Experimental study to estimate per capita sea urchin (Strongylocentrotus polyacanthus) grazing rates on the alga Clathromorphum nereostratum as a function of seawater temperature and pCO2 concentration

Website: https://www.bco-dmo.org/dataset/755735
Data Type: experimental
Version: 1
Version Date: 2019-02-13

Project
» Ocean Acidification: Century Scale Impacts to Ecosystem Structure and Function of Aleutian Kelp Forests (OA Kelp Forest Function)

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

Contributors	Affiliation	Role
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Abstract
Estimates of per capita sea urchin (Strongylocentrotus polyacanthus) grazing rates on the alga Clathromorphum nereostratum, evaluated as a function of seawater temperature and pCO2 concentration that each were simultaneously cultured in for three months. Incubations and assays were performed in a controlled mesocosm setting.

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Coverage

Temporal Extent: 2016-01-14 - 2016-02-04

Dataset Description

Estimates of *per capita* sea urchin (*Strongylocentrotus polyacanthus)* grazing rates on the alga *Clathromorphum nereostratum*, evaluated as a function of seawater temperature and pCO2 concentration that each were simultaneously cultured in for three months. Incubations and assays were performed in a controlled mesocosm setting.

Methods & Sampling

To evaluate whether rates of sea urchin grazing on C. nereostratum have changed or will change with ocean warming and acidification, we cultured C. nereostratum and S. polyacanthus under experimental conditions mimicking past, present, and predicted future levels of ocean temperature and pCO2 in the region, then followed this three-month culturing period with a controlled feeding experiment conducted under the same conditions. Small C. nereostratum colonies (~4-5 cm diameter) and large S. polyacanthus (~45-60 mm test diameter) were live collected from Adak in 2015 and immediately transported to the Northeastern University Marine Science Center in Nahant, Massachusetts. There, all specimens were acclimated to laboratory conditions at 8.5 °C for two weeks, after which individual C. nereostratum colonies were attached to the underside of plastic petri dishes using cyanoacrylate glue and then allowed to acclimate for an additional two weeks before being moved to experimental aquaria. Conditions were then incrementally modified to achieve target temperature and pCO2 levels (see below) over a one-week period. After reaching target conditions, each 42-L aquarium was dosed with 213 mL of calcein fluorescent dye (Western Chemicals Inc.), which was recirculated in the aquaria for three days and then flushed from the system. Coralline algae incorporate the dye into their skeleton, thus creating a distinct line that can be viewed via fluorescent microscopy to demark the region of new growth within each individual.

We employed four pCO2 conditions and three temperatures that, while factorially crossed, spanned pre-industrial, present-day, and projected year 2100 conditions (assuming an IPCC "business as usual" carbon emissions scenario; Pachauri and Meyer 2014). More extreme temperature (12.5 degrees C) and pCO2 (2800 micro-atm) conditions were also employed in the broader experiment but were not included in our experimental feeding assay because they are not predicted to occur until year 2500, or later. For each treatment, we set temperature to average summertime conditions, the time when ~75% of C. nereostratum growth occurs (Adey et al. 2013).

All treatments (4 pCO2 concentrations x 3 temperatures, fully factorial) were housed on individual shelves and consisted of three 42-liter acrylic aquaria and one 65-liter sump (n = 3 tanks/treatment). The aquaria were connected to a sump via a common overflow and return line but were each independently and continuously replenished with new seawater-thereby establishing them as true experimental replicates. The sump contained a filter box with a nylon mesh particle filter and activated carbon, a protein skimmer (Eshopps PSK-75), and a return pump, all of which was connected to a water chiller (Coralife 1/4HP). Filtered natural seawater was added via Darhor manual flow controllers at a rate of 50 mL/min/tank, resulting in full replacement of treatment water every ~21 hours-sufficiently fast to prevent material depletion of the dissolved constituents of the seawater yet slow enough to allow the mixed gases being sparged into the experimental treatments to approach equilibrium with the seawater. Mixed gases were sparged into each tank with 91 cm long flexible bubblers at the rate of ~1 L/min via Darhor needle-valve gas flow controllers. Two 12,000K LED light arrays (Ecoxotic Panorama, Pro 24V) were mounted above each tank and set to an irradiance that mirrored average summer daylight irradiance at 10 m depth in the Aleutian Islands (~258 micro-E m-2 s-1; 12 hr light:12 hr dark cycle).

