Coral bleaching and mortality data from a field experiment manipulating herbivore pressure and nutrient availability on a coral reef in Moorea, French Polynesia from 2018 to 2022

Website: https://www.bco-dmo.org/dataset/1000902
Data Type: Other Field Results
Version: 1
Version Date: 2026-09-11

Project
» Collaborative Research: Tipping points in coral reefs and their associated microbiomes: interactive effects of herbivory, nutrient enrichment, and temperature (RECHARGE)

Contributors	Affiliation	Role
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Abstract
Here, we used a large-scale field experiment on the forereef of Moorea, French Polynesia to directly test how different levels of simulated fishing impacted the dynamics of coral reef communities before, during, and after a major MHW that caused significant coral bleaching and mortality. We used 16, ~1.25m2 exclosures to create four different levels of consumer pressure (Very Low, Low, Medium, and High) by altering the hole sizes in the exclosures to allow access to fishes based on body size. These treatments created a gradient of access for important herbivorous fishes (e.g., parrotfishes, surgeonfishes), as well as corallivorous fishes, and allowed us to examine how reductions in consumer pressure, as would happen with intensifying fishing, impact benthic dynamics. At the beginning of the experiment in 2018, coral cover across treatments was 57%, and we assessed the temporal dynamics of coral and macroalgae in response to altering consumer pressure. In 2019, Moorea experienced one of the most intense MHWs on record resulting in widespread coral mortality. Thus, we were able to directly test how varying consumer pressure impacted coral reef communities during the months prior to the MWH, during the MHW, and then for three years after the immediate impact of the MHW. Using Olympus TG cameras, we took ~64 individual photographs of each exclosure which were then stitched together using Agisoft Metashape software. The creation of these photomosaics generates high-resolution imagery that allows identification of benthic space holders with high taxonomic resolution. The photomosaics allowed us to track the fates of individual corals across our time series. At the first time point in our time series (Aug 2018), we gave each individual Pocillopora and Acropora a unique identifying number. During the peak of coral bleaching, in May 2019, we took additional top-down photographs of each exclosure, allowing us to quantify whether each individual coral had bleached and, if so, what proportion of the colony surface area (to the nearest 5%) was bleached or dead. Because corals undergo natural, seasonal variation in Symbiodiniaceae density that can affect their coloration, we defined bleached tissue only as tissue that had lost all pigmentation. Bleaching severity was bimodal, with most corals either 0 or 100 percent bleached. However, approximately 36% of corals with some bleaching had less than 100% of their tissue bleached. For analyses, we defined 50% bleached as a severe bleaching threshold. Using our photomosaics, we then tracked the annual survival or mortality of each coral in August of each year (Aug 2019, Aug 2020, Aug 2021, Aug 2022). Corals frequently had partial mortality, with colonies sometimes having small amounts of remnant tissue which would remain for many months. Therefore, we used a threshold of the loss of 90% of live tissue to define a coral as being dead since we never observed recovery from this level of tissue loss.

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Coverage

Location: Moorea, French Polynesia 17.47° S, 149.82° W
Spatial Extent: **Lat**:17.47 **Lon**:149.82
Temporal Extent: 2018-08-01 - 2022-08-01

Methods & Sampling

Experimental Setup

In June 2018, we established a factorial experiment manipulating consumer pressure and nutrient availability in areas that mimicked disturbance from a cyclone. At 12m depth on the north shore forereef of Moorea, French Polynesia (17.47° S, 149.82° W) we established 8 ~30m^2 plots. Within each plot, we then nested 4 different consumer exclosures (~1.25 m^2 each) with different size openings that allowed different size fishes (herbivores and corallivores, hereafter referred to as 'consumers') access to the benthos. The exclosure frames consisted of 0.5cm stainless steel all-thread drilled into the reef matrix and epoxied into place. These frames were then wrapped with plastic-coated, galvanized wire to create the following levels of consumer pressure: 1) Very Low (2.5cm × 2.5cm (1inx1in) openings); 2) Low (5cm × 5cm (2inx2in) openings); 3) Medium (7.5cm × 7.5cm (3inx3in) openings); 4) High (4 sides of 2.5cm × 2.5cm (1inx1in) openings but no top). Others have used a similar design to create a gradient of consumer pressure to mimic the effects of different levels of fishing (Holbrook et al. 2016, Schmitt et al. 2019). We included sides, but not tops, on the High consumer pressure treatment to control for potential artifacts on water flow, although we have shown these are minimal (Zaneveld et al. 2016). Exclosures were scrubbed every 12-16 weeks to remove fouling organisms.

