Benthic community composition from a field experiment manipulating consumer pressure and nutrient availability on a coral reef in Moorea, French Polynesia from 2018 to 2022

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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 experimentally test the relative importance of alterations to top-down and bottom-up processes in driving community development and variability after a simulated disturbance on a coral reef. We use a factorial experiment manipulating consumer pressure and nutrient enrichment for four years on a coral reef in Moorea, French Polynesia. Our experiment consisted of plots (~1.25 m2 each) that manipulated access by consumers via different size openings that allowed different size fishes access to the benthos, creating four levels of consumer pressure (Very Low, Low, Medium, High). These four levels of consumer pressure were crossed with manipulations of nutrient availability with either ambient or nutrient enriched conditions. At the start of the experiment, we removed all live corals and fleshy macroalgae from the plots to mimic the effects of a severe cyclone. We quantified the abundance of benthic organisms (e.g., corals, macroalgae, etc.) for four years to assess how experimental treatments affected community development. At three time points each year (April, July/August, November - except for two time points missed due to the COVID-19 pandemic, April 2020 and November 2020), 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 and then generated photomosaics by stitching photographs together using Agisoft Metashape software (Agisoft Metashape Professional Version 17.0). 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). It was not possible to reliably distinguish among filamentous turf algae, bare space, and very small encrusting algae (including small CCAs and other encrusting algae) from photographs, therefore these taxa were categorized as one group. We used these data to generate percent cover estimates for each exclosure at each timepoint. Percent cover of benthic space holders was estimated via 225 random points per m2 exclosure using CoralNet software.

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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 16 ~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.

Within the exclosures we effected a second treatment in order to simulate the effects of a cyclone. To do so, we removed all branching corals (mostly *Acropora* spp. and *Pocillopora* spp.) and transplanted them to other areas of the reef away from the experiment. The removal of branching corals simulated a pulse disturbance such as the cyclone that reduced coral cover to < 5% on the forereefs of Moorea in 2010. Remaining patches of encrusting corals (mostly *Montipora* spp.) and mounding corals (mostly *Porites* spp.) and macroalgae (which were rare) were scrubbed with wire brushes to mimic the scouring from sediments that occurs during a large cyclone. Thus, after coral and macroalgae removal, mean coral cover in the plots was ~7% and macroalgae was ~0.5%. These treatments were called 'Disturbed' as opposed to plots where we did not remove corals that are referred to as 'Intact'.

We also included a third 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.

The treatments were arranged as in this example:

- Plot A1 was Intact (coral remained) with Ambient nutrients and contained one replicate of each of the exclosure treatments (Very Low, Low, Medium, and High consumer pressure).
- Plot A2 was Intact (coral remained) with Enriched nutrients and contained one replicate of each of the exclosure treatments (Very Low, Low, Medium, and High consumer pressure).
- Plot A3 was Disturbed (coral removed) with Enriched nutrients and contained one replicate of each of the exclosure treatments (Very Low, Low, Medium, and High consumer pressure).
- Plot A4 was Disturbed (coral removed) with Ambient nutrients and contained one replicate of each of the exclosure treatments (Very Low, Low, Medium, and High consumer pressure).

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

Data Collection

At three time points each year (April, July/August, November - except for two time points missed due to the COVID-19 pandemic, April 2020 and November 2020), 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 and then generated photomosaics by stitching photographs together using Agisoft Metashape software (Agisoft Metashape Professional Version 17.0). These photomosaics generate high-resolution imagery that allows identification of benthic space holders. Percent cover of benthic space holders was estimated via 225 random points per m^2 exclosure using CoralNet software (Beijbom et al. 2015) with the space holder underlying each of the 225 points identified to the lowest taxonomic level possible (usually genus for most macroalgae, corals, and other invertebrates). It was not possible to reliably distinguish among filamentous turf algae, bare space, and very small encrusting algae (including small CCAs and other encrusting algae) from photographs, therefore these taxa were categorized as one group. We used these data to generate percent cover estimates for each exclosure at each timepoint.

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 17.0). 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). Percent cover of benthic space holders was estimated via 225 random points per m^2 exclosure using CoralNet software.

