International Coral Reef Initiative (ICRI)

Member's Report | 37th General Meeting

19th – 23rd September 2023 Hawai'i, – United States of America

Reporting Period: 2021 – 2023

A. Member Information:

- Name of ICRI member: Mote Marine Laboratory (mote.org)
- Name of person(s) completing member's report: Dr. M.P. Crosby (President & CEO) with significant input from numerous Mote Marine Laboratory scientists
- Email: mcrosby@mote.org
- Are you a Focal Point: ☒ Yes ☐ No
    - If no, who are you completing the form on behalf of:
- Which was the last General Meeting you attended: n/a
- Will you be attending the 37th ICRI General Meeting: ☒ Yes ☐ No
- Member social media:
    - Twitter: @motemarinelab
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B. Reporting on the implementation of ICRI Plan of Action 2021-2024: turning the tide for coral reefs. *Your responses will help inform the Secretariat about members' contributions toward the current Plan of Action*

Theme 1 - Preparing for the Future: Promoting Resilient Coral Reefs

1.A - Strengthening policies - Supporting conservation and recovery of coral reefs and associated ecosystems through resilience-based management frameworks.

- (ICRI) How have you embedded resilience-based management into your policies? *(Tip – refer to the RBM policy brief: https://icriforum.org/resilience-hub/)*

Answer:
Mote Marine Laboratory's Coral Reef Research and Restoration initiatives supports numerous scientists working across multiple disciplines to reverse decades of ecosystem decline, bringing new life and new hope to Coral Reefs around the world. The very premise behind Mote's efforts includes incorporating mechanisms that promote resilience within restored populations. Specifically, we study and promote the incorporation of genotypes resistant to major threats such as infectious diseases, high water temperatures, and ocean acidification processes. These resistant genets are widely distributed within the restoration broodstock, but also are utilized as parents for the next generation to incorporate potentially heritable resilient traits while also creating new genetic combinations within the next generation of corals. The incorporation of resistant individuals is coupled with genetic management actions that promote diversity, which inherently work in concert to create resilient coral communities that can recover after disturbance events. Additionally, Mote has integrated noncoral species with key ecological functions (*i.e.*, grazing) that facilitate and reinforce ecosystem recovery and resilience. We have created the first ever land-based Caribbean King Crab hatchery at Mote's Aquaculture Research Park that will allow for the production of this native herbivore which will be stocked onto degraded reefs along with coral outplants. After stocking, these reef grazers significantly reduce algal cover leading to a benthic community that promotes a more abundant and rich fish community, increases the survival of coral outplants, and provides suitable habitat for natural coral recruitment. Finally, Mote is a key partner of the Florida Keys National Marine Sanctuary and collaborates with this entity as well as other local and state partners to promote sustainable use and conservation of Florida's Coral Reef.

1.B - Promote capacity building for applying resilience-based management approaches to coral conservation Ad Hoc Committee on Resilience-based Management.

- (ICRI) Please list any examples of leading practices, techniques and strategies for building reef resilience that your organisation/country is involved in. Include their location and extent, methods of implementation, financing, and an assessment of their results (or likely results), with links for more information if possible.

Answer:
Mote's primary regional focus on coral reef resilience is Florida's Coral Reef, spanning from Martin County (Central East Coast of Florida to the Dry Tortugas west of Key West). However, our methodologies have been adopted on a global scale and our network of collaborations is worldwide. Funding of our strategic operations and scientific endeavours comes from a diverse suite of philanthropic, local, state, and federal entities. Results of our efforts are shared within our several targeting working groups, openly accessible databases, GitHub repositories, and peer-reviewed publications.

Strategic Focal Areas of Study and Implementation are Described Below:

Increasing the efficiency (*e.g.*, cost, labor, material, survival) of large-scale coral restoration

Mote has, to date, outplanted more than 200,000 corals onto Florida's Coral Reef. With resilience and adaptive potential of the restored community as a core tenet of Mote's restoration strategy, improving the efficiency (*e.g.*, cost, labor, material, survival) of the entire restoration pipeline is critical to scale interventions, and effects, moving forward. Mote is approaching this quandary from a number of different angles. To maximize production and minimize the duration of a fragment's tenure in land-based or offshore nurseries, Mote is evaluating the survival and growth of coral fragments with respect to size (*e.g.*, time since microfragmentation). Preliminary data suggest that fragments with a shorter nursery duration (to a point) may grow faster and exhibit equal or greater survival after outplanting than larger (~3 cm 2) fragments. Additionally, Mote data suggests that the optimal nursery environment (*in* vs *ex situ*) differs between and among species and potentially genotypes within species. Mote is actively evaluating the growth of fragments in field and land-based nurseries to determine where each species' propagation and production is maximized. A key component of both of these research endeavors is the response of cultured corals to the conditions at the eventual outplanting location. In collaboration with researchers from the University of Alabama and the University of Southern California, Mote is evaluating the physiological responses (and survival) of outplanted corals. These data are critical in adjusting system and husbandry parameters to best prepare the new corals for growth and survival on the reef as well as identifying critical bottlenecks to success. Further, Mote is actively evaluating the physiological effects of *in situ* nursery structures on the corals produced under climate change and ocean acidification conditions to better estimate the efficacy of restoration interventions in a changing climate. Mote is collaborating with researchers from Florida International University to develop and evaluate methods for deterring predation of newly outplanted corals potentially significantly increasing survival, and thereby efficiency in restoration efforts. To increase efficiency in production workflows, Mote is actively evaluating the effect of new and novel substrates as well as coral genotype on coral growth and survival in a nursery setting as well as performance post-outplanting. These new and, in some cases, novel substrates may reduce costs with improved growth and/or survival of corals in production and/or after outplanting.

Resilience, of corals and the restored community, is a core tenet of Mote's Coral Reef Restoration programs. Mote is continuing to focus on this more than decade-long research focus in evaluating the effects of species richness, genotype richness, outplant density, and outplant frequency on the ecological recovery and resilience of coral reef ecosystems. By outplanting multiple genotypes from more than 17 different species of corals across more than 90 restoration locations, Mote is continually contributing to long-term ecological restoration data sets with broad, landscape-scale spatial context in a degraded reef system - Florida's Coral Reef. Further, Mote employs a microfragmentation and fusion approach to coral production and outplanting which capitalizes on the physiological response of corals to fragmentation wherein after the trauma associated with fragmentation, coral growth increases dramatically (~20-40 times greater). With careful genetic management, Mote outplants multiple species in clusters of fragments from a single genotype. As these fragments grow rapidly, their tissues meet and, because they are all clonal fragments of a single genetic individual, the fragments fuse into a single larger colony. This microfragmentation and fusion process allows Mote to produce reproductive size colonies substantially faster than with other approaches and even more so than wild corals. For instance, a cluster of *Oribicella faveolata* fragments outplanted in 2015 was observed spawning in 2020, just five years after the fragments were outplanted.