We also included a second treatment of Ambient or Enriched nutrient conditions with each plot (which included four nested consumer exclosures) was then assigned to either Ambient or Enriched nutrient conditions. Thus, each combination of consumer pressure (Very Low, Low, Medium, High) and nutrients (Ambient or Enriched) had n=4 for replication. For the enrichment we placed 175 g of Osmocote® (19-6-12, N-P-K) slow-release garden fertilizer into 5 cm diameter PVC tubes with 10, 1 cm holes drilled into them. These tubes were wrapped in fine plastic mesh to retain the fertilizer. This method is similar to our previous work (e.g., Zaneveld et al. 2016). PVC enrichment tubes were attached to the corners of each exclosure and onto a piece of stainless steel all-thread in the center of each plot (5 enrichment tubes per exclosure). We replaced enrichment tubes every 12-16 weeks except for two periods during the COVID-19 pandemic when travel to Moorea was not possible and enrichment tubes were deployed for longer than usual before replacement (deployed from 01-30-2020 to 08-31-2020, and from 08-31-2020 to 02-08-2021). We analyzed water samples from the experimental plots to evaluate the effect of nutrient enrichment. We showed that the enrichment treatment effectively enriched nutrients throughout the experiment, but that the effect of the enrichment decreased with time since replacement of enrichment tubes. This suggests that the enrichment may have been negligible by the end of each deployment of the enrichment tubes, and during the two periods during the pandemic when tubes were deployed longer than usual.

The treatments were arranged as in this example:

- Plot A1 was Ambient nutrients and contained one replicate of each of the exclosure treatments (Very Low, Low, Medium, and High consumer pressure).
- Plot A2 was Enriched nutrients and contained one replicate of each of the exclosure treatments (Very Low, Low, Medium, and High consumer pressure).

n=4 for each nutrient-consumer pressure combination e.g., - Enriched/High consumer pressure; Ambient/Very Low consumer pressure etc.

Data Collection

During three periods each year from 2018-2022 (April, August, November - except for two time points missed due to the COVID-19 pandemic), we quantified benthic cover in each exclosure via point contacts on orthorectified photomosaics. Using Olympus TG cameras, we took ~64 individual photographs of each

exclosure which were then stitched together using Agisoft Metashape software. The creation of these photomosaics generates high-resolution imagery that allows identification of benthic space holders with high taxonomic resolution. At the first time point in our time series (Aug 2018), we gave each individual *Pocillopora* and *Acropora* a unique identifying number. During the peak of coral bleaching, in May 2019, we took additional top-down photographs of each exclosure, allowing us to quantify whether each individual coral had bleached and, if so, what proportion of the colony surface area was bleached or dead.

Working in ImageJ, investigators estimated the surface area of each individual coral colony to be bleached or dead to the nearest 5%. Because corals undergo natural, seasonal variation in Symbiodiniaceae density that can affect their coloration, we defined bleached tissue only as tissue that had lost all pigmentation (i.e., completely white). Bleaching severity was bimodal, with most corals either 0 or 100 percent bleached. However, approximately 36% of corals with some bleaching had less than 100% of their tissue bleached. For analyses, we defined 50% bleached as a severe bleaching threshold. Using our photomosaics, we then tracked the annual survival or mortality of each coral in August of each year (Aug 2019, Aug 2020, Aug 2021, Aug 2022) by visually estimating the mortality of each individual coral colony to the nearest 5% as we had done for the initial bleaching and mortality quantification. Corals frequently had partial mortality, with colonies sometimes having small amounts of remnant tissue which would remain for many months. Therefore, we used a threshold of the loss of 90% of live tissue to define a coral as being dead since we never observed recovery from this level of tissue loss.

