in-water rearing nurseries or directly to restoration sites, to maximize survival and minimize in-water maintenance.

- Development of species-specific probiotic treatments for health support of corals to "boost" coral recruits (sexual and asexual) prior to being moved into open water or onto restoration sites.
- Identification of appropriate grow out substrate types and sizes (e.g., tiles, discs, plugs, tetrapods) for rearing coral recruits on land so that these substrates can later be affixed to in-water nursery structures for additional grow out in-water. This will need to take into consideration coral recruit size when transferred from land-based to in-water rearing nurseries (see priority directly above) and in-water maintenance needs.
- Investigation of both land-based and in-water fragmenting methodologies with regards to tissue loss, attachment failure, disease susceptibility, and time spent executing the activity to improve efficiencies and survival.
- Development of efficient techniques/best management practices/specialized equipment/symbiotic relationships to clean nursery systems/structures and coral recruits, control competitors (e.g., crabs, snails, urchins, surgeonfish), and control predators (e.g., amphipods, corallivorous snails, fireworms, butterflyfishes, damselfishes, corallivorous parrotfishes).
- Study(ies) to determine differences of survival between asexually and sexually propagated colonies reared both in-water and land-based.
- Identification of expected spawning time for each species with regional considerations; development of a Florida spawn prediction calendar.

4. Restoration Planning

a. Hire a Restoration Coordinator to take point on restoration strategy development, partner collaboration, etc. (**4.1**)
b. Develop a comprehensive restoration strategy for Florida's Coral Reef through coordination and facilitation assistance provided by, preferably, an entity outside of managing agencies. (**4.1**)
c. Conduct restoration site selection studies to inform restoration strategy development: Larval Connectivity and Disease Risk Assessment Modeling. (**4.2.2**)
d. Data mining and summarization of what we know about corals. (**4.2.3**)

5. Direct Restoration Activities

a. Large-scale study to examine the potential disease risks and survival related to outplanting SCTLD-susceptible corals for restoration (depending on funding available, may need to consider breaking down into a phased approach by region). This study has been partially funded. (**5.2**)
b. Outplant design studies to determine optimal size, number, genotype and placement of corals to enhance direct restoration outcomes. (**5.3.1**)
c. Development of predation control outplant methods, tools, technology, etc. (**5.3.2**)

6. Restoration of Coral Reef Ecosystem Functions

a. Propagation and outplanting of reef-associated species. (**6.1**)