Absolutely critical to all of Mote's coral reef restoration efforts is the continual evaluation, revision, and innovation in monitoring techniques - both *in* and *ex situ*. Mote is evaluating the utility of novel digital tools such as SfM, photogrammetry, and 3D scanning technologies for the purpose of measuring growth (in multiple dimensions) of corals in nursery settings as well as through time on the reef. In the nursery, Mote is evaluating laser 3D scanning systems alongside SfM photogrammetry to measure and track growth of cultured coral fragments through time. These techniques allow for quanitative assessments of the effect of culture conditions not just on tissue extension (*e.g.*, 2D laminar growth), but also of skeletal deposition and 3D growth in response to environmental conditions and husbandry practices. These tools also represent methods that may be systematically reproduced anywhere in the world facilitating standard methods for global collaborations. In the field, Mote is investing substantially in the innovation of large area imaging systems to improve efficiency in the collection, processing, and analysis of monitoring data. Further, the integration of large area imagery into Mote's coral reef restoration monitoring pipelines leads to an invaluable long-term data set whose data value increases with every technological advancement in computing architecture and software through time. This data rich record of the reefscape and effects of restoration interventions through time is imperative to Mote's research into integrating automation and machine learning into monitoring and ecological data analysis. Mote is actively collaborating with SeaFoundry, a technology company whose mission involves integrating technology and automation systems into the production and management of restoration corals, on the development, testing, and implementation of app-based inventory management software, computer numeric control (CNC) based robotics, and deep learning neural networks into the day-to-day and strategic management of restoration efforts. Mote and SeaFoundry are currently testing a CNC robot which is capable of automating much of the coral nursery inventory data collection (including time series growth metrics) with SfM technology in land-based nursery systems. SeaFoundry is also working closely with Mote scientists to build and refine a digital app-based coral nursery inventory management platform allowing nursery technicians to collect, update, and review inventory data from any wi-fi connected device in near real time. These, and other digital tools in development, demonstrably streamline otherwise substantially labor-intensive tasks - measurable increases in production efficiency.

Finally, Mote is actively integrating the restoration of other key ecological functions, such as grazing, into its holistic coral reef restoration strategy. The production and stocking of native grazers such as the Caribbean king crab, allows Mote to actively intervene in the incidence and effects of coral-algal interactions. The introduction of these crabs, and their effect on the distribution and abundance of benthic algae, also results in cascading ecosystem-level effects such as significant increases in the richness and abundance of reef-associated fishes and a significant increase in the survival of juvenile corals. The integration of reef grazers both facilitates increased coral survival and growth, but also potentially improves the conditions for coral settlement and recruitment.

Implementation of a Living Coral Gene Bank

Mote's International Coral Gene Bank's mission is to preserve coral species and genetic diversity for future research, propagation, and restoration within a storm-safe infrastructure focused on providing critical life support for living coral colonies. Mote's Gene Bank is located in an environmentally hardened category 4 hurricane resistant building with redundant power and re-circulating seawater systems on the 200-acre Mote Aquaculture Research Park campus ~20 miles inland from the coast. Mote's International Coral Gene Bank contains two emergency generator backup sources and enough supplies on site to conduct three complete water changes during any emergency situation. The current holding facility within the main warehouse contains four separate life-support systems thus ensuring genetic preservation through independent redundancy among the raceways. Each of the four systems contains four raceways, measuring 4'x 8'x 3', with an independent sump for maintaining optimal seawater chemistry conditions. The entire Gene Bank has the capacity to contain approximately 7200 gallons (27,250 liters) of seawater and can hold up to 500 reproductive-sized corals for focusing on coral spawning initiatives, or at least 15,000 small fragments of corals (the size used for research, propagation, gene banking, and outplanting for restoration purposes). The raceways can also hold coral recruits for growout purposes, with the capacity to hold approximately 1,000 ceramic plugs per raceway. The system is temperature controlled and monitored using APEX computer automated controller systems, which provide real-time monitoring data and automatic alarm notifications. A total of four Hydra 64HD aquarium lights, which are programmable and customizable, are positioned above each raceway and can mimic true environmental cycles through time. Environmental regulation of the seawater provides the optimal environmental conditions for coral survival and growth. Parameters for each raceway can be modified to suit the needs for species-specific requirements and region-specific environmental conditions.

Mote's International Coral Gene Bank also includes four land-based spawning systems that are self-contained, independent 200 gallon aquaria that hold reproductive sized coral colonies for the induction of spawning. These systems are automated to provide optimal water quality and environmental conditions to cue the production and release of gametes during the normal reproductive cycle.

Additional infrastructure for coral larval settlement and growout includes a larvae settlement system, which is a closed recirculating system that allows for settlement within a simulated flow-through environment. This reduces the workload of conducting constant water changes and provides clean healthy water to the larvae for optimal settlement. To date, Mote Gene Bank staff have settled a variety of broadcast spawners and brooding coral species. Mote's total holdings of distinct coral genotypes within its International Coral Gene Bank and other campuses in the Florida Keys and Sarasota, are currently in the order of tens of thousands.

Managed Breeding Program Implementation

Mote utilizes a variety of tools, techniques, and state-of-the-art technologies to produce large, genetically diverse offspring populations in order to diversify Mote's restoration gene pools and impart increased stress-tolerance, adaptive potential, and resilience to Mote-restored coral populations on Florida's Coral Reef

Mote scientists at Summerland Key's IC2R3 and Mote's International Coral Gene Bank are currently sexually propagating more than 10 scleractinian coral species for research and restoration purposes. Of these species, several represent Florida's Rescue Corals which were rescued from the wild ahead of the stony coral tissue loss disease (SCTLD) outbreak and transferred to Mote's International Gene Bank in Sarasota for long-term holding and sexual propagation where offspring will be used for active restoration in Florida. To spawn these corals in captivity, we are using state-of-the-art ex-situ spawning systems to induce gametogenesis and synchronized gamete release in the lab. These systems also allow us to expand our capacity for sexually propagating corals in the lab by spawning species out-of-season and year-round (instead of just once annually). To maximize reproductive success and diversity of collections and productions, Rescue Corals will be exchanged among partners over time, which is coordinated by the Coral Rescue & Propagation Team of the Florida Fish and Wildlife Commission. Similar exchanges for non-Rescue corals and incorporating all life stages including gametes, larvae, juvenile and adult corals are continuously being brokered with partner organizations in Florida to diversify Mote's restoration gene pools and incorporate as many source populations, reefs, and regions as possible (e.g. assisted gene flow).

