

Bigelow's REU Program 2020



Research Experience for Undergraduates The Gulf of Maine and the World Ocean

REU Symposium Program & Abstracts
Wednesday - Thursday, July 29-30, 2020



Bigelow's REU Program 2020

Wednesday July 29

Bigelow's REU Program 2020

1:00 Opening Comments

1:15 Benjamin Bromberg – Lewis and Clark College, Portland, OR

Building a framework to generate an iPSC line for *Crassostrea virginica*

Benjamin H. Bromberg^{1,2}, José Antonio Fernández Robledo² (1) Lewis & Clark College, Portland, OR, USA (2) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, USA

1:30 Cameron Carlson – University of Alaska Anchorage AK

Simulating hydrocarbon gradients in the water column with mesocosms

Cameron Carlson^{1,2}, Dr. Christoph Aeppli², Dr. David Fields²

University of Alaska Anchorage¹, Bigelow Laboratory for Ocean Sciences

1:45 Hannah Primiano – Drew University Madison NJ

Phytoplankton patterns at the Subantarctic Front in the Southern Indian Ocean

Hannah Primiano^{1,2}, Dr. William Balch² (1) Drew University Madison NJ, (2) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, USA

2:00 Sam McNeely– University of North Carolina Wilmington, Wilmington, NC

Tiny Travelers: Behavioral Response of Copepod (*Calanus finmarchicus*) to Crude Oil Spills

Sam McNeely^{1,3}, Cameron Carlson^{2,3}, Maura Niemisto³, Erin Beirne³, Abigail Tyrell³, Christoph Aeppli³, David Fields³, (1)University of North Carolina Wilmington, Wilmington, NC, United States, (2) University of Alaska Anchorage, Anchorage, AK, United States, (3) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, USA

2:15 Katherine Squires - Colby College, Waterville, ME

Calibrating Cr as a paleoproxy: The effects of Fe, Mn, and organic C on Cr deposition and accumulation in marine sediments

Squires KR^{1,2}, Rauschenberg S¹, McManus J¹ Bigelow Laboratory for Ocean Sciences¹, Colby College²

2:30 Estelle Baldwin - Colby College, Waterville, ME

Predicting Respiration in Coastal Waters is Complex

Estelle Baldwin^{1,2}, Dr. Patricia Matrai,¹ (1) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States, (2) Colby College, USA

2:45 Turner Johnson– Haverford College, Ardmore, PA

Forecasting Whale Populations in the Northwest Atlantic with Machine Learning and Big Data

Turner Johnson^{1,2}, Ben Tupper², Nick Record², (1) Haverford College, Ardmore, PA, United States (2) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, USA.

3:00 Molly Spencer – University of Southern Maine, Portland, ME

Day and Night Influences on the Zooplankton community in a Coastal Environment

Molly Spencer¹, Maura Niemisto², David M Fields², (1) University of Southern Maine, Biological Sciences, Portland, ME, United States, (2) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, USA

3:15 Annabelle Adams-Beyea– The New School, NY, NY

What are they doing in the ocean crust? Investigating the DNA of candidate phylum OP8 collected from crustal fluid.

Adams-Beyea A^{1,2}, Booker A¹, Brown J¹, Orcutt BN¹ Bigelow Laboratory for Ocean Sciences, East Boothbay, ME¹, The New School²

Bigelow's REU Program 2020

Thursday July 30

Bigelow's REU Program 2020

1:00 Opening Comments

1:15 Dylan Halbeisen – Texas A&M University, College Station, TX

The Power of Three: Comparing Upper Ocean Dissolved, Particulate, & Phytoplankton Trace Metal Micronutrient Stoichiometries Within and Between the Atlantic and Pacific.

Dylan J. Halbeisen¹, Benjamin S. Twining², (1)Texas A&M University, College Station, TX, United States; (2)Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States.

1:30 Ajay Patel– University of Florida. FL

Historical Overview of Known Breeding Seabird Ecology in the Gulf of Maine

Ajay Patel¹ and Doug Rasher² ¹University of Florida, ²Bigelow Laboratory for Ocean Sciences

1:45 Alexis Oetterer – Truman State University, Kirksville, MO

Predator-prey dynamics of *Dinophysis* spp. and *Mesodinium* spp. in Booth Bay region of the Gulf of Maine

Alexis Oetterer¹, Laura Lubelczyk², Nicole Poulton²

Truman State University, Kirksville, MO, United States¹, Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States²

2:00 Allegra Rocha – University of the Pacific, Stockton, CA

An Analysis of the Trends of Phytoplankton Fluorescence along the Maine Coast

Allegra Y Rocha¹, Abigail S Tyrell² and David M Fields², (1) University of the Pacific, Stockton, CA, United States (2) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States.

