Experimental results: calcification by primary coral polyps under high bicarbonate and low pH from 2007-2008 (OA Nutrition and Coral Calcification project)

Website: https://www.bco-dmo.org/dataset/491463
Version: 2014-01-31

Project
» An Investigation of the Role of Nutrition in the Coral Calcification Response to Ocean Acidification (OA Nutrition and Coral Calcification)

Programs
» Science, Engineering and Education for Sustainability NSF-Wide Investment (SEES): Ocean Acidification (formerly CRI-OA) (SEES-OA)
» Ocean Carbon and Biogeochemistry (OCB)

Contributors	Affiliation	Role
Cohen, Anne L.	Woods Hole Oceanographic Institution (WHOI)	Principal Investigator
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Dataset Description

Data used in the published manuscript: 'The impact of seawater saturation state and bicarbonate ion concentration on calcification by new recruits of two Atlantic corals'. Carbonate chemistry and coral skeletal weights from two aquaria based OA experiments at the Bermuda Institute of Ocean Sciences: in 2007 acid was used to decrease the pH and in 2008 pCO2 bubbling was used. Comparison of the results determined the relative importance of [HCO3-] versus [CO32-] for early calcification by the coral species Favia fragum and Porites astreoides. Data analysis was performed at Woods Hole Oceanographic Institution.

These data have also been deposited to PANGAEA where additional carbonate system variables were calculated as described by Nisumaa et al. (2010; doi: 10.5194/essd-2-167-2010). See: http://doi.pangaea.de/10.1594/PANGAEA.770070

Related References:

de Putron, S. J., D. C. McCorkle, A. L. Cohen, A. B. Dillon.(2011) The impact of seawater saturation state and bicarbonate ion concentration on calcification by new recruits of two Atlantic corals. Coral Reefs, 30:321-328. DOI: 10.1007/s00338-010-0697-z

Drenkard, E., Cohen, A.L., McCorkle D.C., de Putron S.J., Zicht, A., Starczak, V. (3013) The Impact of Heterotrophic Feeding on the Coral Calcification Response, Coral Reefs. 10.1007/s00338-013-1021-5

Methods & Sampling

Larval collection and settlement
Mature colonies of the brooding corals F. fragum and P. astreoides were collected from inshore patch reefs in Bermuda just prior to their predicted time of larval release in July 2007 (F. fragum), August 2007 (P. astreoides), and July 2008 (both species). Colonies were maintained at the Bermuda Institute of Ocean Sciences (BIOS) in outdoor flow-through seawater aquaria under near-ambient temperature and light conditions, and were held in either jars or mesh bags of aerated seawater during the nights of release to isolate the larvae. Zooxanthellate larvae were collected daily as they were released by the adults, and were settled on preconditioned tiles in small (0.5 L) plastic containers of seawater at the saturation state of each experimental aquarium (see below). Preconditioning of tiles was achieved by leaving racks of tiles on nearby reefs for 4-6 weeks, allowing them to obtain the biofilms and algae needed to induce larval settlement. After a settlement period of 24-48 h, the tiles containing metamorphosed primary polyps were transferred to the experimental aquaria. The polyps were grown for two weeks, after which the polyp tissue was removed by bleaching to reveal the underlying corallite. The skeleton of each polyp was removed from the tile and individually weighed using a micro balance. Since all skeletal carbonate retrieved from the experiments was formed under the experimental conditions, total corallite weight provides a direct measure of the amount of calcification ($CaCO_3$ production) achieved by each polyp under the different experimental conditions. For statistical analysis, corallite weight data were square root transformed to meet assumptions and were analyzed using One-Way ANOVA followed by Multiple Comparison of Means TK, GT2, T' tests (BIOMstat33).

