



**Modeling coral population dynamics to better conserve, manage, and restore coral reef ecosystems.**

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**Client:** Moorea Coral Reef Long Term Ecological Research Site (MCR-LTER). Marine Science Institute, UC Santa Barbara.

**Objective:** This capstone project will identify demographic mechanisms that inhibit coral population recovery from recent catastrophic disturbances in Moorea, French Polynesia, predict coral community state in future time steps, and design alternative management interventions that might help speed reef recovery.

**Environmental Motivation:** As the human population increases, so do the diversity and severity of disturbances to communities of organisms that shape ecosystems. Understanding what influences the recovery of communities from disturbance is therefore growing more difficult and important in terms of conservation and management. This is especially true for tropical coral reefs that are being degraded at increasing frequency and severity by human activities yet still provide a plethora of ecosystem services (Hughes et al. 2017). Annual coral population surveys have been conducted on the island of Moorea, French Polynesia for the Moorea Coral Reef Long-Term Ecological Research Site (MCR-LTER) since 2013, with the intent of identifying how patterns of coral recruitment, growth, and mortality influence recovery from repeated storms, coral predator outbreaks, bleaching events, and other environmental perturbations (Kayal et al. 2018). Understanding what demographic constraints limit recovery of coral populations is key to identifying management interventions, such as coral restoration and reef manipulations that enhance coral recruitment and growth (Lenihan et al. 2008, 2011, 2015).

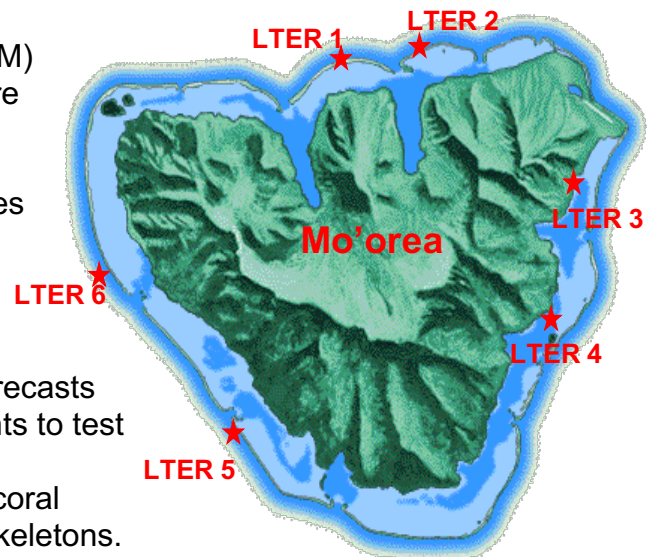
An increasing number of reefs around the world have experienced major coral loss with an alarming portion of them shifting to a macroalgae-dominated or other non-coral state (Anthony et al. 2015). Some of the most important work on this topic has been conducted in Moorea by UCSB's MCR-LTER. For example, in Kayal et al. (2018), we used powerful Integral Projection Population models (IPMs; Ellner et al 2016) to make accurate predictions of coral recovery after an outbreak of predatory sea stars and a cyclone that wiped out almost all corals in 2009-2010. By 2015, coral cover had recovered to a pre-disturbance level, mainly because the cyclone cleared away skeletons of dead coral colonies allowing for massive coral recruitment (Holbrook et al. 2018). In 2019, a near-global marine heatwave caused massive coral bleaching that once again killed many corals on Moorea, but recovery similar to that seen in 2010-2015 has not occurred, perhaps because so many coral skeletons remain (Speare et al. 2021, 2025). If, how, and when the reefs will recover again is uncertain. The answers lie in part in demographic processes ("bottlenecks") that are preventing recovery.

**Data science need:** The main goal of this project is to examine the demographic mechanisms that explain why Moorea's reefs have not yet recovered from the 2019 marine heat wave, and to produce hypotheses as to what environmental management interventions (e.g., dead coral skeleton removals, coral restoration) might speed recovery. The information necessary to identify constraints on coral recovery and develop possible management solutions lies buried in the extensive coral demography data set at the heart of the proposed project.

The **research questions** that the MEDS project will address are:

- (1) *How do patterns of coral recruitment, growth, and mortality differ before and after the 2019 marine heatwave?* Addressing this question will help identify specific demographic mechanisms, or “bottlenecks” that are constraining coral recovery.
- (2) *Would transplanting coral colonies in restoration experiments, or clearing dead coral skeletons, have a positive impact on reef recovery?* Addressing this question will help identify restoration bottlenecks that can be overcome with management interventions.
- (3) *What will coral assemblages look like in 5-20 years with and without restoration interventions?* Developing IPM model projections of coral communities will motivate and guide research and conservation actions.

