Census of heat tolerance among Florida's threatened staghorn corals from a study of Acropora cervicornis conducted from August to October 2020

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Data Type: Other Field Results, experimental
Version: 1
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Project
» Collaborative Research: Investigating the genomic basis of key performance traits to quantify the evolutionary potential of coral populations under climate change (AcroBaT)

Contributors	Affiliation	Role
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Abstract
The rapid loss of reef-building corals owing to ocean warming is driving the development of interventions such as coral propagation and restoration, selective breeding and assisted gene flow. Many of these interventions target naturally heat-tolerant individuals to boost climate resilience, but the challenges of quickly and reliably quantifying heat tolerance and identifying thermotolerant individuals have hampered implementation. Here, we used coral bleaching automated stress systems to perform rapid, standardized heat tolerance assays on 229 colonies of Acropora cervicornis across six coral nurseries spanning Florida's Coral Reef, USA. Analysis of heat stress dose–response curves for each colony revealed a broad range in thermal tolerance among individuals (approx. 2.5°C range in Fv/Fm ED50), with highly reproducible rankings across independent tests ($r = 0.76$). Most phenotypic variation occurred within nurseries rather than between them, pointing to a potentially dominant role of fixed genetic effects in setting thermal tolerance and widespread distribution of tolerant individuals throughout the population. The identification of tolerant individuals provides immediately actionable information to optimize nursery and restoration programs for Florida's threatened staghorn corals. This work further provides a blueprint for future efforts to identify and source thermally tolerant corals for conservation interventions worldwide.

Table of Contents

- Coverage
- Dataset Description
  - Methods & Sampling
  - Data Processing Description
  - BCO-DMO Processing Description
- Data Files
- Related Publications
- Related Datasets
- Parameters
- Instruments
- Project Information
- Funding

Coverage

Location: Southeast Florida and the Florida Keys, ranging from Ft. Lauderdale to Key West
Spatial Extent: **N**:26.198 **E**:-80.0875 **S**:24.4639 **W**:-82.9052
Temporal Extent: 2020-08 - 2020-10

Methods & Sampling

During two ship-based research expeditions in August and October 2020 on the R/V Coral Reef II, we measured the thermal tolerance of 229 *Acropora cervicornis* colonies from six coral nurseries along Florida's Coral Reef (figure 1a; electronic supplementary material, table S1 of Cunning et al. 2021). The nurseries, from north to south, are operated by Nova Southeastern University (NSU), the University of Miami (UM), the Coral Restoration Foundation (CRF), Reef Renewal (RR), the Florida Fish and Wildlife Conservation Commission (FWC) and Mote Marine Laboratory (MML). Thermal tolerance of nursery corals was measured by Coral Bleaching Automated Stress System ("CBASS"), which are portable, field-deployable experimental tanks used to apply rapid, acute heat stress challenges. Fragments of each coral colony were independently exposed to each of eight temperature stress profiles of increasing magnitude (with maximum temperatures between 30 and 38 degrees Celsius (°C)) for 7 hours, after which maximum photochemical efficiency (Fv/Fm) was measured as an indicator of each fragment’s stress response. These data were used to construct a dose-response curve for each colony, from which the effective dose of heat stress required to reduce Fv/Fm by 50% (ED50 value) was calculated as a metric of each colony’s thermal tolerance. A full description of the study methodology can be found in Cunning et al. 2021 (DOI: 10.1098/rspb.2021.1613).