2:15 Jess Liu, Vassar College, Poughkeepsie, NY

The Hunt for Carnivorous Algae and Solar-Powered Sea Creatures:

Creating Gene-Based Predictive Trophic Models for Unicellular Mixotrophic Organisms

Jess Liu¹, Tre'Andice Williams², and John Burns³, (1) Vassar College, United States, (2) Truman State University, United States, (3) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States

2:30 Emily Cunningham – Colby College, Environmental Science, Waterville, ME.

Global Trends in the Biogeography of Coral Recruitment

Emily Cunningham¹, Nichole Price², Pete Edmunds³ (1) Colby College, Environmental Science, Waterville, ME, United States, (2) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States, (3) California State University, Northridge, Los Angeles, CA, United States

2:45 Taylor Rouse – Iowa State University, Environmental Science, Ames, IA

Evaluating the Performance of Standard Ocean Color Algorithms for Carbon in the Gulf of Maine

Taylor Rouse¹, Catherine Mitchell², (1) Iowa State University, Environmental Science, Ames, Iowa, United States, (2) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States

3:00 Elizabeth Westbrook – University of Maryland MD

Predicting the Dissolved Organic Matter-Water Partitioning for Short-Chain Chlorinated Paraffins

Elizabeth Westbrook¹, Christoph Aeppli², Brian DiMento²; (1) University of Maryland, (2) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States

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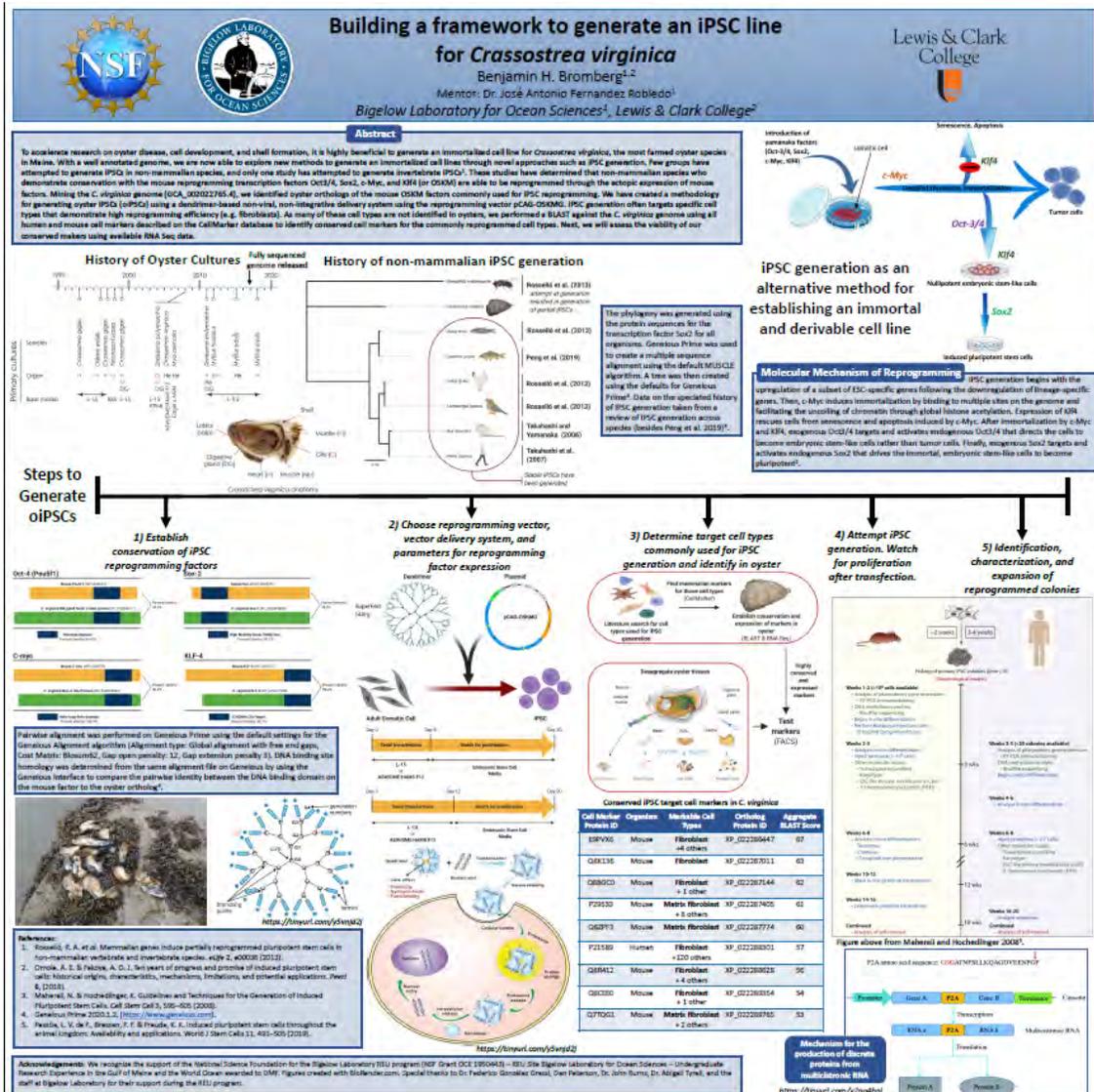
Abstracts and Posters