We survey for coral demographic data annually on Moorea at reef sites that are used in the MCR-LTER to collect many types of ecological data (<https://mcr.lternet.edu/>). Four survey sites (LTER 1, 2, 4 and 5) are located around the island, with each site composed of a forereef habitat and a lagoon habitat. This project will produce graphical representations of coral recruitment, growth, and mortality as a function of site, year, spatial scale, coral taxonomy, and coral colony size. General Linear Mixed Model (GLMM) regression analyses will be executed to compare demographic performance of corals across time (e.g., 2013-2019 vs. 2020-2024), genera, sites, and habitat types. Coral demographic rates generated from the GLMM regressions can be used in a multi-species, open population IPM model of coral assemblage dynamics designed to predict how the coral communities will look in future time steps. The IPM-based forecasts can be parameterized to run *in-silico* experiments to test the potential response of coral communities to restoration interventions, for example, through coral transplanting and the clearance of dead coral skeletons.



**Deliverables:** Deliverables are targeted at MCR-LTER scientists, other coral reef ecologists in the general science community, and coral reef conservation practitioners and managers.

- (1) An organized, functional, and cleaned data set that will live on the MCR-LTER main server.
- (2) Code in R or Python that generates visualizations of demographic patterns to address specific research questions (e.g., how does recruitment vary across years, coral taxonomy, and habitat types? Are growth rates lowest and mortality highest for corals that recruit to dead skeletons?)
- (3) GLMM statistical analyses to quantitatively compare patterns of coral recruitment, growth, and mortality generated in Step 2.

(4) IPM model projections (forecasts) of the coral community at each site as a function of time into the future and with different restoration interventions.

**Broader Impacts:** Project deliverables will advance coral reef science and management, in part by identifying and assessing potential restoration actions. Production of an innovative way to visualize coral community change in the data will provide state-of-the-art-for-science that will motivate new science in the MCR-LTER, the general scientific community, and French Polynesian scientists and reef managers. IPM model forecasts will advance general community ecology by increasing our capacity to predict future states of natural communities. and enhance reef management by simulating alternative management interventions.

Data Access and Availability:

1. Time-series data of coral demography around the island of Moorea, French Polynesia, is available for the capstone project at <https://drive.google.com/drive/folders/1so0t0DA-7EpKXZ8ol2b-mBZa009w8Ksw?usp=sharing>. These data have been collected annually since 2013, recording the location of individual corals, following and measuring their change in size over time. (*Data linked above are not allowed to be used without written permission from H. Lenihan*).

Project Requirements:

- Students will use R or Python when creating visualizations, as they are the most widely used in the MCR-LTER academic community. The goal for MCR-LTER researchers is to maintain this project, adding to it once new data has been collected to see the change in coral individuals and the community over time.
- Students will use the IPM code developed by Kayal et al. (2018), which is available at a <https://zenodo.org/records/573772>



## Supplementary information

### References:

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### Publications that have used the coral demography data:

- Speare, K.E., D.E. Burkepile, T.C. Adam, H.S. Lenihan, E. Winslow, R.J. Schmitt, S.J. Holbrook, and M.K. Donovan. 2025. Nitrogen enrichment determines coral mortality during a marine heatwave. *Marine Pollution Bulletin* 222:118758.
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Capstone Project Program  
Masters in Environmental Data Science  
Bren School of Environmental Science and Management  
University of California, Santa Barbara

Dear Colleagues,

The Moorea Coral Reef Longterm Ecological Research Project (MCR LTER) is excited about the possibility of a Bren School MEDS Capstone Project that focuses on our Coral Demography project. This long-term time series documenting changes in the size structure of the coral community is an important component of our research because it provides quantitative, spatially-extensive information about the state of coral communities on Moorea, French Polynesia. A substantial amount of our research involves ecological processes that both depend upon and influence coral populations. Working with MEDS students on the proposed project will advance our understanding of the status and dynamics of coral populations, and thus help us with our research mission in many ways.

Professor Lenihan has collected coral demography data since 2013, over which time a series of natural disturbances has occurred to dramatically change coral community composition and structure. Demographic data from our surveys have been used in a series of peer-reviewed scientific papers published by MCR LTER scientists that have reported examples of dramatic coral recovery from disturbance, as well as the lack of recovery. In fact, Professor Lenihan's dataset on coral demography is one of the most robust time series in the world tracking individual corals and their fate through time. It is uniquely valuable in the field, and has the capacity to make significant contributions to how we understand the dynamics of coral populations before, during, and after disturbances. The Capstone project, designed to address key questions about coral recovery, through graphical representations of coral demography, and statistical analyses of those patterns, will advance our understanding of the mechanisms that promote and constrain recovery. The construction of IMP models will give us a future view of coral communities, and test *in silico* effects of possible restoration interventions.

The MCR LTER will support the project with the provision of coral demography data, assistance from our Information Manager Hillary Krumbolz, collaborative interactions with MCR LTER researchers and Ph.D. students, the opportunity to present results at our annual All Scientists Meeting, and aid in publishing papers produced by Professor Lenihan and the MEDS team of students. We look forward to working with the Bren School and MEDS program on this project.

Sincerely

A handwritten signature in black ink, appearing to read "Deron Burkepile".

Deron Burkepile  
Principal Investigator, MCR-LTER