Seasonal hydrography, abundance, and distribution of pteropods from MOCNESS and CTD casts during R/V Tioga cruises in the Gulf of Maine from 2013 to 2015

Website: https://www.bco-dmo.org/dataset/780874
Version: 1
Version Date: 2019-11-05

Project
» Seasonal and Ontogenetic Effects of Ocean Acidification on Pteropods in the Gulf of Maine (Gulf of Maine Pteropods)

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

Contributors	Affiliation	Role
Maas, Amy	Woods Hole Oceanographic Institution (WHOI)	Principal Investigator
Lawson, Gareth	Woods Hole Oceanographic Institution (WHOI)	Co-Principal Investigator
Tarrant, Ann M.	Woods Hole Oceanographic Institution (WHOI)	Co-Principal Investigator
York, Amber D.	Woods Hole Oceanographic Institution (WHOI BCO-DMO)	BCO-DMO Data Manager

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Coverage

Spatial Extent: **N**:42.4193 **E**:-69.7127 **S**:42.3153 **W**:-69.7941
Temporal Extent: 2013-05 - 2015-07

Dataset Description

Seasonal hydrography, abundance, and distribution of pteropods from MOCNESS and CTD casts during R/V Tioga cruises in the Gulf of Maine from 2013 to 2015.

These data were published in Maas et al. (2018) and Maas et al. (in review).

Related Datasets:
* Pteropod shell quality: https://www.bco-dmo.org/dataset/780791
* Pteropod respiration experiments: https://www.bco-dmo.org/dataset/780886

Methods & Sampling

Methodology:

Abundance and distributional sampling of pteropods was conducted in the western Gulf of Maine (GoM) at Murray Basin (42 21’ N and 69 47’ W) on various cruises aboard the R/V Tioga. During each cruise, vertically stratified net and hydrographic sampling was conducted using a standard 1/4-m2 Multiple Opening/Closing Net and Environmental Sensing System (MOCNESS; Wiebe et al., 1985) with 150-m mesh nets that was towed at 8 discrete depths throughout the water column. All net tows were conducted during daylight hours. The upper nets consistently targeted 0–25, 25–50, 50–75, 75–100, and 100–150 m. The depths of the lower three nets were chosen adaptively during each cruise based on transmissometer profiles such that the deepest two nets sampled exclusively within the benthic nepheloid layer, in order to examine any associations of pteropods with the particular chemistry of this bottom resuspension zone (see Wang et al. 2017). Zooplankton samples were preserved in 70% ethanol for later enumeration and size classification. In the lab, splits of each MOCNESS net sample were examined under a lighted stereomicroscope and L. retroversa were enumerated based on size class (<0.5 mm, 0.5-1 mm, 1-3 mm and >3 mm) based on the generalized developmental stage size categories developed by Hsiao (1939).

CTD casts were also routinely conducted at the Murray Basin site using 3-L Niskin bottles and a SBE3/SBR4 sensor set, to characterizing the local hydrography (salinity, temperature, fluorescence, dissolved oxygen, and beam transmission) and carbonate chemistry. Depths for bottle sampling were chosen based on station water depth with a typical profile sampling the upper 100 m depths at 10 m intervals, the 100-200 m depths at 20 m intervals, and less frequently below. Samples for dissolved inorganic carbon (DIC) and total alkalinity (TA) were collected in 250 mL Pyrex borosilicate glass bottles following the best practice of seawater CO2 measurements (Dickson et al. 2007). Air head space of about one percent of the bottle volume was left to allow room for expansion. Each sample was then poisoned with 100 L of saturated mercuric chloride, capped with an Apiezon-L greased stopper, thoroughly mixed, and then tied with a rubber band over the glass stopper.