Bigelow's REU Program 2020

Building a framework to generate an iPSC line for *Crassostrea virginica*

Benjamin H. Bromberg^{1,2}, José Antonio Fernández Robledo²; (1) Lewis & Clark College, Portland, OR, USA (2) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, USA

To accelerate research on oyster disease, cell development, and shell formation, it is highly beneficial to generate an immortalized cell line for *Crassostrea virginica*, the most farmed oyster species in Maine. With a well annotated genome, we are now able to explore new methods to generate an immortalized cell line through novel approaches such as iPSC generation. Few groups have attempted to generate iPSCs in non-mammalian species, and only one study has attempted to generate invertebrate iPSCs¹. These studies have determined that non-mammalian species who demonstrate conservation with the mouse reprogramming transcription factors Oct3/4, Sox2, c-Myc, and Klf4 (or OSKM) are able to be reprogrammed through the ectopic expression of mouse factors. Mining the *C. virginica* genome (GCA_002022765.4), we identified oyster orthologs of the mouse OSKM factors commonly used for iPSC reprogramming. We have created a methodology for generating oyster iPSCs (oiPSCs) using a dendrimer-based non-viral, non-integrative delivery system using the reprogramming vector pCAG-OSKMG. iPSC generation often targets specific cell types that demonstrate high reprogramming efficiency (e.g. fibroblasts). As many of these cell types are not identified in oysters, we performed a BLAST against the *C. virginica* genome using all human and mouse cell markers described on the CellMarker database to identify conserved cell markers for the commonly reprogrammed cell types. Next, we will assess the viability of our conserved makers using available RNA Seq data.



Bigelow's REU Program 2020

Historical Overview of Known Breeding Seabird Ecology in the Gulf of Maine

Ajay Patel¹ and Doug Rasher²; ¹University of Florida, ²Bigelow Laboratory for Ocean Sciences

The Gulf of Maine is seasonally home to 14 different species of breeding seabirds, spanning 4 taxonomic orders. With a few exceptions, these birds form colonial nesting sites along about 10% of Maine's coast and coastal islands. This was not always the case; 9 species were extirpated from New England in the 18th and 19th centuries, following European settlement on coastal islands. Four of these species have since recolonized islands, 3 species occur in the gulf but no longer nest, and 2 species are now extinct (Drury 1973). The beginning of the 20th century brought many boons for the seabirds of Maine. Protective legislation for seabirds, combined with waning human inhabitation of the coastal islands, has allowed for recolonization of the islands, continuing through the present (USFWS 2019). Management of the seabirds has similarly varied over time. Initial efforts involved species-specific research of habitat use and life histories. The 1970's brought a broad management targeted at general habitat restoration aimed at recruiting seabirds. In more recent times, The Gulf of Maine Seabird Working Group, a partnership between various public and private entities, spearheads various conservation and management strategies for seabirds in the region (GOMSWG 2019). Their current conservation efforts include, active management of 10 islands, GPS logging of tern foraging habitat, DNA analysis to determine diet, along with many other strategies (USFWS 2019).



Historical Overview of Known Breeding Seabird Ecology in the Gulf of Maine

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¹University of Florida, ²Bigelow Laboratory for Ocean Sciences



Abstract

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Population Trends

- Since 1999, Common tern populations have increased by 68.9%, while Arctic terns have decreased by 33.8%. The reason for this decline is unknown, though this trend has been noted in populations globally.
- Roseate terns experienced a 31% decline from 2000 to 2009 for reasons unknown. From 2009 to 2019, the population increased by 37%, again for unknown reasons (USFWS 2019).
- Common Murres nested successfully in 2019; only the second successful fledging in 130 years (USFWS 2019).
- From 1973 to 2013, Herring gull populations are estimated to have declined 17%, while Black-backed Gull populations are estimated to have declined by 30%. This decline is speculated to be caused by predation from mammals and Bald Eagles, as well as changes to food availability (Mittelhauser et al.).

Research Objectives

- Complete a synthetic overview pertaining to seabird ecology in the context of larger climatic, historic, and ecological phenomena for future reference in the Rasher Lab.
- Synthesize a thorough research plan and project proposal for future use by the Rasher Lab.