Experimental conditions
Static, 30 L, glass-lidded aquaria containing reef seawater were pre-adjusted to a range of seawater saturation states (Table 1). In 2007, the aquarium seawater alkalinity was decreased by small additions of HCl and bubbled with lab air. The seawater pCO_2, calculated from alkalinity and DIC, was approximately 450 ppmv. In 2008, the aquarium seawater pCO_2 and DIC levels were set by bubbling with air from a compressor room separate from the lab, and with air+CO_2 mixtures produced with pairs of mass flow controllers. The composition of the bubbling gas mixtures in 2008 was monitored daily using a Qubit infra-red CO_2 analyzer and mean ppmv ± SD were: 394 ± 9 (ambient air; control), 753 ± 12 (mid CO_2), and 2327 ± 23 (high CO_2). The seawater temperature in all aquaria in each experiment was monitored using Hobo temperature loggers (Onset Corp.) Average seawater temperatures for the two week period were: 25 °C ± 0.5 (mean ± SD) for 2007 F. fragum; 28.5 ± 0.2 for 2007 P. astreoides; and 29.4 ± 1.3 for both species in 2008. The polyps were not fed during the two week experiments (apart from particulate matter initially present in the aquaria), and were kept on a 12/12 hr light-dark cycle with the maximum light levels achievable with the aquarium lights: mean (± SD) of 61 ± 6 µmol m-2 s-1.

The chemical conditions for all treatments in each experiment are summarized in the manuscript. Salinity was determined with an Autosal salinometer. Discrete water samples for analysis of salinity, alkalinity (Alk), and dissolved inorganic carbon (DIC) were collected weekly; the Alk/DIC samples were poisoned immediately after collection. Alkalinity and DIC were measured using a closed cell titration (inorganic carbon and alkalinity analyser) with non-linear curve fitting on ~100 mL samples, standardized using certified reference materials obtained from Dr. A Dickson (SIO). The pH (NBS) of the aquaria during all experiments was checked twice weekly using an Orion 3-star pH meter and calibrated electrode; the precision of replicate pH measurements was +/- 0.015 units. The measured seawater temperature, salinity, alkalinity, and DIC concentrations were used to calculate other carbonate system parameters ($[HCO_3^-]$, $[CO_3^{2-}]$ and Omega), using a spreadsheet version of the CO2SYS program of Lewis and Wallace (1998), with the dissociation constants of Roy et al. (1993) and the aragonite solubility of Mucci (1983). The precision of the titrations was ± 0.2 % for both alkalinity and DIC in ambient seawater, but only ± 0.6 % and ± 1.7 %, respectively, in the most strongly acidified treatment. This resulted in an analytical uncertainty in calculated saturation state of roughly ± 0.5 % at ambient conditions and ± 16 % in the lowest Omega treatment.

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Data Files

File
coral_chem.csv (Comma Separated Values (.csv), 2.37 KB) MD5:14644d1731ba80350f30420e82dd1ac0 Primary data file for dataset ID 491463

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Parameters

Parameter	Description	Units
species	species of coral used in experiment	unitless
date_expt	date that experiment was performed	unitless
treatment	treatment identification	unitless
weight	total corallite skeletal weight; average of all replicate tanks for the given experimental treatment	micrograms
weight_se	standard error of corallite wt	micrograms
OM_ar	omega; aragonite saturation state; average of all replicate tanks for the given experimental treatment. (The saturation state of seawater with respect to aragonite is a measure of the thermodynamic potential for aragonite to form or to dissolve and is defined as the product of the concentrations of dissolved calcium and carbonate ions in seawater divided by their product at equilibrium.)	unitless
OM_ar_sd	standard deviation of omega	unitless
HCO3	concentration of bicarbonate ions; average of all replicate tanks for the given experimental treatment	micromoles/kilogram
HCO3_sd	standard deviation of HCO3	micromoles/kilogram
CO3	concentration of carbonate ions; average of all replicate tanks for the given experimental treatment	micromoles/kilogram
CO3_sd	standard deviation of CO3	micromoles/kilogram
sal	average salinity of all replicate tanks for the given experimental treatment	psu

sal_sd	standard deviation of Salinity	psu
alkalinity	average alkinity of all replicate tanks for the given experimental treatment	microequivalent/kilogram
alk_sd	standard deviation of Alkalinity	microequivalent/kilogram
DIC	Concentration of dissolved inorganic carbon; average of all replicate tanks for the given experimental treatment	micromoles/kilogram
DIC_sd	standard deviation of DIC	micromoles/kilogram
pCO2	partial pressure of carbon dioxide; average of all replicate tanks for the given experimental treatment	parts per million by volume
pCO2_sd	standard deviation of pCO2	parts per million by volume
pH	average pH of all replicate tanks for the given experimental treatment; NBS scale	unitless
pH_sd	standard deviation of pH; NBS scale	unitless

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Instruments

Dataset-specific Instrument Name	Aquarium
Generic Instrument Name	Aquarium
Dataset-specific Description	Static, 30 L, glass-lidded aquaria containing reef seawater.
Generic Instrument Description	Aquarium - a vivarium consisting of at least one transparent side in which water-dwelling plants or animals are kept

Dataset-specific Instrument Name	salinometer
Generic Instrument Name	Autosal salinometer
Generic Instrument Description	The salinometer is an instrument for measuring the salinity of a water sample.