Sampling and analytical procedures:

For lab measurements of carbonate chemistry, DIC was measured using an Apollo SciTech DIC auto-analyzer, while TA was measured using an Apollo SciTech alkalinity auto-titrator, a Ross combination pH electrode, and a pH meter (ORION 3 Star) based on a modified Gran titration method (detailed in Wang et al., 2017). pH and aragonite saturation state (ΩAr) were calculated from bottle sample measurements and concurrent temperature and salinity measures from the CTD cast using the CO2SYS program by Pierrot et al. (2006) with constants from Mehrbach (1973) as refit by Dickson and Millero (1987).

Data Processing Description

CO2sys_v2.1

Problem report: There were a few cruises where instrumentation on the MOCNESS malfunctioned (the O2 sensor or transmissometer).

BCO-DMO Data Manager Processing Notes:
* Excel file exported as csv
* added a conventional header with dataset name, PI name, version date
* modified parameter names to conform with BCO-DMO naming conventions
* blank values in this dataset are displayed as "nd" for "no data." nd is the default missing data identifier in the BCO-DMO system.
* ISO_DateTime_UTC_Start added from year, month, day, time start (local) columns.
* Lat and Long converted to decimal degrees and rounded to four decimal places.

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Data Files

File
pter_dist.csv(Comma Separated Values (.csv), 21.16 KB) MD5:b7edaca6ab2852ca76b292ddff4fed7d Primary data file for dataset ID 780874

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Related Publications

Dickson, A. G., & Millero, F. J. (1987). A comparison of the equilibrium constants for the dissociation of carbonic acid in seawater media. Deep Sea Research Part A. Oceanographic Research Papers, 34(10), 1733–1743. doi:10.1016/0198-0149(87)90021-5
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

Maas, A. E., Lawson, G. L., Bergan, A. J., & Tarrant, A. M. (2017). Exposure to CO2influences metabolism, calcification and gene expression of the thecosome pteropodLimacina retroversa. The Journal of Experimental Biology, 221(3), jeb164400. doi:10.1242/jeb.164400
General

Maas, A. E., Lawson, G. L., Bergan, A. J., Wang, Z. A., & Tarrant, A. M. (2020). Seasonal variation in physiology and shell condition of the pteropod Limacina retroversa in the Gulf of Maine relative to life cycle and carbonate chemistry. Progress in Oceanography, 186, 102371. https://doi.org/10.1016/j.pocean.2020.102371
General

Mehrbach, C., Culberson, C. H., Hawley, J. E., & Pytkowicx, R. M. (1973). Measurement of the apparent dissociation constants of carbonic acid in seawater at atmospheric pressure. Limnology and Oceanography, 18(6), 897–907. doi:10.4319/lo.1973.18.6.0897
Methods

Pierrot, D. E. Lewis,and D. W. R. Wallace. 2006. MS Excel Program Developed for CO2 System Calculations. ORNL/CDIAC-105a. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee. doi: 10.3334/CDIAC/otg.CO2SYS_XLS_CDIAC105a.
Methods

Wang, Z. A., Lawson, G. L., Pilskaln, C. H., & Maas, A. E. (2017). Seasonal controls of aragonite saturation states in the Gulf of Maine. Journal of Geophysical Research: Oceans, 122(1), 372–389. doi:10.1002/2016jc012373 https://doi.org/10.1002/2016JC012373
Methods

Wiebe, P. H., Morton, A. W., Bradley, A. M., Backus, R. H., Craddock, J. E., Barber, V., … Flierl, G. R. (1985). New development in the MOCNESS, an apparatus for sampling zooplankton and micronekton. Marine Biology, 87(3), 313–323. doi:10.1007/bf00397811 https://doi.org/10.1007/BF00397811
Methods

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Parameters

Parameter	Description	Units
Year	Year for cruise of collection	unitless
Day	Month for cruise of collection	unitless
Month	Month for cruise of collection	unitless
Net_ID	Mocness sample ID	unitless
Cruise	Tioga cruise number	unitless