Figure 2. Actively Managed Seabird Restoration Islands in the Gulf of Maine (map by USFWS)

Global Context

- According to Bird Life International (2012), of the 346 known species 28% are globally threatened with 5% being Critically Endangered, and 10% being Near Threatened.
- 52% of known seabird population trends suggest population declines. Many of these declines are attributed to anthropogenic effects.
- Seabirds are often connected to biogeochemical cycles, many times in arcane ways. Population reductions in seabirds on a global scale could foreshadow upcoming changes to many local ecosystems.
- Croft et al (2016) asserts a coupling between "migratory Arctic seabirds and cloud radiative effects", with a potential to affect climatic phenomena.

Management Past & Present

- Management initiatives are conducted by the Gulf of Maine Seabird Working Group.
- Protection of all seabirds on 13 islands, starting in 1901, allowed initial recovery of tern and gull colonies.
- Resulting effects of initial conservation efforts worked so well, that lethal control of cormorant and gull eggs was necessary in order to protect tern and eider offspring from predation. (Drury 1973).
- Current management includes procurement of islands for addition to the MCINWR, active management of 10 islands, and predator control amongst many other endeavors. (USFWS 2019)
- Control of Laughing Gull population on 3 managed islands occurs in an attempt to enhance tern productivity.
- Research efforts are underway to enhance our understanding of the foraging ecology and diet of Maine's coastal seabirds.



Figure 3. Picture of Atlantic puffins (*Fratercula arctica*) on a coastal Maine island. Picture taken by the USFWS.

References

USFWS (2019) Seabirds of the Gulf of Maine. <https://www.usfws.gov/gulf-of-maine/seabirds>. Accessed 10/15/2019.

Drury, W. (1973) Seabirds of the Gulf of Maine. <https://www.usfws.gov/gulf-of-maine/seabirds>. Accessed 10/15/2019.

USFWS (2019) Seabirds of the Gulf of Maine. <https://www.usfws.gov/gulf-of-maine/seabirds>. Accessed 10/15/2019.

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Acknowledgments

We recognize the support of the National Science Foundation for the Bigelow Laboratory REU program (NSF Grant OCE-1650422) and the Bigelow Laboratory for Ocean Sciences - Undergraduate Research Experiences in the Gulf of Maine and the World Ocean awarded to DMR. Special thanks to Linda Walsh at USFWS, and the Gulf of Maine Seabird Working Group for providing site access in the project.

Bigelow's REU Program 2020

Phytoplankton patterns at the Subantarctic Front in the Southern Indian Ocean

Hannah Primiano^{1,2}, Dr. William Balch²; (1) Drew University, (2) Bigelow Laboratory for Ocean Sciences

The Great Calcite Belt (GCB) is an area in the Southern Ocean that contains dense populations of coccolithophores. Coccolithophores are an important phytoplankton due to their ability to sequester carbon into their calcium carbonate plates. Other types of phytoplankton, such as dinoflagellates are less understood in this area. All phytoplankton in the GCB scrub the water of nutrients before the water is subducted to the north. Understanding the phytoplankton groups that reside in the GCB is important for understanding the ecology of the region and greater global nutrient availability. In this study, we quantified and compared the abundance of coccolithophores, dinoflagellates, cyanobacteria, and other types of phytoplankton in the GCB using light-, polarized-, and epi-fluorescence microscopy. These samples were taken from a semi-enclosed eddy that had spun off of the GCB in the Southern Indian Ocean. We compared the phytoplankton abundance data with nutrient measurements that were sampled at the same stations. Our research shows that dinoflagellates and coccolithophores significantly covary. Other important relationships that we observed are between cyanobacteria and coccolithophores as well as between coccolithophores and silicate. These results suggest that these phytoplankton groups are using similar nutrients and scrubbing these nutrients out of the water. Further research could increase understanding of the nutrient availability and provide an explanation for the relationship between silicate and coccolithophores.

Phytoplankton Patterns at the Subantarctic Front in the Southern Indian Ocean

Hannah Primiano¹ and Dr. William Balch²
Drew University¹ Bigelow Laboratory for Ocean Science²



Email: hprimiano@drew.edu

Abstract

The Great Calcite Belt (GCB) is an area in the Southern Ocean that contains dense populations of coccolithophores. Coccolithophores are an important phytoplankton due to their ability to sequester carbon into their calcium carbonate plates. Other types of phytoplankton, such as dinoflagellates are less understood in this area. All phytoplankton in the GCB scrub the water of nutrients before the water is subducted to the north. Understanding the phytoplankton groups that reside in the GCB is important for understanding the ecology of the region and greater global nutrient availability. In this study, we quantified and compared the abundance of coccolithophores, dinoflagellates, cyanobacteria, and other types of phytoplankton in the GCB using light-, polarized-, and epi-fluorescence microscopy. These samples were taken from a semi-enclosed eddy that had spun off of the GCB in the Southern Indian Ocean. We compared the phytoplankton abundance data with nutrient measurements that were sampled at the same stations. Our research shows that dinoflagellates and coccolithophores significantly covary. Other important relationships that we observed are between cyanobacteria and coccolithophores as well as between coccolithophores and silicate. These results suggest that these phytoplankton groups are using similar nutrients and scrubbing these nutrients out of the water. Further research could increase understanding of the nutrient availability and provide an explanation for the relationship between silicate and coccolithophores. We discuss possible reasons for these strong relationships.