Instruments:
CBASS were constructed following the general design of Voolstra et al. (2020), using beverage coolers (Coleman 24 Can Party Stacker) partitioned into two independent halves (tanks) with an acrylic divider. Each 8-liter (L) tank was equipped with one titanium aquarium heater (Finnex TH-300 W) and two thermoelectric chillers (Nova Tec IceProbe). Seawater was circulated within each tank using a submersible powerhead (SUNSUN JVP 530 GPH), and fresh incoming seawater was supplied to each tank at a rate of approximately 1 milliliter per second (mL s-1) (turnover = approx. 2.2 hours). Light was provided by LED aquarium lights (Phlizon 165 W) mounted above each cooler and manually adjusted to provide 550 micrmoles photons per square meter per second (µmol photons m-2 s-1) at the center of each tank, measured at the depth of the coral fragments with an underwater photosynthetically active radiation sensor (Apogee Instruments). Temperature profiles were executed by custom controllers (ELEGOO Mega 2560) with temperature sensors (Vktech DS18b20) activating the heaters and/or chillers as needed to achieve prescribed set points. For the tanks heated to 34°C or below on the October field expedition, Inkbird (ITC-308) temperature controllers were used instead. Temperature profiles consisted of a 30°C baseline temperature, a 3-hour ramp up to a prescribed maximum temperature (ranging from 30°C to 38°C), a 3-hour hold at the maximum temperature and a 1-hour ramp down to 30°C. Profiles were timed such that the end of the maximum temperature hold period coincided with local sunset, and the temperature ramped back down in darkness. After returning to 30°C, Fv/Fm was measured for each coral fragment using a DIVING-PAM-II (Walz, Effeltrich, Germany) chlorophyll fluorometer. Fluorometer settings included: measuring light intensity = 1, measuring light frequency (ML-F) = 4, ML-F high = off, damping = 2, F0mode = off, saturatingpulseintensity = 8 and saturatingpulsewidth = 0.8 s. The gain setting was adjusted as needed to produce an F0 measurement above 100. Two Fv/Fm measurements were taken for each coral fragment (if possible depending on size), from non-overlapping areas of tissue that were facing upward, perpendicular to incident light. See Cunning et al. (2021) for additional information and figures.

Data Processing Description

For each coral fragment, one or two data records were generated that included F0 (background fluorescence), Fm (maximum fluorescence), and Fv/Fm (maximum photochemical efficiency). All data were processed in batches according to the CBASS assay date. For each batch, an initial data pre-filtering step was applied which removed any record with Fv/Fm greater than 0.75, and any record from a high-stress treatment (greater than or equal to 36°C) where both a high Fv/Fm and low F0 indicated a multi- variate outlier by Mahalanobis distance. The latter filter was applied to remove data points from severely bleached corals where very low signal resulted in spuriously high Fv/Fm. After pre-filtering, Fv/Fm data were then adjusted to account for the physical position (i.e. coordinate grid location) of each coral genet within each tank: the number of rows and columns from the tank centre were used as linear predictors of Fv/Fm, and residuals were added to the mean for each tank to generate adjusted values. This step was taken to account for attenuation of light towards tank edges that tended to result in higher Fv/Fm. Dose-response curves (e.g. figure 1c of Cunning et al., 2021) were then used to model the decline in Fv/Fm as a function of the maximum treatment temperature for each genet.

The mean temperature recorded during the 3-hour hold period in each tank was used rather than the target temperature because there were some minor deviations from target values, particularly in the Ink- bird-controlled tanks. Dose-response curves were fitted as three-parameter log–logistic functions using the drc package, with the following constraints on parameter values: maximum Fv/Fm = [0.55,0.72]; slope = [10,120]; ED50 = [30,40]. The lower limit was set equal to zero. Based on initial model fits, additional data filtering was performed to remove points with Cook's distance greater than 4/n (where n is the number of data points for the colony), or with a positive residual exceeding 2 standard deviations. Dose-response curves were then re-fitted with filtered data to generate parameter values (and standard errors) for each colony. ED50 parameter values are interpreted as the quantitative thermal tolerance phenotype for each colony and are the primary metric used in downstream statistical analyses. All Fv/Fm data analysis and dose-response curve fitting is detailed with R code in the accompanying data repository.