Data Processing Description

Using Olympus TG cameras, we took ~64 individual photographs of each exclosure and then generated photomosaics by stitching photographs together using Agisoft Metashape software (Agisoft Metashape Professional Version 1.7). These photomosaics generate high-resolution imagery that allows identification of benthic space holders to the lowest taxonomic level possible (genus for most corals and macroalgae).

BCO-DMO Curation Notes

This section documents curation actions performed prior to publication review with the submitter, and additional information relevant to understanding and reusing this dataset. It distinguishes changes made to the submitted (meta)data from unresolved issues and/or enhancements that improve future reuse and interoperability.

CURATION ACTIONS PERFORMED ON DATA

- Loaded coral_bleaching_mortality.csv from file storage, using filename as table name, with headers on row 1; set missing value markers to empty string and "nd" during load
- Edited cell in row 229, column Next_to_bleached_coral_YN, setting value to "Y", upon submitter request
- Output as 1000902_v1_coral_bleaching_mortality.csv

CURATION ACTIONS PERFORMED ON METADATA

- BCO-DMO's standard metadata entry and text formatting steps were performed. See: https://www.bco-dmo.org/how-to/standard-curation-edits

ISSUES POTENTIALLY IMPACTING REUSE

- N/A

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Data Files

File
1000902_v1_coral_bleaching_mortality.csv (Comma Separated Values (.csv), 31.35 KB) MD5:ebbd992024e5b5d26207347be141ee0a Primary data file for dataset ID 1000902, version 1

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Related Publications

Beijbom, O., Edmunds, P. J., Roelfsema, C., Smith, J., Kline, D. I., Neal, B. P., Dunlap, M. J., Moriarty, V., Fan, T.-Y., Tan, C.-J., Chan, S., Treibitz, T., Gamst, A., Mitchell, B. G., & Kriegman, D. (2015). Towards Automated Annotation of Benthic Survey Images: Variability of Human Experts and Operational Modes of Automation. PLOS ONE, 10(7), e0130312. https://doi.org/10.1371/journal.pone.0130312
Methods

Holbrook, S. J., Schmitt, R. J., Adam, T. C., & Brooks, A. J. (2016). Coral Reef Resilience, Tipping Points and the Strength of Herbivory. Scientific Reports, 6(1). https://doi.org/10.1038/srep35817
Methods

Schmitt, R. J., Holbrook, S. J., Davis, S. L., Brooks, A. J., & Adam, T. C. (2019). Experimental support for alternative attractors on coral reefs. Proceedings of the National Academy of Sciences, 116(10), 4372–4381. https://doi.org/10.1073/pnas.1812412116
Methods

Zaneveld, J. R., Burkepile, D. E., Shantz, A. A., Pritchard, C. E., McMinds, R., Payet, J. P., ... Thurber, R. V. (2016). Overfishing and nutrient pollution interact with temperature to disrupt coral reefs down to microbial scales. Nature Communications, 7(1). doi:10.1038/ncomms11833
Methods

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Parameters

Parameter	Description	Units
Block	Experiment was arranged in 4 blocks - A, B, C, D	unitless
Plot	Each block had 4 plots within denoted as 1, 2, 3, or 4 - each plot had one replicate of each of the herbivore treatments (Herb_TRT) nested within	unitless
Genus	Genus of focal coral: Either Pocillopora or Acropora	unitless
Block_plot	Experiment was arranged in 4 blocks - A, B, C, D with four plots 1, 2, 3, or 4 within each block: Combination of block and plot - e.g. Block A plot 1 would be 'A1'	unitless
Herb_Trt	Herbivore exclusion treatments representing 4 different levels of herbivory intensity: 1x1 = Very Low, 2x2 = Low, 3x3 Medium, and Open = High, denoted with the size of the holes in the exclosures, e.g. 1x1 = 1 in x 1 in holes in the exclosure, while Open denotes 4 sides of 1in× 1in openings but no top.	unitless