Over the course of the four-month experiment, we measured pH (Accumet AB15 pH meter with Accufet solid state probe), salinity (YSI3200 meter with K=10 conductivity electrode and temperature probe), and temperature (NIST traceable red spirit glass thermometer) in each tank every Monday, Wednesday, and Friday. The pCO2 of the gas mixtures was measured with a Qubit S151 infrared CO2 analyzer and calibrated with certified mixed CO2 from Airgas Incorporated. Every 10 days, we characterized the full carbonate system chemistry of the experimental treatments from measured total alkalinity, dissolved inorganic carbon, temperature, and salinity. For this, seawater samples were obtained in 250 mL borosilicate ground-glass-stoppered bottles and immediately poisoned with 100 micro-L of saturated HgCl2 solution to halt biological activity (Dickson et al. 2007). Total alkalinity was measured via closed-cell potentiometric Gran titration and dissolved inorganic carbon was measured with a UIC 5400 Coulometer on a VINDTA 3C (Marianda Incorporated) using Dickson certified seawater reference material. Seawater pCO2, pH, carbonate ion concentration ([CO32-]) bicarbonate ion concentration ([HCO3-]), aqueous CO2, and calcite saturation state were calculated with the program CO2SYS (Lewis and Wallace 1998), using Roy and colleague's (1993) values for the K1 and K2 carbonic acid constants, the Mucci (1983) value for the stoichiometric calcite solubility product, the seawater pH scale, and an atmospheric pressure of 1.015 atm.

At the beginning of the experiment we measured the buoyant weight of each specimen. We then scrubbed each specimen with a toothbrush and reweighed it every month and at the end of the experiment. With each weighing, we also photographed the specimen with a ruler and Reef Watch coral bleaching card in the field of view. We then measured the 2-d surface area (coralline algae) or test diameter (urchin) of the photographed

specimens (Image J, NIH). Following a three-month incubation, a subset of the coralline algae was placed individually in cages and paired with a single urchin to quantify bioerosion rate under the different treatments, while the remaining algae were retained as experimental controls during the 20-day feeding experiment, and subsequently measured for skeletal density. Following the feeding experiment, all coralline algae were sectioned with a diamond lapidary saw (Inland Craft SwapTop 6.5" Diamond Trim Saw) and either frozen for genetic analysis or sectioned into 6 mm slices, rinsed in a series of two 90% Ethanol baths, and allowed to air dry for further examination of growth and skeletal density.

After three months of culturing C. nereostratum and large S. polyacanthus (mean test diameter ± SE = 53 ± 1 mm) under various temperature and pCO2 conditions (see above), we conducted a controlled feeding assay. Individual coralline algae were randomly paired with sea urchins from the same tank and placed into small cages (n = 5/tank, 15/treatment) and returned to aquaria, with the remaining coralline algae from each tank serving as controls. Buoyant weight measurements and photographs of each alga and urchin were obtained at the beginning of the experiment (as described above) and again every five days. We excluded replicates where: (i) the sea urchin appeared moribund or died during the assay; or (ii) negligible grazing occurred throughout the experiment, indicating severe stress to the animal. Buoyant weights were converted to dry weight (mg) using an empirically-derived conversion factor (linear regression: -0.117448 + 1.746361 * buoyant mass; adjusted $R^2 = 0.9996$; $p < 0.001$). To calculate the amount of C. nereostratum (mg $CaCO_3$ dry weight) consumed by each urchin at each sampling interval while also accounting for the potential gain or loss of mass within the treatment alga, we used the equation [Ti x (Cf/Ci)] - Tf, where Ti and Tf is the initial and final mass (respectively) of an alga exposed to herbivory, and Ci and Cf is the initial and final mass (respectively) of its paired control. For this exercise, we averaged correction factors (Cf/Ci) for all control algae in a given tank, and applied this average correction factor to each treatment alga in the same tank. We then computed grazing rate (amount consumed/day) for each sea urchin, as well as per capita grazing rates standardized by the surface area of C. nereostratum.