Research Questions

1. Are coccolithophores the only phytoplankton in the GCB or are there other functional groups of phytoplankton?
2. What, if any, nutrients are affecting the abundance of these phytoplankton?
3. How does the cell concentration compare over time in a semi-enclosed oceanographic eddy feature?

Introduction and Methods

Introduction

The GCB is a region of concentrated coccolithophore populations in the Southern Ocean which contains elevated levels of particulate inorganic carbon (PIC). It is generally found south of the Subantarctic Front, which is associated with Subantarctic Mode Water (SAMW). Overall, phytoplankton in the GCB are not as well quantified. All phytoplankton in the GCB "condition" or scrub the SAMW of nutrients before the water is subducted to the north. This process allows these phytoplankton to directly influence global nutrient availability and primary productivity as far as the northern hemisphere.

Methods

- Data was collected from the Southern Indian Ocean from a cyclonic eddy that had spun off of a meandering system in the GCB.
- Water samples were taken from the eddy two times about two weeks apart.
- Samples were photographed under a microscope under four different types of illumination including bright field, polarized, epi-fluorescence (blue [490nm] excitation/ red [676nm] emission, and green [530nm] excitation/ red [676nm] emission).
- Cells were calculated using the program ImageJ to tally the different types of cells.

Future Research

- Another expedition will be going to the Southern Pacific Ocean to continue this research in the coming January 2021.
- Additional research may show similar trends in a different region of the Great Calcite Belt.
- Future studies should also delve into the significance of silicate and coccolithophores.

Results and Discussion

Statistics

Variable	Variable	r ² value	df	df lower	df upper	intercept	intercept error	intercept error 1 sigma	1-sigma	
log(coccolithophores/cell)	log(dinoflagellates/cell)	0.7032	12	10.8719	14.2093	0.4740	0.0984	0.0005	0.4196	0.88794
log(coccolithophores/cell)	log(cyanobacteria/cell)	0.6949	11	10.5253	13.8227	0.4620	0.1215	0.0012	0.4100	17.0953
log(coccolithophores/cell)	log(silicate/cell)	0.6259	13	10.9700	13.1200	0.2004	0.0457	0.0019	0.0257	17.4422
log(coccolithophores/cell)	log(silicate/cell)	0.6201	11	10.8942	13.1498	0.2004	0.0457	0.0019	0.0257	15.3678
log(coccolithophores/cell)	log(silicate/cell)	0.5368	11	10.5310	12.7202	0.1630	0.0388	0.0018	0.0094	9.5045

Table 1: Significant relationships between different phytoplankton functional groups as well as the specific functional groups and specific nutrients examined in this study. Results show the r² of the least squares linear regression, the slope and intercept values. Each regression was evaluated using an F test and the calculated F is shown along with its significance. For correlations involving cell abundance estimates, the data were first log transformed (log[+1]) as the data were approaching log normality. Note that the highest correlation was between coccolithophores and dinoflagellates (including armored and unarmored).

Phytoplankton Comparisons

Fig. 1 shows a comparison of coccolithophores and dinoflagellates in cells/mL on logarithmic axis scale. This trend shows a very significant relationship between the number of coccolithophores/mL to the number of dinoflagellates/mL. It is not significantly different from a 1:1 ratio (Table 1).

Fig. 2 shows a comparison of coccolithophores and cyanobacteria in cells/mL on logarithmic axis scale. This relationship is statistically significant. (p<0.05)

Fig. 3 Comparison of dinoflagellates and cyanobacteria in cells/mL on logarithmic axis scale. These results are significant when plotted on log transformed data. (p<0.05)

Nutrient Analysis

Fig. 4 shows an inverse relationship between Si(OH)₄ and average coccolithophores/mL. This was the only nutrient to show significant results. This was unexpected because silicate is not thought to be required for coccolithophore growth.

Time Comparison

Fig. 5 shows a comparison of the log of the number of cells/mL. Because phytoplankton have a logarithmic distribution, the number of cells/mL data was log transformed.

Panel A and B: Coccolithophore data from the interior of the eddy. Station 29 is the first sampling on February 4, 2020. Station 70 is from the second sampling on February 21, 2020. Panel C and D: Coccolithophore data from the center of the eddy. Data from station 20 was taken during the first occupation of the eddy, and data from station 50 was taken from the second occupation of the eddy.