Coral_ID	Unique coral ID for each coral in each replicate: A for Acropora, P for Pocillopora and then the unique number for that individual so A1 would be Acropora 1 in that replicate	unitless
Size_class	Corals were binned into size classes based on the largest diameter for each colony for analyses: Size classes represent: 0 < 5cm. 1 = 5-10cm, 2 = 10-19 cm, 3 = 20-29cm, 4 = >29cm	unitless
Percent_bleached_May2019	Percent of a coral colony that was bleached in May 2019	percent
Percent_dead_May2019	Percent of a coral colony that was dead in May 2019	percent
Percent_bleached_plus_dead_May2019	Percent of a coral colony that was bleached plus dead in May 2019	percent
Bleached50_May2019	Binary 0=no, 1=yes if colony was bleached at least 50% in May 2019	unitless
Bleached90_May2019	Binary 0=no, 1=yes if colony was bleached at least 90% in May 2019	unitless
Dead50_May2019	Binary 0=no, 1=yes if colony was dead at least 50% in May 2019	unitless
Dead90_May2019	Binary 0=no, 1=yes if colony was dead at least 90% in May 2019	unitless
Next_to_bleached_coral_YN	Was the coral next to a coral that bleached Y/N in May 2019	unitless
Percent_bleached_Aug2019	Percent of a coral colony that was bleached in August 2019	percent
Percent_dead_Aug2019	Percent of a coral colony that was dead in August 2019	percent
Dead50_Aug2019	Binary 0=no, 1=yes if colony was dead at least 50% in August 2019	unitless
Dead90_Aug2019	Binary 0=no, 1=yes if colony was dead at least 90% in August 2019	unitless
Percent_bleached_Aug2020	Percent of a coral colony that was bleached in August 2020	percent

Percent_dead_Aug2020	Percent of a coral colony that was dead in August 2020	percent
Dead50_Aug2020	Binary 0=no, 1=yes if colony was dead at least 50% in August 2020	unitless
Dead90_Aug2020	Binary 0=no, 1=yes if colony was dead at least 90% in August 2020	unitless
Percent_bleached_Aug2021	Percent of a coral colony that was bleached in August 2021	percent
Percent_dead_Aug2021	Percent of a coral colony that was dead in August 2021	percent
Dead50_Aug2021	Binary 0=no, 1=yes if colony was dead at least 50% in August 2021	unitless
Dead90_Aug2021	Binary 0=no, 1=yes if colony was dead at least 90% in August 2021	unitless
Percent_bleached_Aug2022	Percent of a coral colony that was bleached in August 2022	percent
Percent_dead_Aug2022	Percent of a coral colony that was dead in August 2022	percent
Dead50_Aug2022	Binary 0=no, 1=yes if colony was dead at least 50% in August 2022	unitless
Dead90_Aug2022	Binary 0=no, 1=yes if colony was dead at least 90% in August 2022	unitless

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Instruments

Dataset-specific Instrument Name	Olympus TG cameras
Generic Instrument Name	Camera
Dataset-specific Description	Using Olympus TG cameras, we took ~64 individual photographs of each exclosure which were then stitched together using Agisoft Metashape software.
Generic Instrument Description	All types of photographic equipment including stills, video, film and digital systems.

Dataset-specific Instrument Name	consumer exclosures
Generic Instrument Name	Manual Biota Sampler
Dataset-specific Description	Within each plot, we then nested 4 different consumer exclosures (~1.25 m2 each) with different size openings that allowed different size fishes (herbivores and corallivores, hereafter referred to as 'consumers') access to the benthos.
Generic Instrument Description	"Manual Biota Sampler" indicates that a sample was collected in situ by a person, possibly using a hand-held collection device such as a jar, a net, or their hands. This term could also refer to a simple tool like a hammer, saw, or other hand-held tool.