Dataset-specific Instrument Name	CO2 Analyzer
Generic Instrument Name	CO2 Analyzer
Dataset-specific Description	Qubit infra-red CO2 analyzer is a non-dispersive infrared CO2 analyzer that measures CO2 in 0 to 2000 ppm range with 1 ppm resolution. The composition of the bubbling gas mixtures was monitored daily using a Qubit infra-red CO2 analyzer. http://www.qubitbiology.com/animal-and-insect/gas-analysis-control-a-i/s...
Generic Instrument Description	Measures atmospheric carbon dioxide (CO2) concentration.

Dataset-specific Instrument Name	inorganic carbon and alkalinity analyser
Generic Instrument Name	MARIANDA VINDTA 3C total inorganic carbon and titration alkalinity analyser
Dataset-specific Description	The Alk/DIC samples were poisoned with mercuric chloride immediately after collection and analyzed using a Marianda VINDTA-3C analysis system at WHOI.
Generic Instrument Description	The Versatile INstrument for the Determination of Total inorganic carbon and titration Alkalinity (VINDTA) 3C is a laboratory alkalinity titration system combined with an extraction unit for coulometric titration, which simultaneously determines the alkalinity and dissolved inorganic carbon content of a sample. The sample transport is performed with peristaltic pumps and acid is added to the sample using a membrane pump. No pressurizing system is required and only one gas supply (nitrogen or dry and CO2-free air) is necessary. The system uses a Metrohm Titrino 719S, an ORION-Ross pH electrode and a Metrohm reference electrode. The burette, the pipette and the analysis cell have a water jacket around them. Precision is typically +/- 1 umol/kg for TA and/or DIC in open ocean water.

Dataset-specific Instrument Name	MFC
Generic Instrument Name	Mass Flow Controller
Dataset-specific Description	Tthe aquarium seawater pCO2 and DIC levels were set by bubbling with air from a compressor room separate from the lab, and with air+CO2 mixtures produced with pairs of mass flow controllers.
Generic Instrument Description	Mass Flow Controller (MFC) - A device used to measure and control the flow of fluids and gases

Dataset-specific Instrument Name	pH Sensor
Generic Instrument Name	pH Sensor
Dataset-specific Description	The pH (NBS) of the aquaria during all experiments was checked twice weekly using an Orion 3-star pH meter and calibrated electrode; the precision of replicate pH measurements was +/- 0.015 units.
Generic Instrument Description	An instrument that measures the hydrogen ion activity in solutions. The overall concentration of hydrogen ions is inversely related to its pH. The pH scale ranges from 0 to 14 and indicates whether acidic (more H+) or basic (less H+).

Dataset-specific Instrument Name	Scale
Generic Instrument Name	scale or balance
Dataset-specific Description	The skeleton of each polyp was removed from the tile and individually weighed using a micro balance.
Generic Instrument Description	Devices that determine the mass or weight of a sample.

Dataset-specific Instrument Name	Water Temp Sensor
Generic Instrument Name	Water Temperature Sensor
Dataset-specific Description	The seawater temperature in all aquaria in each experiment was monitored using Hobo temperature loggers (Onset Corp.)
Generic Instrument Description	General term for an instrument that measures the temperature of the water with which it is in contact (thermometer).