For all species, we develop best-practices protocols and conduct experiments to optimize and upscale every stage of the sexual propagation process including spawning, fertilization, larval rearing, settlement, algal symbiont acquisition, recruit grow-out (post-settlement survival), and outplanting. Such experiments include evaluating reproductive compatibility in terms of spawning synchronicity and fertilization success among broodstock, testing for trade-offs between reproductive output and disease susceptibility, upscaling larval propagation techniques, testing spectral and chemical settlement cues, developing optimal artificial light regimes for increasing recruit growth and survival during the indoor lab grow-out phase, identifying anti-fouling strategies for reducing interspecific competition and increasing recruit survival also during the indoor lab grow-out phase, determining when to transition sexual recruits from the land nursery to the field nursery for an in-water grow-out phase before outplanting on the reef, identifying the potential for corals to use endogenous sexual cues (e.g., pheromones) to regulate the timing of gamete release, incorporating results of coral stress-testing experiments to inform specific crosses as part of managed/selective breeding interventions, studying the heritability of disease resistance and potential for conducting selective breeding based on this trait, confirming that reducing the time until the first onset of sexual reproduction (i.e., sexual maturity) can be achieved using Mote's microfragmentation-fusion methodology to create larger colonies faster, utilizing closed-system ex-situ larval rearing/settlement systems for rearing/settling larvae and growing out recruits under controlled conditions post-settlement, determining when to use 2-parent versus batch fertilization crosses to meet certain research or restoration needs, optimizing feeding regimes by life stage and species, developing multiple strategies for rapid integration of sexual recruits and novel diversity into Mote's various research and restoration pipelines, and incorporating cryopreservation methodologies for assisted gene flow interventions, increasing diversity of crosses, and mitigating occurrences of spawning in temporal isolation. To support this work, replicate in-situ spawning nurseries have been created within Mote's existing Looe Key and Sand Key coral nurseries which hold replicate colonies of reproductive size of up to 16 genetic varieties sourced from various reefs and regions for both acroporid species. Corals of opportunity are utilized for working with boulder and brain species as well as larval donations from collaborating partners

Operations of this work also extend to the field and include comparing the outcomes of outplanting single recruits versus those that have been fragmented and outplanted as clonal clusters, conducting long-term monitoring of Mote-restored populations to ensure they are meeting developmental milestones (e.g., sexual maturity) within expected timeframes -and if not- to investigate why, testing the potential for using sexual recruits with varying symbiont clades for restoring nearshore patch reefs, understanding microbiome dynamics of sexual recruits across various life stages as well as ex- and in-situ environments, and comparing spawning behavior (e.g., timing, duration, synchronization) across reef outplants, in-situ coral spawning nurseries and corals brought on land for ex-situ spawning.

Increasing Resilience Within Restored Populations

Integrate Targeted Genetic Management: Restoration conducted without consideration for genetic diversity carries risks of maladaptation and inbreeding, reducing the likelihood of restoring self-sustaining populations. Mote aims to integrate resilience and diversity mindfully into restoration, ensuring that our outplanted corals can withstand existing and future stressors while preventing genetic bottlenecks by maintaining high genetic diversity regardless of phenotype. While numerous new genotypes are produced through sexual reproduction activities when successful, the production of these genotypes must be balanced with wild-collected "founder" genotypes to ensure maximum diversity. Mote therefore randomly selects genotypes for pre-production and incorporates knowledge of cohort diversity from genetic tools into decisions regarding retention for production. As genets are selected for pre-production, we ensure high diversity of phenotypes represented by randomly selecting from available genotypes, rather than selecting for high performers under nursery conditions. For example, while fast-growers in nursery conditions may be easier to propagate and increase biomass, slower-growing genets may have advantageous traits that are not readily apparent but may influence long-term survival and reproductive capabilities, as well as the overall fitness and diversity of the reef gene pool. Mote conducts research to quantify genetic diversity and relatedness within our restoration populations as well as take into consideration resistance to major threats and has developed an internal decision-making framework to maximize diversity throughout coral production.

Identifying stress tolerant genets: Integrating genetic diversity is a key goal for population level resilience, however, the current state of stress within much of Florida's Coral Reef include chronic threats that unfortunately are not reducing in the near term. Therefore, significant effort has been used to identify stress-tolerant genetic varieties for increased thermal resilience, disease resistance, and tolerance to ocean acidification conditions. In addition, research efforts aim to ensure that there are not obvious life history trade-offs that are also occurring so that reproductive effort and growth are also maintained within these more tolerant genotypes. We then incorporate these genotypes into managed breeding regimes to create more stress-tolerant offspring and populations, ultimately using this knowledge to ensure the success of long-term reef restoration efforts.

Integrating Holobiont Partners as Biomarkers for Resistance: In addition to identifying resilient genotypes, which focuses on the coral host genetics, much of Mote's research efforts are aimed at identifying biomarkers of resistance within the coral holobiont partners including the microbiome and the algal symbionts. We have identified markers of disease resistance using bacterial communities as an indicator alone (Klinges et al. 2020) and have integrated heat tolerant symbiont screening within our coral restoration broodstock to help identify corals that may be more likely to survive nearshore temperature variable environments that no longer support some thermally intolerant coral species (Klepac et al. in prep).

Refugia to Acidification: Some marine ecosystems such as mangroves and seagrass beds can buffer against climate change impacts and therefore serve as refugia for corals. Mangrove and seagrass habitats experience high spatio-temporal variability in seawater physico-chemical conditions compared to adjacent coral reefs and coastal ocean. Sea surface temperature variability has been shown to reduce coral bleaching across the globe and may partially explain why corals have lower bleaching and higher recovery in mangrove habitats. In addition, corals growing in habitats with naturally variable pH may have less sensitivity to ocean acidification. Mote is currently researching how these types of ecosystems may serve as refugia against acidification in collaboration with Woods Hole Oceanographic Institute, NOAA and the University of Miami (Hall et al., in prep).