Lat	Latitude	decimal degrees
Long	Longitude	decimal degrees
TimeStart_local	Time (local EST/EDT) in format HHMM	unitless
ISO_DateTime_UTC_Start	Timestamp (UTC) in standard ISO 8601 format YYYY-mm-ddTHH:MMZ	unitless
max	max depth of net	meters (m)
min	min depth of net	meters (m)
Net	net ID	unitless
volume_filtered	volume filtered in MOCNESS tow	cubic meters (m3)
Salinity	average salinity of the MOCNESS net	Practical Salinity Units (PSU)
Pressure	average pressure of the MOCNESS net	decibars (db)
Fluorescence	average fluorescence of the MOCNESS net	milligrams per cubic meter (mg m-3)
Temperature	average temperature of the MOCNESS net	degrees Celsius (C)
Turbidity	average turbidity of the MOCNESS net	Formazin Turbidity Units (FTU)
Oxygen	average oxygen of the MOCNESS net	micromoles per kilogram (umol kg-1)
Beam_Transmission	average transmissivity of the MOCNESS net	percent (%)
DIC	average DIC from CTD bottles sampled within the range of the MOCNESS net	micromoles per kilogram (umol kg-1)
TA	average total alkalinity (TA) from CTD bottles sampled within the range of the MOCNESS net	micromoles per kilogram (umol kg-1)
pH	calculaed pH (from measured TA,DIC,temp,salinity)	pH scale
Ar	calculaed aragonite saturation state (from measured TA,DIC,temp,salinity)	dimensionless
CO2	calculaed pCO2 (from measured TA,DIC,temp,salinity)	microatmospheres (uatm)
split	portion of net analyzed	dimensionless
all	total pteropod abundance in net	number per cubic meter (#/m3)
lt_0pt5	abundance of pteropods under 0.5 mm	number per cubic meter (#/m3)
from_0pt5_lt_1	abundance of pteropods between 0.5-1 mm	number per cubic meter (#/m3)
from_1_lt_3	abundance of pteropods between 1-3 mm	number per cubic meter (#/m3)
gt_3	abundance of pteropods over 3 mm	number per cubic meter (#/m3)

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Instruments

Dataset-specific Instrument Name	Apollo SciTech DIC auto-analyzer
Generic Instrument Name	Apollo SciTech AS-C3 Dissolved Inorganic Carbon (DIC) analyzer
Generic Instrument Description	A Dissolved Inorganic Carbon (DIC) analyzer, for use in aquatic carbon dioxide parameter analysis of coastal waters, sediment pore-waters, and time-series incubation samples. The analyzer consists of a solid state infrared CO2 detector, a mass-flow controller, and a digital pump for transferring accurate amounts of reagent and sample. The analyzer uses an electronic cooling system to keep the reactor temperature below 3 degrees Celsius, and a Nafion dry tube to reduce the water vapour and keep the analyzer drift-free and maintenance-free for longer. The analyzer can handle sample volumes from 0.1 - 1.5 milliliters, however the best results are obtained from sample volumes between 0.5 - 1 milliliters. It takes approximately 3 minutes per analysis, and measurement precision is plus or minus 2 micromoles per kilogram or higher for surface seawater. It is designed for both land based and shipboard laboratory use.

Dataset-specific Instrument Name	Apollo SciTech alkalinity auto-titrator
Generic Instrument Name	Automatic titrator
Generic Instrument Description	Instruments that incrementally add quantified aliquots of a reagent to a sample until the end-point of a chemical reaction is reached.

Dataset-specific Instrument Name	
Generic Instrument Name	CTD Sea-Bird 9
Dataset-specific Description	CTD casts were also routinely conducted at the Murray Basin site using 3-L Niskin bottles and a SBE3/SBR4 sensor set, to characterizing the local hydrography (salinity, temperature, fluorescence, dissolved oxygen, and beam transmission) and carbonate chemistry.
Generic Instrument Description	The Sea-Bird SBE 9 is a type of CTD instrument package. The SBE 9 is the Underwater Unit and is most often combined with the SBE 11 Deck Unit (for real-time readout using conductive wire) when deployed from a research vessel. The combination of the SBE 9 and SBE 11 is called a SBE 911. The SBE 9 uses Sea-Bird's standard modular temperature and conductivity sensors (SBE 3 and SBE 4). The SBE 9 CTD can be configured with auxiliary sensors to measure other parameters including dissolved oxygen, pH, turbidity, fluorometer, altimeter, etc.). Note that in most cases, it is more accurate to specify SBE 911 than SBE 9 since it is likely a SBE 11 deck unit was used. more information from Sea-Bird Electronics