The average number of coccolithophores decreases between the two samplings of the eddy. This is true of both the interior and center of the eddy. This trend is also seen across all types of cells that were measured including dinoflagellates and cyanobacteria suggesting that the productivity of these eddies decreased as they aged.

Discussion

- Covariance between coccolithophores and dinoflagellates is likely due to the nutrient uptake for each group. Relationships between coccolithophores with nutrients and dinoflagellates with nutrients were almost identical for nitrate, phosphate, silicate, and ammonia. Cyanobacteria followed similar trends with regards to nitrate, silicate, and ammonia.
- Regardless of significance, almost all nutrient and phytoplankton relationships had a negative slope, indicating that phytoplankton are participating in nutrient uptake.
- The inverse relationship between silicate and coccolithophores has two possible explanations. Coccolithophores could be using silicate in the calcification process as suggested by Durak et al. Alternatively, diatoms, which rely on silicate, could be outcompeting or inhibiting coccolithophores in areas of higher silicate concentrations.
- On average phytoplankton abundance decreased over time within the eddy. Nitrate and phosphate levels clearly increased over time within the eddy suggesting that they are no longer being taken up by the phytoplankton. Silicate levels do not follow this trend and may indicate that there is another factor.

Significance

- Dinoflagellate and coccolithophore populations covary significantly. Relationships of these groups with nutrients are similar and could cause the covariance. The uptake of nutrients at the Subantarctic Front will impact the nutrient availability in SAMW as it moves to the equator. This will limit productivity in that region. Distribution of phytoplankton productivity is essential for understanding ocean food chains and for climate modeling.
- Current understanding is that silicate is not an essential nutrient for calcification in coccolithophores. This data suggests that coccolithophores do have a significant relationship with silicate. This may corroborate one paper by Durak et al. If silicate is important for calcification, then silicate levels in the ocean will have important implications for the carbon cycle and impact our overall understanding of coccolithophores.

References

Caronell, L. (2005). "The regional distribution of a model for bi-ocyclical variability in the..." *Journal of Geophysical Research* 110(C7): 10215-10224.

Durak, J., Sain, A., Walker, C., et al. A case for diatom-like silica requirements in calcifying coccolithophores. *Mar. Chemistry* 171, 45-63 (2015). <https://doi.org/10.1016/j.marchem.2015.04.004>.

Acknowledgements

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Bigelow's REU Program 2020

Tiny Travelers: Behavioral Response of Copepod (*Calanus finmarchicus*) to Crude Oil Spills

Sam McNeely^{1,3}, Cameron Carlson^{2,3}, Maura Niemisto³, Erin Beirne³, Abigail Tyrell³, Christoph Aeppli³, David Fields³; (1)University of North Carolina Wilmington, Wilmington, NC, United States, (2) University of Alaska Anchorage, Anchorage, AK, United States, (3)Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States

The Arctic Circle holds massive reserves of undiscovered oil estimated at over 90 billion barrels, and, as sea ice continues to melt due to climate change, exploitation of these oil reserves will only increase as will transportation across the Arctic, increasing the likelihood of oil spills. Copepods, the foundation of the Arctic food web, experience many sublethal and lethal effects from crude oil. An Arctic copepod (*Calanus finmarchicus*), makes daily vertical migrations between the ocean's surface and a depth of 100 m. Our hypothesis is that *C. finmarchicus* can use its vertical migratory behavior to actively avoid the toxic chemicals that come from crude oil. *C. finmarchicus* are placed into a 2 m tall mesocosm, simulating the upper water column, with 4 cameras positioned at different depths. The cameras capture images throughout the 16-hour controls and the 24-hour oil treatments. The videos from the experiment are analyzed in ImageJ, R, and Excel. Our results show that copepod abundance in the upper mesocosm experienced significant decreases in proportion of the control ($p < 0.05$). The two cameras at depth displayed slight changes, however, they were insignificant ($p > 0.05$). This indicates that *C. finmarchicus* interacted with the oil, experienced sublethal and lethal effects, and were immobilized. This provides insight into the behavior of *C. finmarchicus* following the introduction of crude oil indicating the foundation of the Arctic food web are vulnerable to oil spills, highlighting the necessity of proper cleanup methods to minimize the environmental impact.

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University of North Carolina Wilmington¹, University of Alaska Anchorage², Bigelow Laboratory for Ocean Sciences³

Background

ARCTIC OIL
The Arctic Circle holds massive reserves of undiscovered oil estimated at over 90 billion barrels. As sea ice continues to melt due to climate change, exploitation of these oil reserves will only increase as will transportation across the Arctic, increasing the likelihood of oil spills.