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Project Information

Collaborative Research: Tipping points in coral reefs and their associated microbiomes: interactive effects of herbivory, nutrient enrichment, and temperature (RECHARGE)

Coverage: Mo'orea, French Polynesia

NSF Award Abstract:
Coral reefs are some of the most diverse, yet most imperiled, ecosystems on the planet. Global change has driven the decline of corals worldwide with many reefs now lacking corals and being overrun by macroalgae. This research examines the impacts of several factors of thermal stress, overfishing of important herbivorous fishes, and nutrient pollution on the health of corals and their ability to recover after large coral-killing disturbances. Importantly, the investigators address the impacts of global change on the coral microbiome, the microbes that associate with corals and impact coral health. The overarching hypothesis is that factors such as overfishing and nutrient pollution impact coral health via impacts to their microbes. This 6-year experiment on the coral reefs of Mo'orea, French Polynesia examines what levels of herbivory, mostly by parrotfishes and surgeonfishes, are needed to provide resistance and resilience of corals and their microbiomes when reefs are exposed to elevated nutrients and ocean temperatures. Notably, the team tests how local stressors (overfishing, nutrient pollution) potentially interact with global stressors (climate change and rising ocean temperatures) to impact coral reef health. This research may yield insight into how to manage local factors (reducing fishing, mitigating nutrient pollution) to help corals survive the global stress of climate change. The field experiment provides a realistic platform to test questions about how local management of fisheries can alter reef health and provides data about the recoverability of reefs should new water quality management be put into place. This interdisciplinary work trains a new generation of both marine ecologists and microbiologists, including one postdoctoral researcher, two graduate students, as well as numerous undergraduates. The main international outreach effort is to map the microbiome of the island of Mo'orea. Mo'orea is approximately 130 square-kilometers in area and has five major watersheds that transport sediment and nutrients to the nearshore coral reef ecosystems. Thus poor stewardship of these watersheds likely contributes to the local phase shifts currently occurring in several areas of the lagoon. Therefore the team has engaged the local community to help collect microbiome samples from 50 terrestrial, 50 stream, 25 coastal sites, and 25 offshore sites around the island. The sampling effort is generating an island-wide map of the microbial communities associated with the soils, streams, and coastal waters that can be linked to adjacent coral reef health - The Moorea Microbiome! As part of this outreach effort, the team also collaborates with filmmakers to make a trilingual (English, French, and Tahitian) film about the project to serve as local engagement and teaching tool to help educate school groups and different stakeholders about both the seen and unseen connections between land and sea on their island.

On the island of Mo'orea, French Polynesia, coral communities have exhibited strikingly different trajectories, with some reefs recovering from disturbances and others undergoing protracted coral decline, accompanied by an increase in macroalgae. This diversity in coral community dynamics makes Mo'orea an excellent model system for testing why some reefs are resilient and return to abundant coral while others are not and undergo

persistent phase shifts to macroalgal dominance. This 6-year experiment will measure the dynamics of benthic communities, coral demography, and the coral microbiome across seasonal change in ocean temperature, allowing the team to (1) link changes in coral microbiomes (e.g., a rise in pathogenic bacteria) to the trajectories of coral decline or recovery and (2) link nutrients, herbivory, and temperature to phase shifts in both benthic communities and coral microbiomes. Importantly, the team is testing the resistance of phase shifts of benthic communities and coral microbiomes by measuring their changes after removing the nutrient enrichment treatment at the end of year 3 and tracking recovery of the system for 3 more years. Thus, this project begins to answer whether reef and microbial community phase shifts can be easily reversed once they occur. Many studies have focused on the factors that disassemble coral reef communities, but this is the first to examine how reef communities can be reassembled from the microbiome upwards.

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.

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Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-2023701
NSF Division of Ocean Sciences (NSF OCE)	OCE-2023424

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