Dataset-specific Instrument Name	lighted stereomicroscope
Generic Instrument Name	Microscope - Optical
Generic Instrument Description	Instruments that generate enlarged images of samples using the phenomena of reflection and absorption of visible light. Includes conventional and inverted instruments. Also called a "light microscope".

Dataset-specific Instrument Name	
Generic Instrument Name	MOCNESS
Generic Instrument Description	The Multiple Opening/Closing Net and Environmental Sensing System or MOCNESS is a family of net systems based on the Tucker Trawl principle. There are currently 8 different sizes of MOCNESS in existence which are designed for capture of different size ranges of zooplankton and micro-nekton Each system is designated according to the size of the net mouth opening and in two cases, the number of nets it carries. The original MOCNESS (Wiebe et al, 1976) was a redesigned and improved version of a system described by Frost and McCrone (1974).(from MOCNESS manual) This designation is used when the specific type of MOCNESS (number and size of nets) was not specified by the contributing investigator.

Dataset-specific Instrument Name	
Generic Instrument Name	Niskin bottle
Generic Instrument Description	A Niskin bottle (a next generation water sampler based on the Nansen bottle) is a cylindrical, non-metallic water collection device with stoppers at both ends. The bottles can be attached individually on a hydrowire or deployed in 12, 24, or 36 bottle Rosette systems mounted on a frame and combined with a CTD. Niskin bottles are used to collect discrete water samples for a range of measurements including pigments, nutrients, plankton, etc.

Dataset-specific Instrument Name	
Generic Instrument Name	pH Sensor
Dataset-specific Description	Ross combination pH electrode, and a pH meter (ORION 3 Star) based on a modified Gran titration method (detailed in Wang et al., 2017b)
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+).

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Deployments

TI729

Website	https://www.bco-dmo.org/deployment/506265
Platform	R/V Tioga
Report	http://bcodata.whoi.edu/GoME_Pteropods/cruise_reports/Tioga729_Cruise_Report.pdf
Start Date	2014-01-29
End Date	2014-01-30
Description	The central goal of this cruise was to document the abundance and vertical distribution of the pteropod species Limacina retroversa, to capture live individuals for experimentation, and to sample the carbonate chemistry profile of two sites in the Gulf of Maine.

TI746

Website	https://www.bco-dmo.org/deployment/517985
Platform	R/V Tioga
Report	http://bcodata.whoi.edu/GoME_Pteropods/cruise_reports/Tioga746_Cruise_Report_V3.pdf
Start Date	2014-04-25
End Date	2014-04-27
Description	The central goal of this cruise was to document the abundance and vertical distribution of the pteropod species Limacina retroversa, to capture live individuals for experimentation, and to sample the carbonate chemistry profile of two sites in the GoME.

TI777

Website	https://www.bco-dmo.org/deployment/539885
Platform	R/V Tioga
Report	http://bcodata.whoi.edu/GoME_Pteropods/cruise_reports/Tioga777_Cruise_Report.pdf
Start Date	2014-08-19
End Date	2014-08-20
Description	Live capture of pteropod Limacina retroversa for experiments and water sampling for carbonate chemistry profile.