The original Github repository for all data and analysis code for this project:
https://github.com/jrcunning/CBASS_FL_Ac

The Github repository as permanently archived at Zenodo at the time of publication of the resulting manuscript:
Ross Cunning. (2021). Data for: Census of heat tolerance among Florida's threatened staghorn corals finds resilient individuals throughout existing nursery populations (v1.0). Zenodo.
https://doi.org/10.5281/zenodo.5526941

BCO-DMO Processing Description

- Imported original file "Acer_CBASS_data.csv" into the BCO-DMO system.
- Marked "NA" as a missing data identifier (missing data values are empty/blank in the final CSV file).
- Renamed fields to comply with BCO-DMO naming conventions.
- Saved the final file as "920653_v1_acer_cbass.csv"

[table of contents | back to top]

Data Files

File
920653_v1_acer_cbass.csv (Comma Separated Values (.csv), 17.53 KB) MD5:39ffa297be4dd99fb9b460f3474c4d61 Primary data file for dataset ID 920653, version 1

[table of contents | back to top]

Related Publications

Cunning, R., Parker, K. E., Johnson-Sapp, K., Karp, R. F., Wen, A. D., Williamson, O. M., Bartels, E., D'Alessandro, M., Gilliam, D. S., Hanson, G., Levy, J., Lirman, D., Maxwell, K., Million, W. C., Moulding, A. L., Moura, A., Muller, E. M., Nedimyer, K., Reckenbeil, B., … Baker, A. C. (2021). Census of heat tolerance among Florida's threatened staghorn corals finds resilient individuals throughout existing nursery populations. Proceedings of the Royal Society B: Biological Sciences, 288(1961). https://doi.org/10.1098/rspb.2021.1613
Methods

Voolstra, C. R., Buitrago-López, C., Perna, G., Cárdenas, A., Hume, B. C. C., Rädecker, N., & Barshis, D. J. (2020). Standardized short-term acute heat stress assays resolve historical differences in coral thermotolerance across microhabitat reef sites. Global Change Biology, 26(8), 4328-4343. Portico. https://doi.org/10.1111/gcb.15148
Methods

[table of contents | back to top]

Related Datasets

IsRelatedTo

Cunning, R. (2021). Data for: Census of heat tolerance among Florida's threatened staghorn corals finds resilient individuals throughout existing nursery populations (Version v1.0) [Computer software]. Zenodo.

https://doi.org/10.5281/ZENODO.5526941 https://doi.org/10.5281/zenodo.5526941

[table of contents | back to top]

Parameters

Parameter	Description	Units
nursery	Name of the coral nursery at which each coral colony was studied: CRF = Coral Restoration Foundation; MML = Mote Marine Lab; RRT = Reef Renewal Tavernier; UM = University of Miami; FWC = Florida Fish and Wildlife Conservation Commission; NSU = Nova Southeastern University	unitless
colonyID	Name of the coral colony studied	unitless
source_lon	Longitude of original source colony that this coral was collected from	decimal degrees
source_lat	Latitude of original source colony that this coral was collected from	decimal degrees
A_Acer	Symbiodinium (clade A) to host cell ratio	Symbiodinium cells per coral cell
D_Acer	Durusdinium (clade D) to host cell ratio	Durusdinium cells per coral cell
date_CBASS	Date (year and month) that the colony was assayed by CBASS	unitless
CBASS_ed50	Effective dose of temperature to 50% decline in Fv/Fm as measured by CBASS	degrees Celsius

[table of contents | back to top]

Instruments

Dataset-specific Instrument Name	CBASS
Generic Instrument Name	Coral Bleaching Automated Stress System
Generic Instrument Description	CBASS, which stands for "Coral Bleaching Automated Stress System", are portable, field-deployable experimental tanks used to apply rapid, acute heat stress challenges. This system is described in: Voolstra, C. R., Buitrago-López, C., Perna, G., Cárdenas, A., Hume, B. C. C., Rädecker, N., & Barshis, D. J. (2020). Standardized short-term acute heat stress assays resolve historical differences in coral thermotolerance across microhabitat reef sites. Global Change Biology, 26(8), 4328-4343. Portico. https://doi.org/10.1111/gcb.15148

Dataset-specific Instrument Name	DIVING-PAM-II (Walz, Effeltrich, Germany) chlorophyll fluorometer
Generic Instrument Name	Fluorometer
Generic Instrument Description	A fluorometer or fluorimeter is a device used to measure parameters of fluorescence: its intensity and wavelength distribution of emission spectrum after excitation by a certain spectrum of light. The instrument is designed to measure the amount of stimulated electromagnetic radiation produced by pulses of electromagnetic radiation emitted into a water sample or in situ.