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Deployments

lab_dePutron_BIOS

Website	https://www.bco-dmo.org/deployment/59090
Platform	BIOS
Start Date	2010-07-01
Description	Experiments for the project "An Investigation of the Role of Nutrition in the Coral Calcification Response to Ocean Acidification" were carried out at the Bermuda Institute of Ocean Sciences (BIOS) in St. George, Bermuda. Pregnant adult corals were collected from the northwestern Bermuda patch reefs in the area of Bailey's Bay; adult corals were returned to their resident reefs following larval collection.

lab_Cohen_WHOI

Website	https://www.bco-dmo.org/deployment/59089
Platform	WHOI
Description	Experiments and analyses carried out in Anne Cohen's lab at Woods Hole Oceanographic Institution (WHOI) as part of the project "An Investigation of the Role of Nutrition in the Coral Calcification Response to Ocean Acidification". See: Project description from Cohen Lab

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Project Information

An Investigation of the Role of Nutrition in the Coral Calcification Response to Ocean Acidification (OA Nutrition and Coral Calcification)

Coverage: global; experimental

The project description is a modification of the original NSF award abstract.

This research project is part of the larger NSF funded CRI-OA collaborative research initiative and was funded as an Ocean Acidification-Category 1, 2010 award. Over the course of this century, all tropical coral reef ecosystems, whether fringing heavily populated coastlines or lining remote islands and atolls, face unprecedented threat from ocean acidification caused by rising levels of atmospheric CO2. In many laboratory experiments conducted to date, calcium carbonate production (calcification) by scleractinian (stony) corals showed an inverse correlation to seawater saturation state OMEGAar), whether OMEGAar was manipulated by acid or CO2 addition. Based on these data, it is predicted that coral calcification rates could decline by up to 80% of modern values by the end of this century. A growing body of new experimental data however, suggests that the coral calcification response to ocean acidification may be less straightforward and a lot more variable than previously recognized. In at least 10 recent experiments including our own, 8 different tropical and temperate species reared under nutritionally-replete but significantly elevated CO2 conditions (780-1200 ppm, OMEAGar ~1.5-2), continued to calcify at rates comparable to conspecifics reared under ambient CO2. These experimental results are consistent with initial field data collected on reefs in the eastern Pacific and southern Oman, where corals today live and accrete their skeletons under conditions equivalent to 2X and 3X pre-industrial CO2. On these high CO2, high nutrient reefs (where nitrate concentrations typically exceed 2.5 micro-molar), coral growth rates rival, and sometimes even exceed, those of conspecifics in low CO2, oligotrophic reef environments.

The investigators propose that a coral's energetic status, tightly coupled to the availability of inorganic nutrients and/or food, is a key factor in the calcification response to CO2-induced ocean acidification. Their hypothesis, if confirmed by the proposed laboratory investigations, implies that predicted changes in coastal and open ocean nutrient concentrations over the course of this century, driven by both climate impacts on ocean stratification and by increased human activity in coastal regions, could play a critical role in exacerbating and in some areas, modulating the coral reef response to ocean acidification. This research program builds on the investigators initial results and observations. The planned laboratory experiments will test the hypothesis that: (1) The coral calcification response to ocean acidification is linked to the energetic status of the coral host. The relative contribution of symbiont photosynthesis and heterotrophic feeding to a coral's energetic status varies amongst species. Enhancing the energetic status of corals reared under high CO2, either by stimulating photosynthesis with inorganic nutrients or by direct heterotrophic feeding of the host lowers the sensitivity of calcification to decreased seawater OMEGAar; (2) A species-specific threshold CO2 level exists over which enhanced energetic status can no longer compensate for decreased OMEGAar of the external seawater. Similarly, we will test the hypothesis that a nutrient threshold exists over which nutrients become detrimental for calcification even under high CO2 conditions; and (3) Temperature-induced reduction of algal symbionts is one stressor that can reduce the energetic reserve of the coral host and exacerbate the calcification response to ocean acidification.

The investigator's initial findings highlight the critical importance of energetic status in the coral calcification response to ocean acidification. Verification of these findings in the laboratory, and identification of nutrient and CO2 thresholds for a range of species will have immediate, direct impact on predictions of reef resilience in a high CO2 world. The research project brings together a diverse group of expertise in coral biogeochemistry, chemical oceanography, molecular biology and coral reproductive ecology to focus on a problem that has

enormous societal, economic and conservation relevance.

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Program Information

Science, Engineering and Education for Sustainability NSF-Wide Investment (SEES): Ocean Acidification (formerly CRI-OA) (SEES-OA)

Website: https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503477

Coverage: global

NSF Climate Research Investment (CRI) activities that were initiated in 2010 are now included under Science, Engineering and Education for Sustainability NSF-Wide Investment (SEES). SEES is a portfolio of activities that highlights NSF's unique role in helping society address the challenge(s) of achieving sustainability. Detailed information about the SEES program is available from NSF (https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504707).