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 benthic_composition_summary_final.csv from source submission files, with header on row 1; set missing value markers to empty string and "nd"
- Renamed four columns to strip trailing periods for naming compliance: Caulerpa_spp., Dictyota_spp., Galaxaura_spp., Valonia_spp. became Caulerpa_spp, Dictyota_spp, Galaxaura_spp, Valonia_spp
- Converted Date column from M/D/YYYY format to ISO 8601 date format (YYYY-MM-DD), overwriting the original column
- Output as 1000908_v1_benthic_composition_summary.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	
1000908_v1_benthic_composition_summary.csv	(Comma Separated Values (.csv), 129.15 KB) MD5:9feac6406d84e67178f4c9f2f78145e0
Primary data file for dataset ID 1000908, version 1	

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Related Publications

Adam, T. C., Schmitt, R. J., Holbrook, S. J., Brooks, A. J., Edmunds, P. J., Carpenter, R. C., & Bernardi, G. (2011). Herbivory, Connectivity, and Ecosystem Resilience: Response of a Coral Reef to a Large-Scale Perturbation. PLoS ONE, 6(8), e23717. https://doi.org/10.1371/journal.pone.0023717
Methods

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
Results

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Parameters

Parameter	Description	Units
Time_point	Period of sampling; sequential number with 0 = Time point 0, 1 - Time point 1, etc	unitless
Timepoint	Period of sampling; T0 = Time point 0, T1 = Time point 1, etc.	unitless
unitless	Date of sampling	Date
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
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

Block_Plot_Herb_TRT	Represents an individual replicate in the corresponding block, plot, and what herbivore treatment that replicate was; Combination of Block, plot, and herbivore treatment for an invididual replicate - so a 1x1 exclosure in Block a and plot 1 would be A1_1x1	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
Disturbance_Trt	Plots with either corals present (Intact) or corals removed (Disturbed)	unitless
Nutrient_Trt	Plots with either ambient or enriched nutrients	unitless
Acanthastrea_spp	Percent cover of the benthos	percent
Acropora_spp	Percent cover of the benthos	percent
Amphiroa_spp	Percent cover of the benthos	percent
Anemone	Percent cover of the benthos	percent
Asparagopsis	Percent cover of the benthos	percent
Caulerpa_spp	Percent cover of the benthos	percent
CCA	Percent cover of the benthos	percent
Chlorodesmis	Percent cover of the benthos	percent
Colpomenia	Percent cover of the benthos	percent
Cyanobacteria	Percent cover of the benthos	percent
Dictyota_spp	Percent cover of the benthos	percent
Foliose_Lobophora	Percent cover of the benthos	percent
Fungiid	Percent cover of the benthos	percent

Galaxaura_spp	Percent cover of the benthos	percent
Gibsmithia	Percent cover of the benthos	percent
Grateloupia	Percent cover of the benthos	percent
Halimeda_spp	Percent cover of the benthos	percent
Hydroclathrus	Percent cover of the benthos	percent
Hypnea	Percent cover of the benthos	percent
Jania_spp	Percent cover of the benthos	percent
Leptastrea	Percent cover of the benthos	percent
Leptoseris	Percent cover of the benthos	percent
Lobophyla	Percent cover of the benthos	percent
Long_turf	Percent cover of the benthos	percent
Millepora	Percent cover of the benthos	percent
Montipora_spp	Percent cover of the benthos	percent
Padina	Percent cover of the benthos	percent
Pavona	Percent cover of the benthos	percent
Phymastraea	Percent cover of the benthos	percent
Pocillopora_spp	Percent cover of the benthos	percent
Porites_spp	Percent cover of the benthos	percent
Psammocora	Percent cover of the benthos	percent

Rubble	Percent cover of the benthos	percent
Sand	Percent cover of the benthos	percent
Sargassum	Percent cover of the benthos	percent
Soft_coral	Percent cover of the benthos	percent
Spatoglossum	Percent cover of the benthos	percent
Sponge	Percent cover of the benthos	percent
Tridacna	Percent cover of the benthos	percent
Turbinaria	Percent cover of the benthos	percent
Turf_Bare_Encrusting_Algae	Percent cover of the benthos	percent
Unknown_encrusting_coral	Percent cover of the benthos	percent
Unknown_macroalgae	Percent cover of the benthos	percent
Valonia_spp	Percent cover of the benthos	percent
Macroalgae	Percent cover of the benthos	percent
Coral	total percent cover of coral	percent

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Instruments

Dataset-specific Instrument Name	Olympus TG camera
Generic Instrument Name	Camera
Dataset-specific 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
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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