[table of contents | back to top]

Project Information

Collaborative Research: Investigating the genomic basis of key performance traits to quantify the evolutionary potential of coral populations under climate change (AcroBaT)

Coverage: Northern Caribbean

NSF Award Abstract:
Facing an onslaught of environmental stressors, tropical coral reefs around the world have declined dramatically in recent years, particularly in the Caribbean. To help restore the structure and function of coral reef ecosystems, managers have established in-water nurseries specializing in the propagation of several coral species, particularly the endangered staghorn coral, Acropora cervicornis. With support from the Biological Oceanography Program, Integrative Ecological Physiology Program, and the NSF 2026 Idea Machine Fund Program in the NSF Office of Integrated Activities, this project aims to fill critical knowledge gaps in our understanding of the adaptive capacity of staghorn coral by studying how interactions between genetics and environment influence coral performance and thermal resilience. Insights into these interactions, the genes involved in key health traits, and the impacts of nursery rearing on coral performance inform managers attempting to conserve and restore reef ecosystems. Results are communicated directly to stakeholders and practitioners through communication with conservationists, aquariums, and government agencies. The instruments for field-testing coral thermotolerance are built and programmed by high school students in Shedd's Teen Learning Lab, and the proposed research directly involves graduate and undergraduate students at the University of Southern California, the University of South Florida, and the University of Miami. Broader public engagement is facilitated through additional outreach activities at the California Science Center in Los Angeles, Shedd Aquarium in Chicago, and Frost Science Museum in Miami. This project represents one of the most comprehensive investigations into the adaptive capacity of a reef-building coral species to date.

The long-term persistence of Caribbean reefs will ultimately be determined by whether there is sufficient genetic diversity and phenotypic resilience in remaining natural and restored coral populations to survive and reproduce in a rapidly changing climate. This project aims to quantify variation in performance among colonies, determine potential trade-offs between thermal tolerance and other traits, and identify coral genotypes that are most likely to survive under climate change and contribute to adaptive potential. Heritability, plasticity, and trade-offs among key phenotypes are being evaluated using a first-of-its-kind reciprocal transplant experiment across a network of Bahamian coral nurseries spanning a large thermal gradient over 450 km. The relationship between thermal resistance and resilience and the extent to which these traits are environmentally flexible are quantified in a series of heat stress experiments on translocated corals. Following one year of acclimatization to common garden conditions both in situ (at the Cape Eleuthera Institute, The Bahamas) and ex situ (at the University of Miami's Experimental Hatchery, Florida), a suite of phenotypes are assessed to determine whether, and to what extent, thermal tolerance is a fixed effect of host and symbiont genotype or can change in response to transplantation to different sites. Finally, custom-built Coral Bleaching Autonomous Stress Systems (CBASS) are used to quantitatively and precisely field-test the thermal tolerance of ~260 genets of A. cervicornis spanning the entire ~900-km thermal cline of the Bahamian archipelago and nearby Miami-Dade and Broward Counties in Florida. Shallow whole-genome resequencing is used to identify loci associated with thermal tolerance, in addition to assessing fine-scale population structure within hosts and symbionts.

The project directly addresses two of the top thirty-three NSF 2026 Idea Machine entries: “Imagine a Life with Clean Oceans” and “Saving Coral Reef Ecosystems."

This award reflects NSF's statutory mission and has been deemed worthy of support through evaluation using the Foundation's intellectual merit and broader impacts review criteria.

Project Participant Note:
Ross Cunning and Craig Dahlgren are sub-awardees of Award OCE-2023705.

[table of contents | back to top]

Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-2023705

[table of contents | back to top]