Assessing Restoration Methods and Climate Change Resilience: A major focus of coral restoration efforts focus on propagating fragments in-situ and outplanting directly back to degraded reefs. While these restoration efforts have shown promise, there is little known regarding the effects that these in-situ methods have on the physiology of the nursery fragments as they are reared to an appropriate outplant size. Mote is currently studying various physiological factors that could impact the health and survivorship of outplanted colonies based upon commonly used restoration techniques: microfragments, attaching the coral fragments to ceramic pucks on the ocean floor (benthic) and hanging the coral fragments in PVC trees (floating) under climate change scenarios (Hall et al., in prep). This study is in collaboration with California Academy of Sciences.

Integrating Coral Disease Research into Resilience-Based Management

Mote's Coral Health and Disease Program integrates resilience based management of coral disease into Mote's Coral Reef Restoration Program through research on coral disease ecology, variability in susceptibility, mechanisms of resistance, and novel mitigation strategies.

Disease Ecology & Susceptibility: Earlier research by Mote scientists described the epizootiology of stony coral tissue loss disease (SCTLD) in subregion 5 of the Caribbean region (Muller et al., 2020; Williams et al., 2021), which provided essential information on species and reef susceptibility in relation to the contagion dynamics that could then be incorporated into conservation management strategies. In a FL DEP funded collaboration with Louisiana State University, UCLouvain, CIMAS & NOAA AOML, and FWC, this research has helped parameterize hydrodynamic models of SCTLD spread throughout Florida's Coral Reef (FCR, Dobbelaere et al., 2020; Dobbelaere et al., 2022) and of reef connectivity for disease risk and restoration value (Holstein et al., *in review*), which have direct applications for management decisions. As coral disease is prevalent throughout FCR, Mote has quantified the variability of SCTLD and other coral diseases on outplanted corals among sites, regions, habitats, and coral species through the support of Florida Wildlife Conservation Commission and the State of Florida. These data provide valuable information on disease susceptibility of restoration corals to Mote restoration practitioners. Additionally, Mote has collaborated with several partners conducting restoration on FCR (FWC, UM, Nova Southeastern University, Florida Atlantic University, Coral Restoration Foundation) to assess the survival of SCTLD-susceptible corals after conducting regional restoration and monitoring efforts. Since environmental conditions play a role in disease dynamics and in structuring the coral microbiome that can affect disease resistance (e.g. Klinges et al., 2022 & Williams et al., 2022), Mote scientists have also collaborated with Oregon State University to examine the effect of nutrients (like man-made runoff, fertilizer, agriculture) in water on disease susceptibility.

Disease Resistance Mechanisms: Through several research projects exploring genetic variability in disease resistance and the underlying mechanisms of disease resistance, Mote scientists are building a solid foundation for incorporating disease resistant genotypes into coral restoration efforts. In a collaboration funded by Florida's Department of Environmental Protection, Mote conducted transmission experiments that screened 172 putative genotypes of *Orbicella faveolata* for SCTLD resistance and collected over 2,500 samples that will be used by our collaborators at the University of Miami and NOAA AOML in a multi-omics approach to find a biomarker of resistance to SCTLD. These results will be used both to target Mote's outplanting efforts and to reproduce disease-resistant corals, thus creating new resistant genotypes, in Mote's managed coral breeding program. Through a collaboration with NOAA AOML funded by FWC, as well as further funding from the EPA in collaboration with Dry Tortugas National Park, Mote is characterizing the microbiome of corals with SCTLD as well as those resistant to the disease, to determine if a specific microbial signature of the disease exists among species (Clark et al., 2021, Rosales et al. 2023) and can be used to determine potential resistance. Mote scientists have been working with several institutions (University of the Virgin Islands, University of Texas at Arlington, CIMAS & NOAA AOML, WHOI, Louisiana State University, and Rice University) in a collaboration funded by the National Science Foundation quantifying the disease susceptibility and immune response of several species of Caribbean corals to two tissue loss diseases, SCTLD and white plague, to build predictive models of reef community compositions post-outbreaks and inform management and conservation strategies. Additionally, Mote has conducted research to evaluate the epigenetic/microbiome mediated mechanisms underlying the heritability of disease resistance in staghorn corals (in collaborations with Texas A&M University and University of Oregon, respectively).

Disease Mitigation: Current funding from the EPA is supporting Mote scientists to continue testing and developing methods for the treatment of coral diseases within Florida Keys National Marine Sanctuary in collaboration with Ocean Alchemists, LLC. Previous Mote research funded through the NPS and conducted in the Virgin Islands National Park (St. John, USVI) and Buck Island Reef National Monument (St. Croix, USVI; funded through NPS), determined that a novel non-antibiotic ointment developed by Ocean Alchemists was 100% effective at treating black band disease (Eaton et al., 2022) and a similarly formulated ointment with antiviral capabilities was ~60% effective at treating SCTLD.

- (ICRI) Have you developed, or are you aware of, training materials that you can share?

Answer:
Mote's Coral Reef Research and Restoration Programs conduct an annual in person workshop to share best practices and lessons learned. Topics covered included nursery operations and outplanting, monitoring, genetic management, sexual reproduction, and integrating resilience within the restoration pipeline. To date, members of the workshops have attended from over 20 different countries around the world and expertise has spanned from interested citizen scientists and early career students to those managing some of the world's most up and coming restoration initiatives.

2022 Coral Restoration Workshop Flyer - CRWorkshop2022_-_Final.pdf (mote.org)

1.C - Promote and build capacity for the restoration of resilient coral reefs Ad Hoc Committee on Reef Restoration

- (ICRI) Please list any examples of reef restoration mechanisms that your organisation/country is involved in. Include their limits, conditions of implementation, financing and an assessment of their results, with links for more information if possible.