TI787

Website	https://www.bco-dmo.org/deployment/562792
Platform	R/V Tioga
Report	http://bcodata.whoi.edu/GoME_Pteropods/cruise_reports/Tioga787_Cruise_Report.pdf
Start Date	2014-11-04
End Date	2014-11-06
Description	Live capture of pteropod Limacina retroversa for experiments and water sampling for carbonate chemistry profile and MOCNESS tow for later analysis of pteropod community. [underway data not available at this time: 2015-07-28]

TI715

Website	https://www.bco-dmo.org/deployment/472270
Platform	R/V Tioga
Report	http://bcodata.whoi.edu/GoME_Pteropods/cruise_reports/Tioga715_Cruise_Report_final.pdf
Start Date	2013-10-21
End Date	2013-10-23
Description	The central goal of this cruise was to sample the carbonate chemistry profile of two sites in the GoME and to document the abundance and vertical distribution of the pteropod species Limacina retroversa. The long-term goal of this research is to understand forcings by climate, enhanced atmospheric CO2 levels, and coastal eutrophication on seasonal and inter-annual variability in carbonate chemistry of the Gulf of Maine and the associated implications to planktonic calcifiers, notably pteropods. The specific goals of this project are to: 1. Quantify seasonal variations of carbonate system parameters and buffer intensity in deep waters of the Gulf of Maine in order to evaluate the sensitivity of these waters in response to acidification due to anthropogenic forcing, such as increase in atmospheric CO2, freshening of the GoME (decrease in total alkalinity) and increases in water-column respiration due to eutrophication. We will test the hypotheses that deep waters of the GoME are already seasonally under-saturated with respect to aragonite saturation state, and that these waters have low buffer intensity compared to overlying water, which would cause them to be more susceptible to acidification pressures and to reach critical ecological thresholds (OA < 1) more readily. 2. Quantify seasonal patterns in the abundance of the pteropod Limacina retroversa and its vertical distribution relative to concurrent measurements of water column chemical properties, testing the hypothesis that this species is absent in the acidic waters of the near-bottom nepheloid layer. The specific goals of this particular cruise were to: 1. Measure the carbonate chemistry of the water column at multiple sites in the Gulf of Maine, targeting regions where there the depth is greatest and the deep waters are mostly likely to be undersaturated 2. Measure the carbonate chemistry in the nephloid layer 3. Catch pteropods with a vertically stratified net system to quantify their size class, abundance and vertical distribution in the context of the carbonate chemistry. 4. Collect surface water and pteropods to test out methods for shell (70% ethanol), physiology (live) and gene expression studies (RNAlater).

TI668

Website	https://www.bco-dmo.org/deployment/59095
Platform	R/V Tioga
Report	http://bcodata.whoi.edu/GoME_Pteropods/cruise_reports/Tioga668_Cruise_Report_final_Dec.pdf
Start Date	2013-05-21
End Date	2013-05-22
Description	The central goal of this cruise was to sample the carbonate chemistry profile of two sites in the GoME and to document the abundance and vertical distribution of the pteropod species Limacina retroversa. The long-term goal of this research is to understand forcings by climate, enhanced atmospheric CO2 levels, and coastal eutrophication on seasonal and inter-annual variability in carbonate chemistry of the Gulf of Maine and the associated implications to planktonic calcifiers, notably pteropods. The specific goals of this project are to: 1. Quantify seasonal variations of carbonate system parameters and buffer intensity in deep waters of the Gulf of Maine in order to evaluate the sensitivity of these waters in response to acidification due to anthropogenic forcing, such as increase in atmospheric CO2, freshening of the GoME (decrease in total alkalinity) and increases in water-column respiration due to eutrophication. We will test the hypotheses that deep waters of the GoME are already seasonally under-saturated with respect to aragonite saturation state, and that these waters have low buffer intensity compared to overlying water, which would cause them to be more susceptible to acidification pressures and to reach critical ecological thresholds (OA < 1) more readily. 2. Quantify seasonal patterns in the abundance of the pteropod Limacina retroversa and its vertical distribution relative to concurrent measurements of water column chemical properties, testing the hypothesis that this species is absent in the acidic waters of the near-bottom nepheloid layer. The specific goals of this particular cruise were to: 1. Measure the carbonate chemistry of the water column at multiple sites in the Gulf of Maine, targeting regions where there the depth is greatest and the deep waters are mostly likely to be undersaturated 2. Measure the carbonate chemistry in the nephloid layer 3. Catch pteropods with a vertically stratified net system to quantify their size class, abundance and vertical distribution in the context of the carbonate chemistry. 4. Collect surface water and pteropods to test out methods for shell (70% ethanol), physiology (live) and gene expression studies (RNAlater). DMO NOTE: Revised cruise report with updated eventlog submitted 20 Dec. 2013.