Data Processing Description

BCO-DMO Processing Notes:
- added conventional header with dataset name, PI name, version date
- modified parameter names to conform with BCO-DMO naming conventions
- re-formatted date from m/d/yyyy to yyyy-mm-dd

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Data Files

File	
lab_urchin_grazing_assay_fx_temp_pCO2.csv	(Comma Separated Values (.csv), 49.74 KB) MD5:0f0df35a187fb1bc6cdfc8b315290332
Primary data file for dataset ID 755735	

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Related Publications

Adey, W. H., Halfar, J., & Williams, B. (2013). The coralline genus Clathromorphum Foslie emend. Adey: biological, physiological, and ecological factors controlling carbonate production in an arctic-subarctic climate archive. Smithsonian Contributions to Marine Science 40, 1-41 https://hdl.handle.net/10088/21560
Methods

Dickson, A.G., Sabine, C.L. and Christian, J.R. (Eds.) 2007. Guide to best practices for ocean CO2 measurements. PICES Special Publication 3, 191 pp. ISBN: 1-897176-07-4. URL: https://www.nodc.noaa.gov/ocads/oceans/Handbook_2007.html https://hdl.handle.net/11329/249
Methods

Lewis, E., Wallace, D., & Allison, L. J. (1998). Program developed for CO2 system calculations (No. ORNL/CDIAC-105). Brookhaven National Lab., Dept. of Applied Science, Upton, NY (United States); Oak Ridge

National Lab., Carbon Dioxide Information Analysis Center, TN (United States). doi: 10.2172/639712
Methods

Mucci, A. (1983). The solubility of calcite and aragonite in seawater at various salinities, temperatures, and one atmosphere total pressure. American Journal of Science, 283(7), 780-799. doi:10.2475/ajs.283.7.780
Methods

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., ... & Dubash, N. K. (2014). Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (p. 151). IPCC.
https://hdl.handle.net/10013/epic.45156
Methods

Roy, R. N., Roy, L. N., Vogel, K. M., Porter-Moore, C., Pearson, T., Good, C. E., Millero, F. J., Campbell, D. M. (1993). The dissociation constants of carbonic acid in seawater at salinities 5 to 45 and temperatures 0 to 45°C. Marine Chemistry, 44(2-4), 249-267. doi:10.1016/0304-4203(93)90207-5
Methods

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Parameters

Parameter	Description	Units
treatment_temp	target temperature	degrees Celsius
treatment_pCO2	target pCO2 concentration	microatmospheres (uatm)
tank	replicate tank identifier	unitless
tank_temp_ave	average tank temperature during study	degrees Celsius
tank_pCO2_ave	average tank pCO2 concentration during study	microatmospheres (uatm)
replicate	replicate individual urchin or alga	unitless
treatment_grazing	treatment = coralline alga exposed to herbivory; control = no herbivory	unitless
urchin_diameter_mm	size (test diameter) of sea urchin	millimeters
cca_surface_area_cm2	surface area of coralline alga	square centimeters (cm^2)
date_T0	date of sampling at timepoint T0; formatted as yyyy-mm-dd	unitless
sampling_time_T0	time of sampling (24 hr clock) (HH:MM)	unitless
standard_ave_grams_T0	average mass of experimental standard at time point x	grams
sample_mass_grams_T0	average mass of coralline alga at time x	grams
date_T5	date of sampling; formatted as yyyy-mm-dd	unitless
sampling_time_T5	time of sampling (24 hr clock) (HH:MM)	unitless
duration_days_T5	duration of assay at timepoint T0	days
standard_ave_grams_T5	average mass of eT0perimental standard at time point T0	grams
sample_mass_grams_T5	average mass of coralline alga at time T0	grams
correction_factor_T5	correction factor; computed by dividing the final mass of the control alga (at time T0) by its initial mass (at time T0)	unitless