COPEPODS
Copepods, the foundation of the Arctic food web, experience many sublethal and lethal effects from crude oil. An Arctic copepod, *Calanus finmarchicus*, makes daily vertical migrations between the ocean's surface and a depth of 100 m. Our hypothesis is that *C. finmarchicus* can use its vertical migratory behavior to actively avoid the toxic chemicals that come from crude oil.



Fig. 3. Map of *C. finmarchicus* in their migratory habitat. (MORRISON)

Research Question

Do *C. finmarchicus* actively avoid the toxic chemicals from crude oil by utilizing its vertical migratory behavior?

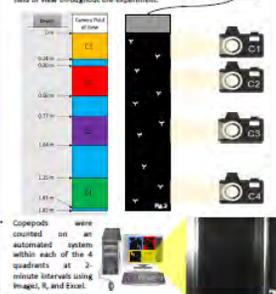
Materials and Methods

The experiment consisted of 4 16-hour control treatments and 4 24-hour oil treatments.

Copepods were placed in a 2 m tall mesocosm, which simulated the upper portion of the water column.

After the 16-hour control, 6 ml of Alaska North Slope (ANS) oil was added at the water's surface, which marked the start of the 24-hour oil treatment.

4 cameras, each placed at different depths, captured images in an approximate 0.25 m field of view throughout the experiment.



Copepods were counted on an automated system within each of the 4 quadrants at 2-minute intervals using ImageJ, R, and Excel.

Results

Fig. 4 & 5: Percentage of copepods present within sight of Camera 1 (Fig. 4), at the surface, and Camera 2 (Fig. 5), 0.5 m deep, relative to the stable control distribution average. These figures show the replicate averages at different times (t). Significant differences are denoted by different letters. Data points that are represented with the same letter are not significantly different. The error bars represent the standard error.

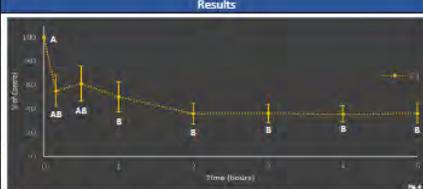


Fig. 6 & 7: A view from the side (Fig. 6) and a top-down view (Fig. 7) of *C. finmarchicus*. The circled black mark on the copepod's head is either ingested oil or oil that it stuck to its carapace.

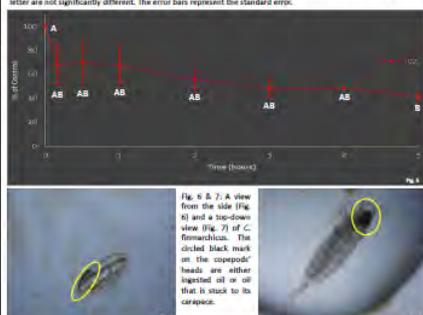
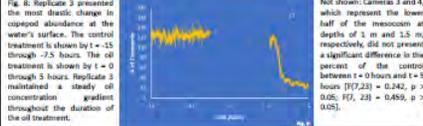


Fig. 8: Replicate 3 presented the most drastic change in copepod abundance at the water's surface. The control treatment is shown by t = 0 through t = 2.5 hours. The oil treatment is shown by t = 0 through 5 hours. Replicate 3 maintained a steady oil concentration gradient throughout the duration of the oil treatment.



Not shown: Cameras 3 and 4, which represent the lower half of the mesocosm at depths of 3 m and 1.5 m, respectively, did not present a significant difference in the percent of the control between t = 0 hours and t = 5 hours (F(7,23) = 0.242, p > 0.05; F(7,23) = 0.459, p > 0.05).

Results, cont.

- Camera 1 (Fig. 4) showed a significant difference in the percentage of the control of the 8 time points (F(7, 24) = 4.83, p < 0.05).
- Post hoc comparisons using a Tukey HSD test indicated a significant difference between t = 0 hours (Mean = 100, SD = 0) and t = 1 hour (Mean = 50.24, SD = 25.67), which also indicates a significant difference between t = 0 and t = 2, 3, 4, and 5 hours.
- There was no significant difference indicated between time = 0.5 hours (Mean = 61.43, SD = 25.85) and time = 4 hours (Mean = 35.51, SD = 13.97), which, by Tukey's post hoc test, shows comparisons between all time points, except t = 0 hours, are not significantly different.
- Camera 2 (Fig. 5) displayed a significant difference between t = 0 hours (Mean = 100, SD = 0) and t = 2 hours (Mean = 41.83, SD = 8.23) (F(7, 24) = 2.74, p < 0.05).
- There was not a significant difference observed between t = 0 hours and t = 3 hours (Mean = 48.25, SD = 13.04) or between t = 0.5 hours (Mean = 69.37, SD = 37.25) and time = 5 hours, which Tukey's post hoc test determines no significant difference between all other time comparisons.
- Cameras 3 and 4 (Not shown) did not exhibit a significant difference among any of the time comparisons (F(7,23) = 0.242, p > 0.05; F(7, 23) = 0.459, p > 0.05).