Answer:
Currently, Mote operates three *ex situ* coral nursery facilities capable of housing ~75,000 microfragments in various stages of production. Each of these systems use natural seawater in a flow-

through design with substantial mechanical and chemical (e.g., ozone, ultraviolet radiation) filtration and temperature control. Recently, Mote has adopted a low flow-through recirculating seawater system design to improve temperature control efficiency and biosecurity.
Additionally, Mote concurrently operates four *in situ* nurseries, each with a 1 acre permitted area and capable of housing >400 coral "tree" structures, >20 elevated benthic grazing crab culture/acclimation cages, hundreds of benthic coral "modules", and other propagation structures. Additionally, Mote maintains a subset of several offshore nurseries with large coral colonies used primarily as sexual reproduction spawning stocks with known lineage. Each offshore nursery is capable of housing >30,000 fragments/colonies of corals from multiple species.

Using these and other science-based methods, Mote has outplanted over 200,000 corals to date, restoring some of Florida's degraded reef tract. Mote's multi-year goal is to increase by ~25% the cover of living coral on Florida's Coral Reef at which point, Mote believes, coral colonies will achieve a critical mass than enables them to propagate, cross-fertilize, and create diverse new strains and generations of corals initiating natural ecosystem-level recovery responses to complement and, eventually, obviate the need for continued human interventions.

Recent Upper Keys and Biscayne National Park Expansion Projects
Mote has established two new coral nursery facilities in the Upper Keys to produce new restoration corals with a priority for the restoration of reef systems throughout the upper Florida Keys and, potentially, those in and adjacent to Biscayne Bay. Located on Islamorada and Key Largo, these nurseries will each house more than 10,000 coral fragments at any given time and produce thousands of new coral colonies for outplanting each year. Each of these new land-based facilities is also paired with a 1 acre offshore *in situ* coral nursery (one offshore of Islamorada, one offshore of Key Largo) capable of housing >30,000 additional fragments of coral for outplanting. Combined, these new Upper Keys coral nurseries and the Elizabeth Moore International Center for Coral Reef Research & Restoration (IC2R3) on Summerland Key, are critical to meeting and exceeding Mote's coral reef restoration goals throughout Florida's Coral Reef over the next decade.

Special Initiatives
Mission: Iconic Reefs - Mote is a core partner in an unprecedented effort to holistically restore seven ecologically and culturally significant coral reefs within the Florida Keys National Marine Sanctuary. Led by NOAA and informed by years of research, successful trials, and expertise, the mission represents one of the largest and most ambitious investments in coral reef restoration anywhere in the world. By focusing additional efforts on coral reef habitat, Mission: Iconic Reefs complements NOAA's ongoing Florida Keys National Marine Sanctuary Restoration Blueprint and management plan.

The effort to shift Florida Keys coral reefs on track for recovery is an enormous undertaking requiring long-term collaboration between many partners. Mission: Iconic Reefs engages world-renowned scientists, local restoration partners, and other federal and state agencies to save these important, iconic natural resources. By restoring these seven iconic reef sites in Florida Keys National Marine Sanctuary, we can change the trajectory of an entire ecosystem and help save one of the world's most unique areas for future generations.

To this end, Mote has applied for and recently been awarded $6.9M in funding to dramatically increase coral reef restoration efforts across the entire Florida Keys National Marine Sanctuary including the outplanting of more than 240,000 new corals and the stocking of more than 34,000 native grazing crabs over just a four year period. This new initiative intends to effect transformative ecological restoration both directly and indirectly with a major goal of increasing the efficiency of the entire restoration pipeline to scale future interventions for landscape-level effects.

Theme 2 – Coral Reef Science and Oceanography: Advancing and Utilizing the Latest Science and Technology

2.A – Coral monitoring capacity building

- (ICRI) Do you have information / case studies that could contribute to the update of the "Methods for ecological monitoring of coral reefs" (https://portals.iucn.org/library/efiles/documents/2004-023.pdf), especially related to the use of new technologies.

Answer: n/a

- (ICRI) Are you aware, developing, or involved with, any capacity building activities related to the use of coral reef monitoring mechanisms, especially regarding the advancement of monitoring practices (noting technology)?

Answer:
Mote is actively collaborating with SeaFoundry, a technology company whose ethos involves integrating technology and artificial intelligence into coral reef restoration to improve efficiency and economy of scale in all aspects of the restoration pipeline. SeaFoundry is developing a series of app- and web-based platforms to digitize coral nursery inventory data collection and management as well as automated data collection and decision-making tools to streamline much of the labor- and time-intensive aspects of coral reef restoration. SeaFoundry has also developed and is testing a computer numeric control (CNC) based robotic gantry system to automate the collection of digital imagery of nursery corals. Paired with a powerful AI, the system is capable of collecting simple inventory data and more complex data such as metrics of growth and health (e.g., fluorescence, color, tissue recession) with a high degree of precision and at any frequency needed to monitor and track growth, survival, and health of corals in a land-based coral nursery facility. Recently, SeaFoundry has begun integrating genetic management and outplanting data to develop decision-making tools/algorithms for planning outplanting operations to maximize genetic diversity and minimize the risk of genetic swamping at the site and reef scales. This tool, with a very convenient visual and map-based user interface, will eventually also integrate Structure from Motion (SfM) large area imagery data overlays.

Mote has, internally, developed a robust workflow for integrating Large-Area Imaging (LAI) and SfM photogrammetry as a powerful monitoring tool for restoration success and regulatory reporting requirements. This workflow leverages a suite of cameras and state-of-the art software to create a scalable photogrammetric pipeline (from square centimeters to hundreds of square meters) to answer a variety of scientific questions with the ultimate goal of increasing our ability to elucidate the ecosystem-level effects of coral reef restoration. Overlapping 2D images are used to create interactive, 3D site representations which allows for virtual surveying of outplant or research sites. Multiple analysis workflows have been developed using cutting edge software (Viscore, TagLab) to generate ecologically relevant data of our outplant sites and restoration techniques allowing for a breadth and depth of data unattainable using conventional in situ monitoring methods. This has led to Mote's collaboration with NOAA's National Centers for Coastal Ocean Science producing a technical report (in prep) compiling various LAI and SfM experts in the field and showcasing multiple workflows. Specifically highlighting Mote's LAI and SfM capabilities as standards among the restoration practitioner community.

2.B – The Global Coral Reef Monitoring Network (GCRMN)
The GCRMN would like to receive feedback on the Status of Coral Reefs of the World: 2020 report to improve the production of future regional and global reports. As such, please kindly respond accordingly to the questions below:

- (ICRI) In reference to the Status of Coral Reefs of the World: 2020 report:
    - Have you read the report?
    - Did you utilise the report and/or use the results and contents?
    - How could the next report be improved (considering the entire process from data acquisition to reporting)?