TI700

Website	https://www.bco-dmo.org/deployment/472226
Platform	R/V Tioga
Report	http://bcodata.whoi.edu/GoME_Pteropods/cruise_reports/Tioga700_Cruise_Report_final.pdf
Start Date	2013-08-27
End Date	2013-08-28
Description	The central goal of this cruise was to sample the carbonate chemistry profile of two sites in the GoME and to document the abundance and vertical distribution of the pteropod species Limacina retroversa. The long-term goal of this research is to understand forcings by climate, enhanced atmospheric CO2 levels, and coastal eutrophication on seasonal and inter-annual variability in carbonate chemistry of the Gulf of Maine and the associated implications to planktonic calcifiers, notably pteropods. The specific goals of this project are to: 1. Quantify seasonal variations of carbonate system parameters and buffer intensity in deep waters of the Gulf of Maine in order to evaluate the sensitivity of these waters in response to acidification due to anthropogenic forcing, such as increase in atmospheric CO2, freshening of the GoME (decrease in total alkalinity) and increases in water-column respiration due to eutrophication. We will test the hypotheses that deep waters of the GoME are already seasonally under-saturated with respect to aragonite saturation state, and that these waters have low buffer intensity compared to overlying water, which would cause them to be more susceptible to acidification pressures and to reach critical ecological thresholds (OA < 1) more readily. 2. Quantify seasonal patterns in the abundance of the pteropod Limacina retroversa and its vertical distribution relative to concurrent measurements of water column chemical properties, testing the hypothesis that this species is absent in the acidic waters of the near-bottom nepheloid layer. The specific goals of this particular cruise were to: 1. Measure the carbonate chemistry of the water column at multiple sites in the Gulf of Maine, targeting regions where there the depth is greatest and the deep waters are mostly likely to be undersaturated 2. Measure the carbonate chemistry in the nephloid layer 3. Catch pteropods with a vertically stratified net system to quantify their size class, abundance and vertical distribution in the context of the carbonate chemistry. 4. Collect surface water and pteropods to test out methods for shell (70% ethanol), physiology (live) and gene expression studies (RNAlater).

TI806

Website	https://www.bco-dmo.org/deployment/780805
Platform	R/V Tioga
Start Date	2015-04-25
End Date	2015-04-27
Description	Metadata from the Tioga data archive (accessed 2019-11-04): https://www.whoi.edu/what-we-do/explore/ships/ships-tioga/data-archive/ Institution: WHOI Cruise: ti806 Start Port: WHOI April 25, 2015 1500 EDT End Port: WHOI April, 27, 2015 2000 EDT Chief Scientist: Gareth Lawson Project: Pteropod Collection Area: Wilkinson Basin Crew: Capt. K.E. Houtler, Ian G. Hanley Participants: Leg 1 (ti806-01) M. Lowe T. Crockford A. Thabet A. Bergan H. Johnson Leg 2 (ti806-02) T. Crockford M. Lowe A. Bergan A. Thebat B. Jones Instrument Status: LowerLabValve: open TSG: On ADCP: UHDAS Knudsen: ON (no data collected) CTD: Yes MassSpec: N/A R2R Eventlog: N/A

TI817-02

Website	https://www.bco-dmo.org/deployment/780905
Platform	R/V Tioga
Start Date	2015-07-02
End Date	2015-07-02
Description	See metadata for separate legs: * https://datadocs.bco-dmo.org/docs/302/GoME_Pteropods/data_docs/ti817-02.... Related cruises: * https://datadocs.bco-dmo.org/docs/302/GoME_Pteropods/data_docs/ti817-04.... * https://datadocs.bco-dmo.org/docs/302/GoME_Pteropods/data_docs/ti817-05....