In recognition of the need for basic research concerning the nature, extent and impact of ocean acidification on oceanic environments in the past, present and future, the goal of the SEES: OA program is to understand (a) the chemistry and physical chemistry of ocean acidification; (b) how ocean acidification interacts with processes at the organismal level; and (c) how the earth system history informs our understanding of the effects of ocean acidification on the present day and future ocean.

Solicitations issued under this program:
NSF 10-530, FY 2010-FY2011
NSF 12-500, FY 2012
NSF 12-600, FY 2013
NSF 13-586, FY 2014
NSF 13-586 was the final solicitation that will be released for this program.

PI Meetings:
1st U.S. Ocean Acidification PI Meeting(March 22-24, 2011, Woods Hole, MA)
2nd U.S. Ocean Acidification PI Meeting(Sept. 18-20, 2013, Washington, DC)
3rd U.S. Ocean Acidification PI Meeting (June 9-11, 2015, Woods Hole, MA – Tentative)

NSF media releases for the Ocean Acidification Program:

Press Release 10-186 NSF Awards Grants to Study Effects of Ocean Acidification

Discovery Blue Mussels "Hang On" Along Rocky Shores: For How Long?

Discovery nsf.gov - National Science Foundation (NSF) Discoveries - Trouble in Paradise: Ocean Acidification This Way Comes - US National Science Foundation (NSF)

Press Release 12-179 nsf.gov - National Science Foundation (NSF) News - Ocean Acidification: Finding New Answers Through National Science Foundation Research Grants - US National Science Foundation (NSF)

Press Release 13-102 World Oceans Month Brings Mixed News for Oysters

Press Release 13-108 nsf.gov - National Science Foundation (NSF) News - Natural Underwater Springs Show How Coral Reefs Respond to Ocean Acidification - US National Science Foundation (NSF)

Press Release 13-148 Ocean acidification: Making new discoveries through National Science Foundation research grants

Press Release 13-148 - Video nsf.gov - News - Video - NSF Ocean Sciences Division Director David Conover answers questions about ocean acidification. - US National Science Foundation (NSF)

Press Release 14-010 nsf.gov - National Science Foundation (NSF) News - Palau's coral reefs surprisingly resistant to ocean acidification - US National Science Foundation (NSF)

Press Release 14-116 nsf.gov - National Science Foundation (NSF) News - Ocean Acidification: NSF awards $11.4 million in new grants to study effects on marine ecosystems - US National Science Foundation (NSF)

Ocean Carbon and Biogeochemistry (OCB)

Website: http://us-ocb.org/

Coverage: Global

The Ocean Carbon and Biogeochemistry (OCB) program focuses on the ocean's role as a component of the global Earth system, bringing together research in geochemistry, ocean physics, and ecology that inform on and advance our understanding of ocean biogeochemistry. The overall program goals are to promote, plan, and coordinate collaborative, multidisciplinary research opportunities within the U.S. research community and with international partners. Important OCB-related activities currently include: the Ocean Carbon and Climate Change (OCCC) and the North American Carbon Program (NACP); U.S. contributions to IMBER, SOLAS, CARBOOCEAN; and numerous U.S. single-investigator and medium-size research projects funded by U.S. federal agencies including NASA, NOAA, and NSF.

The scientific mission of OCB is to study the evolving role of the ocean in the global carbon cycle, in the face of environmental variability and change through studies of marine biogeochemical cycles and associated ecosystems.

The overarching OCB science themes include improved understanding and prediction of: 1) oceanic uptake and release of atmospheric CO2 and other greenhouse gases and 2) environmental sensitivities of biogeochemical cycles, marine ecosystems, and interactions between the two.

The OCB Research Priorities (updated January 2012) include: ocean acidification; terrestrial/coastal carbon fluxes and exchanges; climate sensitivities of and change in ecosystem structure and associated impacts on biogeochemical cycles; mesopelagic ecological and biogeochemical interactions; benthic-pelagic feedbacks on biogeochemical cycles; ocean carbon uptake and storage; and expanding low-oxygen conditions in the coastal and open oceans.

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Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-1041052
NSF Division of Ocean Sciences (NSF OCE)	OCE-1041106

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