Answer:
Yes, we have read the Status of the Coral Reefs of the World: 2020 report and often particularly utilise Chapter 12, Status and trends of coral reefs of the Caribbean region. We often cite metrics conveyed in the report within presentations to the public, within outreach events, and within education materials. Given Mote's emphasis on communication, we provide over 100 public presentations on coral reef ecosystems and resilient reef restoration each year. The contextualized nature of the trends of coral cover and algal cover through time presented within each Chapter are powerful data points that can easily convey the overarching declines observed with the loss of living coral and the subsequent increase in macroalgal cover, particularly within this region.

In addition to utilising the report results for communicating coral reef declines, Mote scientists have used other GCRMN resources. In particular, the monitoring guidelines and protocols have been helpful for planning fieldwork activities that consider the best practices for coral reef surveys.

Our team was not a part of the data acquisition, analysis, or report writing process. However, one small recommendation within the report itself is to provide outputs associated with each subregion within each region Chapter. For example, there are figures showing the trends in coral and algal cover within only three of the five subregions within Chapter 12. Our main subregion of interest is not shown (subregion 5). Having these figures on hand would be a powerful visual for our diverse suite of communication events and presentations.

- (ICRI) The GCRMN intends to establish time-bound task forces to address specific priority issues and to build capability and capacity across the network. As a first priority, a Data Task Force was established. The Task Force brings together subject matter experts to increase the transparency, reproducibility, and robustness of future GCRMN reports alongside capacity in monitoring, data collection, analysis, management and sharing of coral reefs and associated ecosystems. The Task Force will focus on:

- Improving data integration and analyses to facilitate the production of GCRMN regional and global reports; and
- Promoting good data management practices based on FAIR data principles for the coral reef scientific community.

Tell us is if you will be interested in joining the Data Task Force, or upcoming task forces. More so, please inform us if you have data to contribute to upcoming regional, or global, reports and if you will be organising and/or partaking in any capacity building activities regarding data monitoring:

Answer:

- *Taskforces:*

Although this is a worthy endeavour, Mote does not have the capacity to join the Data Task Force at this time.

- *Data to contribute (GCRMN Region Country, Data description):*

Our team contributes extensively to existing regionally coordinated monitoring programs. For example, over the summer of 2023 more than 50 sites were surveyed by Mote staff throughout the Florida Keys for bleaching/mortality as part of the Florida Reef Resilience Program-Disturbance Response Monitoring effort in collaboration with FWC and multiple partners throughout all of Florida. Mote provides survey data for this effort on an annual basis.

Additionally, members of Mote conducted initial surveys around Ilha do Fogo, an island in the Primeiras and Segundas Archipelago off Northern Mozambique in the Western Indian Ocean region. Point intercept transects (PITs, 10 m long) were conducted at five sites via snorkel or SCUBA. Percent hard coral cover ranged from 28-65%. Videos of the PITs were also captured for future analysis and higher resolution taxa identification. Photogrammetry imaging events were also attempted, but resulted in poor quality renderings due to conditions (limited visibility, shallow depths, and high surge).

- *Upcoming capacity building activities:*

Mote is actively investing in increased and expanded data storage infrastructure (currently >160 TB and increasing) at multiple campuses. Mote is also working closely with SeaFoundry, a technology company whose mission is the integrate technology and automation into the restoration space, to develop, test, and implement integrated data collection and management systems. Particularly, SeaFoundry is developing a nursery inventory management platform with a digital user interface for real-time or near real-time data collection from any connected digital device. The team is also working toward integrating genetic management, outplanting, monitoring, spatial data, and reporting into a unified data management platform. Further, the SeaFoundry products are intended to be expanded for use by any organisation in Florida and around the world to offer a standardised series of restoration workflows and data structure.

Theme 3 - Local Threat Reduction: Integrating Response Planning Frameworks

Please tick the most appropriate box/boxes:

- (ICRI) Do you have (or in the process of developing) a coral reef response plan(s) on, for example, but not limited to:
    - x coral disease
    - x vessel groundings
    - x bleaching
    - x invasive species outbreaks (lionfish and COTS)
    - x large storm events
    - x other:

  If yes, please provide us with more information.

Answer:
In general, our overarching restoration initiatives are a direct response to the culmination of all of the above disturbances that have degraded Florida's Coral Reef ecosystem over the last half century.

Theme 4 - Diversity and Inclusion: Expanding the Coral Reef Community

4.A – Connect with youth audiences:

- (ICRI) Are you developing (or planning to develop) any communication campaigns or outreach materials? What will your primary target audiences be and what would your key messages include?

Answer:
In 2022, Mote reached nearly 2,000 participants through educational programs such as outreach, field trips, onsite residential experiences, and utilization of curriculum kits by teachers. Mote also offers an array of internship opportunities for mentees at multiple levels in their education from high-school to undergraduate and graduate students. Research experience for undergraduate (REU) internships provide funding from both NSF (NSF REU) and philanthropic sources (Mote REU) for students to conduct research projects with mentorship from Mote scientists. These programs specifically target and recruit students from underserved, underrepresented groups in marine science. Additionally, a newly funded NSF program, the Marine Science Undergraduate Research Experience Professional and Research Preparation (MarSci-URE PReP) program, will introduce undergraduate students who have not conducted prior scientific internships, to coral reef research through mentorship by a Mote scientist in the Coral Health and Disease Program. The MarSci-URE PReP program will provide undergraduate students with a comprehensive introduction to the realm of research by the development and enhancement of both their scientific and professional skills, along with the essential career skills. The ultimate goal being effectively preparing them to successfully apply for, and ideally partake in, Undergraduate Research Experiences (UREs) in the future. An additional newly funded NSF program, GEOPAths Informal Network Vocational Experiences and Research Training in Marine Science (GP-IN:VERT) is a project designed to increase pre-college student exposure to and participation in marine STEM activities in an effort to increase the number of undergraduate students pursuing a degree in

marine STEM, particularly those from underrepresented populations. This will bring high school students to Motes IC2R3 facility to gain a broader understanding of potential coral reef research research being conducted and associated careers opportunities within the field.

4.B - Collaborate with Indigenous people and seek to incorporate indigenous and local knowledge into policies and management plans:

- (ICRI) How do you incorporate indigenous and local knowledge into policies and management frameworks. Please provide us with some examples. Do you have any plans or strategies to further promote this incorporation?