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Project Information

Seasonal and Ontogenetic Effects of Ocean Acidification on Pteropods in the Gulf of Maine (Gulf of Maine Pteropods)

Website: http://www.whoi.edu/people/glawson/

Coverage: Gulf of Maine

This project will involve a series of five short cruises in 2013 and 2014, during which a variety of hydrographic, chemical, and biological data and samples will be collected, as well as a number of laboratory experiments examining pteropod physiology and gene expression.

From NSF proposal abstract:

Dissolution of excess anthropogenic CO2 into the ocean is causing the marine environment to decrease in pH. This "ocean acidification" is predicted to threaten a broad variety of marine organisms, particularly calcifying animals such as the thecosome (i.e., shelled) pteropods. These pelagic gastropods form an aragonite shell, are prey for a number of commercially important fish, and are significant contributors to carbon biogeochemistry. Their ecosystem importance, abundance, and sensitivity to dissolution position them as an important group for investigating the impacts of acidification. Our understanding of the effect of high CO2 on pteropods and the pelagic ecosystem, however, is limited primarily to short-term studies of adult calcification and respiration response in the polar ecosystems. There have been no seasonal studies of sensitivity and our understanding of the effect of CO2 on pteropod early life stages is limited. Limacina retroversa is a particularly abundant thecosome pteropod in the North Atlantic, where it is prey for a number of fisheries species and other top predators. This species is also the most common pteropod in the Gulf of Maine (GoM) where it is present year round. L. retroversa thus offers the prospect of a useful model pteropod species, given both its ecological importance and its abundance in readily accessible waters. The investigators will conduct a series of short cruises to sample L. retroversa on a seasonal basis from local waters of the GoM near Cape Cod. The carbonate chemistry of the GoM fluctuates seasonally, providing the opportunity to assess the response of wild caught pteropods to natural changes in CO2. By characterizing the carbonate chemistry of the water column and measuring the metabolic rate, shell quality, and gene expression of pteropods throughout the year, the researchers will achieve a time series of pteropod sensitivity to CO2. Subsequently, using experimental manipulations the investigators will explore the effect of seasonal acclimation on pteropod response to short- and medium-term exposure to enhanced CO2. Pteropods frequently lay eggs in captivity, and at WHOI there is institutional expertise in maintaining these individuals in the laboratory. Building on these strengths, the researchers will also study the effect of CO2 on embryonic and larval development in L. retroversa. These earliest life-stages of marine calcifiers are thought to be especially sensitive since initial shell precipitation and the highly energetic processes of growth and development are impeded by CO2 exposure. They will also document mortality, shell production, abnormality, and developmental rate of clutches of pteropod embryos exposed to increased CO2.

Intellectual Merit: Thecosome pteropods are an abundant group of calcifying zooplankters that have been chronically understudied, particularly in temperate regions. Due to its accessibility and ecological importance, L. retroversa can be developed as a valuable model, interesting both as the dominant pteropod in the

commercially-important GoM region and also an abundant pteropod in the temperate waters of the North Atlantic. The goal of this research is to augment our knowledge of the distribution of L. retroversa, to attain an understanding of their seasonal sensitivity to natural variability in CO2, and to see how this exposure impacts responses to both short- and medium-term CO2 exposure. Using powerful transcriptomic technologies, the research will transform our understanding of this group by investigating the molecular mechanisms of response in L. retroversa to both seasonality and varying durations and intensities of acidification, contextualized by ecosystem- and organism-level metrics. Furthermore the study will examine the effect of CO2 on the eggs of pteropods for the first time, providing insight into their sensitivity to an acidifying environment.

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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)

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