ave_correction_factor_T5	the average correction factor computed for all control coralline algae in a given tank at time T0	unitless
corrected_initial_mass_grams_T5	sample.mass.grams.T0 * ave.correction.factor.T0	grams
amount_mg_consumed_T5	the total amount of coralline algae consumed by a sea urchin at time T0; computed by subtracting sample.mass.grams.T0 from corrected.initial.mass.grams.T0; then * 1000	milligrams
amount_mg_consumed_day_T5	rate of algal consumption (per day); computed by dividing amount.mg.consumed.T0 by duration.days	milligrams
amount_mg_consumed_cm2_day_T5	rate of algal consumption (per day); standardized by the surface area of the coralline alga (using cca.surface.area.cm^2)	milligrams
date_10	date of sampling at timepoint T5; formatted as yyyy-mm-dd	unitless
sampling_time_10	time of sampling (24 hr clock) (HH:MM)	unitless
duration_days_10	duration of assay at timepoint T10	days
standard_ave_grams_T10	average mass of eT10perimental standard at time point T10	grams
sample_mass_grams_T10	average mass of coralline alga at time T10	grams
correction_factor_T10	correction factor; computed by dividing the final mass of the control alga (at time T10) by its initial mass (at time T0)	unitless
ave_correction_factor_T10	the average correction factor computed for all control coralline algae in a given tank at time T10	unitless
corrected_initial_mass_grams_T10	sample.mass.grams.T0 * ave.correction.factor.T10	grams
amount_mg_consumed_T10	the total amount of coralline algae consumed by a sea urchin at time T10; computed by subtracting sample.mass.grams.T10 from corrected.initial.mass.grams.T10; then * 1000	milligrams
amount_mg_consumed_day_T10	rate of algal consumption (per day); computed by dividing amount.mg.consumed.T10 by duration.days	milligrams
amount_mg_consumed_cm2_day_T10	rate of algal consumption (per day); standardized by the surface area of the coralline alga (using cca.surface.area.cm^2)	milligrams
date_T15	date of sampling at timepoint T15; formatted as yyyy-mm-dd	unitless
sampling_time_T15	time of sampling (24 hr clock) (HH:MM)	unitless
duration_days_T15	duration of assay at timepoint T15	days
standard_ave_grams_T15	average mass of eT15perimental standard at time point T15	grams
sample_mass_grams_T15	average mass of coralline alga at time T15	grams
correction_factor_T15	correction factor; computed by dividing the final mass of the control alga (at time T15) by its initial mass (at time T0)	unitless
ave_correction_factor_T15	the average correction factor computed for all control coralline algae in a given tank at time T15	unitless

corrected_initial_mass_grams_T15	sample.mass.grams.T0 * ave.correction.factor.T15	grams
amount_mg_consumed_T15	the total amount of coralline algae consumed by a sea urchin at time T15; computed by subtracting sample.mass.grams.T15 from corrected.initial.mass.grams.T15; then * 1000	milligrams
amount_mg_consumed_day_T15	rate of algal consumption (per day); computed by dividing amount.mg.consumed.T15 by duration.days	milligrams
amount_mg_consumed_cm2_day_T15	rate of algal consumption (per day); standardized by the surface area of the coralline alga (using cca.surface.area.cm^2)	milligrams
date_T20	date of sampling at timepoint T20; formatted as yyyy-mm-dd	unitless
sampling_time_T20	time of sampling (24 hr clock) (HH:MM)	unitless
duration_days_T20	duration of assay at timepoint T20	days
standard_ave_grams_T20	average mass of eT20perimental standard at time point T20	grams
sample_mass_grams_T20	average mass of coralline alga at time T20	grams
correction_factor_T20	correction factor; computed by dividing the final mass of the control alga (at time T20) by its initial mass (at time T0)	unitless
ave_correction_factor_T20	the average correction factor computed for all control coralline algae in a given tank at time T20	unitless
corrected_initial_mass_grams_T20	sample.mass.grams.T0 * ave.correction.factor.T20	grams
amount_mg_consumed_T20	the total amount of coralline algae consumed by a sea urchin at time T20; computed by subtracting sample.mass.grams.T20 from corrected.initial.mass.grams.T20; then * 1000	milligrams
amount_mg_consumed_day_T20	rate of algal consumption (per day); computed by dividing amount.mg.consumed.T20 by duration.days	milligrams
amount_mg_consumed_cm2_day_T20	rate of algal consumption (per day); standardized by the surface area of the coralline alga (using cca.surface.area.cm^2)	milligrams

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Instruments

Dataset-specific Instrument Name	Coralife 1/4HP
Generic Instrument Name	Aquarium chiller
Generic Instrument Description	Immersible or in-line liquid cooling device, usually with temperature control.

Dataset-specific Instrument Name	Accumet AB15 pH meter with Accufet solid state probe
Generic Instrument Name	Benchtop pH Meter
Dataset-specific Description	To measure pH of tanks
Generic Instrument Description	An instrument consisting of an electronic voltmeter and pH-responsive electrode that gives a direct conversion of voltage differences to differences of pH at the measurement temperature. (McGraw-Hill Dictionary of Scientific and Technical Terms) This instrument does not map to the NERC instrument vocabulary term for 'pH Sensor' which measures values in the water column. Benchtop models are typically employed for stationary lab applications.