Answer:
The **Florida Keys BleachWatch Program** operated by Mote staff and modeled after Great Barrier Reef's BleachWatch, is a team of trained recreational, commercial and scientific divers who help monitor and report on conditions at the reefs. After each visit to the reef, the divers complete a data form, either printed or online, and send it to the BleachWatch coordinator. Information from NOAA's Coral Reef Watch (CRW) remote sensing and Integrated Coral Observing Network (ICON) in-situ environmental monitoring analysis are combined with "BleachWatch" volunteer observations in the field to provide a comprehensive overview of "current conditions" throughout the FKNMS. The data are compiled biweekly and provided as open access reports on the conditions throughout the Florida Keys.

ICARE Partnership: I.Care is a non-profit partner whose mission is to engage recreational SCUBA divers in coral reef conservation and restoration activities through informal and hands-on training and education. Mote has partnered with I.Care since their inception in 2020. I.Care receives corals produced by Mote's *in* and *ex situ* nursery facilities and, with recreational divers, outplants these corals as part of their hands-on outreach and education program. I.Care further engages recreational divers in conducting routine monitoring and maintenance of the outplanted corals.

- (ICRI) Do you have any, or know of, best practices to solicit Indigenous and local community knowledge?

Answer:
Mote fosters a strong connection between the scientific community and the public, allowing individuals to actively participate in coral reef research and restoration. We involve citizen scientists in various research and conservation initiatives to contribute to the understanding and preservation of marine ecosystems throughout the Florida Keys.

Our volunteer program serves as a way to engage citizen scientists in our coral restoration efforts. Volunteers help with activities such as land-based coral husbandry, coral outplanting, maintaining coral nurseries, and monitoring the health of restored coral populations.
This hands-on involvement directly contributes to the recovery of our coral reef ecosystems and aids in building ocean literacy in the community.

Another key component of our citizen scientist program is monitoring and data collection. Once they have completed the training, citizen scientists may assist in monitoring coral diseases and coral bleaching. This increase in data leads to a better understanding of the spread and impact of diseases and bleaching on coral reefs. Their observations and data are submitted to our staff and aid in formulating the reports for the Florida Keys BleachWatch Program.

We also value the role of citizen scientists as educators and ambassadors for marine conservation. Volunteers may be involved in educational programs and outreach initiatives, sharing their knowledge and passion for coral reef ecosystems with the community through local presentations and events.

Through our citizen science programs, Mote empowers volunteers to make meaningful contributions to the protection, restoration, and preservation of Florida's marine environments, including its iconic coral reefs.

C. Kunming-Montreal Global biodiversity framework

- (ICRI) Do your current National Biodiversity Strategies and Action Plans (NBSAP) incorporate coral reefs? If not, what kind of material will be useful for your Country/organisation to ensure coral reefs are integrated in the revision of NBSAPs?

Answer: n/a

- (ICRI) How are you planning to implement the Kunming-Montreal Global biodiversity framework. For you, which targets are the most relevant for coral reefs?

Answer: n/a

D. Upcoming events

Please tick the most appropriate box/boxes:

x September 19th – 23rd 2023: 37th ICRI GM, USA, Hawaii

☐ 30th November – 12th December 2023: 28th Conference of the Parties to the United Nations Framework Convention on Climate Change

☐ 26th February – 1st March 2024: 6th session of the United Nations Environment Assembly

☐ 10th – 12th April 2024: 2024 UN Ocean Decade Conference, Barcelona, Spain.

☐ 2024: United Nations Biodiversity Conference (COP16) of the Parties to the UN Convention on Biological Diversity (CBD), Turkey.

☐ Other

Please list any upcoming regional / international events relevant to ICRI that your organisation plans to attend:

Answer: n/a

E. Publications. Please list relevant publications / reports you have released recently (+ add a link if possible)

Publication	**URL**
2023 Klepac C.N., Eaton K.R., Petrik C.G., Arick L.N., Hall E.R., Muller E.M. Symbiont composition and coral genotype determines massive coral species performance under end-of-century climate scenarios. Front. Mar. Sci. 10:1026426. doi: 10.3389/fmars.2023.10264262022	doi: 10.3389/fmars.2023.10264262022
2022 Osborne, E., X. Hu, E.R. Hall, K. Yates, J. Vreeland-Dawson, K. Shamberger, L. Barbero, J.M. Hernandez-Ayon, F.A. Gomez, T. Hicks, Y.Y. Xu. Ocean acidification in the Gulf of Mexico: Drivers, impacts, and unknowns. Progress in Oceanography, p.102882.	
2022 Burnham, K.A., Nowicki, R.J., Hall, E.R., Pi, J. and Page, H.N. Effects of ocean acidification on the performance and interaction of fleshy macroalgae and a grazing sea urchin. Journal of Experimental Marine Biology and Ecology, 547, p.151662.	
2022 Mallon, J., T. Cyronak, E.R. Hall, A.T. Banaszak, D.A. Exton, A.M. Bass. Light-driven dynamics between calcification and production in functionally diverse coral reef calcifiers. Limnol and Oceanogr 9999, 2022, 1–16.	
2021 Page, H.N., C. Hewett, H. Tompkins, E.R. Hall. Ocean acidification and direct interactions affect coral, macroalga, and sponge growth in the Florida Keys. J. Mar. Sci. Eng. 2021, 9, 739. https://doi.org/10.3390/jmse9070739	https://doi.org/10.3390/jmse9070739
2021 Muller EM, Dungan AM, Million WC, Eaton KR, Petrik C, Bartels E, Hall ER, Kenkel CD. Heritable variation and lack of tradeoffs suggest adaptive capacity in *Acropora cervicornis* despite negative synergism under climate change scenarios. Proc. R. Soc. B 288: 20210923.	

2022 Dobbelaere, T., Holstein, D.M., Muller, E.M., Gramer, L.J., McEachron, L., Williams, S.D., and Hanert, E. Connecting the dots: Transmission of stony coral tissue loss disease from the Marquesas to the Dry Tortugas. Frontiers in Marine Science.	https://www.frontiersin.org/articles/10.3389/fmars.2022.778938/full
2022 Williams SD, Klinges JG, Zinman S, Clark AS, Bartels E, Villoch Diaz Maurino M, and Muller EM. Geographically driven differences in microbiomes of Acropora cervicornis originating from different regions of Florida's Coral Reef. PeerJ 10:e13574	https://peerj.com/articles/13574/
2021 Clark, A.S., Williams, S.D., Maxwell, K., Rosales, S.M., Huebner, L.K., Landsberg, J.H., Hunt, J.H., and Muller, E.M. Characterization of the Microbiome of Corals with Stony Coral Tissue Loss Disease along Florida's Coral Reef. Microorganisms, 9 (11): 2181. doi:10.3390/microorganisms9112181.	https://www.mdpi.com/2076-2607/9/11/2181
2021 Williams, S.D., Walter, C.S., and Muller, E.M. Fine scale temporal and spatial dynamics of the stony coral tissue loss disease outbreak within the lower Florida Keys. Frontiers in Marine Science.	https://www.frontiersin.org/articles/10.3389/fmars.2021.631776/full
2021 Koch HR. Chapter 9: Assisted evolution and coral reef resilience. In: Active Coral Reef Restoration: Techniques for a Changing Planet. Ed., David Vaughan. J. Ross Publishing. ISBN: 978-1-60427-143-0	
2021 Koch HR. Chapter 10: Genetic considerations for coral reef restoration. In: Active Coral Reef Restoration: Techniques for a Changing Planet. Ed., David Vaughan. J. Ross Publishing. ISBN: 978-1-60427-143-0	
2021 Koch HR. Can direct sperm exposure be used as a tool to induce female corals to spawn? Bulletin of Marine Science: Portraits of Marine Science.	https://doi.org/10.5343/bms.2020.0057
2021 Koch HR, Muller EM & Crosby M. Restored Corals Spawn Hope for Reefs Worldwide. The Scientist.	https://www.the-scientist.com/features/restored-corals-spawn-hope-for-reefs-worldwide-68368

2021 Koch HR, Wallace B, DeMerlis A, Clark A & Nowicki RJ. 3D scanning as a tool to measure growth rates of live coral microfragments used for coral reef restoration. Frontiers in Marine Science. Coral Reef Restoration in a Changing World: Science-based Solutions.	https://doi.org/10.3389/fmars.2021.623645
2021 Baker L, Reich H, Kitchen S, Klinges G, Koch HR, Baums I, Muller E, & Vega Thurber R. The coral symbiont Candidatus Aquarickettsia is variably abundant in threatened Caribbean acroporids and transmitted horizontally. ISMEJ.	https://doi.org/10.1038/s41396-021-01077-8
2022 Koch HR, Matthews B, Leto C, Engelsma C and Bartels E. Assisted sexual reproduction of Acropora cervicornis for active restoration on Florida's Coral Reef. Front. Mar. Sci. 9:959520.	https://doi.org/10.3389/fmars.2022.959520
2022 Koch HR, Azu Y*, Bartels E, & Muller EM. No apparent cost of disease resistance on reproductive output in Acropora cervicornis genets used for active coral reef restoration in Florida. Frontiers in Marine Science – Marine Conservation & Sustainability.	https://doi.org/10.3389/fmars.2022.958500
2022 Gravinese PM, Perry SA, Spadaro AJ, Boyd AE, Enochs IC. Caribbean king crab larvae and juveniles show tolerance to ocean acidification and ocean warming. Marine Biology 169:65.	https://link.springer.com/article/10.1007/s00227-022-04053-8
Merck D, Petrik CG, Manfroy AA, Muller EM (2022) Optimizing seawater temperature conditions to increase the growth and survival of corals within an ex-situ coral nursery. PeerJ, *10*, e13017.	
Cunning R, Parker KE, Johnson-Sapp K, Karp RF, Wen AD, Williamson OM, Bartels E, D'Alessandro M, Gilliam DS, Hanson G, levy J, Lirman D, Maxwell K, Million WC, Moulding AL, Moura A, **Muller EM**, Nedimyer K, Reckenbeil B, na Hooidonk R, Dahlgren C, Kenkel C, Parkinson JE, Baker AC. (2021). Census of heat tolerance among Florida's threatened staghorn corals finds resilient individuals throughout existing nursery populations. Proc. R. Soc. B 288: 20211613	https://doi.org/10.1098/rspb.2021.1613

Shaver E, Mcleod E, Hein H, Palumbi S, Quigley K, Vardi T, Mumby P, Smith D, Montoya-Maya P, **Muller EM**, Banaszak A, McCleod I, Wachenfeld D (2022). Integrating resilience and climate change adaptation into coral reef restoration. Global Change Biology.	
Hoadley KD, Lockridge G, McQuagge A, Pahl KB, Lowry S, Wong S, Craig Z, Petrik C, Klepac C and **Muller EM** (2023) A phenomic modeling approach for using chlorophyll-a fluorescence-based measurements on coral photosymbionts. Front. Mar. Sci. 10:1092202. doi: 10.3389/fmars.2023.1092202	doi: 10.3389/fmars.2023.1092202
Gantt, S.E., Keister, E.F., Manfroy, A.A., Merck, D.E., Fitt, W.K., Muller, E.M. and Kemp, D.W., 2023. Wild and nursery-raised corals: comparative physiology of two framework coral species. *Coral Reefs*, pp.1-12.	
Klinges, J. G., Patel, S. H., Duke, W. C., Muller, E. M., & Vega Thurber, R. L. (2023). Microbiomes of a disease-resistant genotype of Acropora cervicornis are resistant to acute, but not chronic, nutrient enrichment. *Scientific Reports*, *13*(1), 3617.	
Rosales, S.M., Huebner, L.K., Evans, J.S., Apprill, A., Baker, A.C., Becker, C.C., Bellantuono, A.J., Brandt, M.E., Clark, A.S., Del Campo, J., Dennison, C.E., Eaton K.R., Huntley N.E., Kellogg C.A., Medina M, Meyer JL, **Muller EM**, Rodriguez-Lenetty M., Salerno JL, Schill WB, Shilling EN, Stewart JM, Voss JD. 2023. A meta-analysis of the stony coral tissue loss disease microbiome finds key bacteria in unaffected and lesion tissue in diseased colonies. *ISME communications*, *3*(1), p.19.	

F. ICRI Member Feedback. What do you find most valuable about being a member of ICRI as well as completing the ICRI member reports? If you have any ideas to improve the Member Reports, please list below:

Answer: n/a