Dataset-specific Instrument Name	Qubit S151 infrared CO2 analyzer
Generic Instrument Name	CO2 Analyzer
Dataset-specific Description	To measure pCO2 in tanks
Generic Instrument Description	Measures atmospheric carbon dioxide (CO2) concentration.

Dataset-specific Instrument Name	UIC 5400 Coulometer on a VINDTA 3C
Generic Instrument Name	CO2 Coulometer
Dataset-specific Description	To measure dissolved inorganic carbon
Generic Instrument Description	A CO2 coulometer semi-automatically controls the sample handling and extraction of CO2 from seawater samples. Samples are acidified and the CO2 gas is bubbled into a titration cell where CO2 is converted to hydroxyethylcarbonic acid which is then automatically titrated with a coulometrically-generated base to a colorimetric endpoint.

Dataset-specific Instrument Name	
Generic Instrument Name	MARIANDA VINDTA 3C total inorganic carbon and titration alkalinity analyser
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	Darhor manual flow controllers
Generic Instrument Name	Mass Flow Controller
Generic Instrument Description	Mass Flow Controller (MFC) - A device used to measure and control the flow of fluids and gases

Dataset-specific Instrument Name	YSI3200 meter with K=10 conductivity electrode and temperature probe
Generic Instrument Name	Salinometer
Dataset-specific Description	To measure salinity and temperature of tanks
Generic Instrument Description	A salinometer is a device designed to measure the salinity, or dissolved salt content, of a solution.

Dataset-specific Instrument Name	NIST traceable red spirit glass thermometer
Generic Instrument Name	Thermometer
Dataset-specific Description	To measure temperature in the tanks
Generic Instrument Description	A device designed to measure temperature.

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Project Information

Ocean Acidification: Century Scale Impacts to Ecosystem Structure and Function of Aleutian Kelp Forests (OA Kelp Forest Function)

Extracted from the NSF award abstract:

Marine calcifying organisms are most at risk to rapid ocean acidification (OA) in cold-water ecosystems. The investigators propose to determine if a globally unique and widespread calcareous alga in Alaska's Aleutian archipelago, *Clathromorphum nereostratum*, is threatened with extinction due to the combined effects of OA and food web alterations. *C. nereostratum* is a slow growing coralline alga that can live to at least 2000 years. It accretes massive 'bioherms' that dominate the regions' rocky substrate both under kelp forests and deforested sea urchin barrens. It develops growth bands (similar to tree rings) in its calcareous skeleton, which effectively record its annual calcification rate over centuries. Pilot data suggest the skeletal density of *C. nereostratum* began to decline precipitously in the 1990's in some parts of the Aleutian archipelago. The investigators now propose to use high-resolution microscopy and microCT imaging to examine how the growth and skeletal density of *C. nereostratum* has changed in the past 300 years (i.e., since the industrial revolution) across the western Aleutians. They will compare their records of algal skeletal densities and their variation through time with reconstructions of past climate to infer causes of change. In addition, the investigators will examine whether the alga's defense against grazing by sea urchins is compromised by ongoing ocean acidification. The investigators will survey the extent of *C. nereostratum* bioerosion occurring at 10 sites spanning the western Aleutians, both inside and outside of kelp forests. At each site they will compare these patterns to observed and monitored ecosystem trophic structure and recent *C. nereostratum* calcification rates. Field observations will be combined with laboratory experiments to determine if it is a decline in the alga's skeletal density (due to recent OA and warming), an increase in grazing intensity (due to recent trophic-level dysfunction), or their interactive effects that are likely responsible for bioerosion patterns inside vs. outside of forests. By sampling *C. nereostratum* inside and outside of forests, they will determine if kelp forests locally increase pH via photosynthesis, and thus buffer the effects of OA on coralline calcification. The combination of field observations with laboratory controlled experiments, manipulating CO2 and temperature, will help elucidate drivers of calcification and project how these species interactions will likely change in the near future. The project will provide the first in situ example of how ongoing ocean acidification is affecting the physiology of long-lived, carbonate producing organisms in the subarctic North Pacific. It will also be one of the first studies to document whether OA, ocean warming, and food web changes to ecological processes are

interacting in complex ways to reshape the outcome of species interactions in nature.

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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)

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Funding

Funding Source	Award
NSF Arctic Sciences (NSF ARC)	PLR-1316141

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