Discussion

IMPLICATIONS:

- C. finmarchicus* abundance significantly decreased in the upper water column but did not significantly increase in the lower water column. This suggests the copepods interacted with the oil, experienced sublethal and lethal effects, and were immobilized, which caused them to either float to the surface or sink to the floor of the tank.
- We expected both changes to be significant had the copepods been actively avoiding the crude oil.
- Some copepods were observed actively interacting with the crude oil, as shown in Fig. 6 & 7. This presents concern that they may be ingesting the oil or getting stuck in the oil.

FIGURE:

- Continuing with this study, the same experiments will be performed with both oil and dispersants. This will give more insight as to how and when dispersants should be applied, if at all. If not, then alternative methods for cleaning up from oil spills must be explored.
- Within 30 minutes after the oil was added at the water's surface, a minor surge of copepods moved into Camera 1 before diving down into the water column (Fig. 8: t = 0 hours through t = 2 hours). This phenomenon should be explored further to determine if they are attracted to the oil or if they are simply investigating the disturbance at the surface.



Fig. 9: A side view of a fluorescent *C. finmarchicus*.

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Acknowledgments

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Bigelow's REU Program 2020

Calibrating Cr as a paleoproxy: The effects of Fe, Mn, and organic C on Cr deposition and accumulation in marine sediments

Squires KR^{1,2}, Rauschenberg S¹, McManus J¹; Bigelow Laboratory for Ocean Sciences¹, Colby College²

Chromium's concentration in marine sediments has the potential to serve as a predictor for past ocean chemistry. This potential arises because the solubility of Cr is sensitive to the presence or absence of oxygen. This sensitivity could allow for reconstruction of the evolution of dissolved oxygen in ancient oceans. However, because understanding of the mechanisms for Cr uptake is uncertain, a detailed investigation of Cr's depositional controls is essential for exploiting this potential tool. The central hypothesis of this research is that Cr will exhibit predictable behavior tied to Fe-oxide, Mn-oxide, and organic C cycling.

Marine sediments were analyzed for their Cr, Fe, and Mn concentrations in cores that were collected from a diverse range of oceanographic chemical conditions. An Inductively Coupled Plasma Mass Spectrometer was used to quantify metal abundances. Depth profiles highlighted relationships between [Fe-oxide] and [Cr], and between %C and [Cr], but not between [Mn-oxide] and [Cr]. These data indicate that under oxidizing conditions, Cr adsorbs onto Fe-oxides within marine sediments. These data also indicate that %C and [Cr] covary when %C > 2%, but not when %C < 2%. These observations suggest that under reducing conditions, organic C and sulfides likely reduce Cr to insoluble Cr(III), which is then sequestered within the sediment package. Additional synthesis of our data suggest that there is no significant relationship between Mn-oxide phases and Cr, thus indicating that oxidation of Cr by Mn-oxides does not have significant control over Cr burial.

Calibrating Cr as a paleoproxy: The effects of Fe, Mn, and organic C on Cr deposition and accumulation in marine sediments

Katherine Squires^{1,2}, Sara Rauchenberg¹, James McManus¹
Bigelow Laboratory for Ocean Sciences¹, Colby College²




Introduction:

The solubility of chromium (Cr) is sensitive to the presence or absence of oxygen. Under anoxic conditions Cr is present in the less soluble Cr(III) oxidation state, whereas in the presence of oxygen Cr is present in both the Cr(III) and the more soluble Cr(VI) oxidation state. Due to these sensitivities, sedimentary Cr concentration has the potential to serve as a predictor for past ocean chemistry, in particular to the presence or absence of oxygen. This opportunity could thus inform our understanding of climate change and the evolution of oxygen in the ocean. However, because our understanding of the mechanisms for Cr burial are uncertain, a detailed investigation of the controls on Cr burial in modern environments is important for accurately exploiting this potential proxy.

Study sites:

- Sediment cores were collected during two cruises — one to Dorado Outcrop, which lies in the western Pacific off the coast of Costa Rica, and one along the California and Mexico continental margins.
- Dorado Outcrop is characterized by low-temperature hydrothermal fluid discharge.
- Sites were chosen for their diverse range of sedimentary redox conditions.

Site	Depth (m)	Latitude (°N)	Longitude (°W)	Water Depth (m)	Water Depth (m)
Farallon Mocha	438	21.37	128.07	-0.1	84 v.13
San Blas, Mexico	592	20.27	102.77	-0.1	32 v.02
San Pedro Basin, CA	806	28.01	124.81	1.8	23 v.08
Continental Shelf, CA	1008	33.37	119.87	20	12 v.03
San Clemente Basin, CA	2053	32.67	118.17	50	9 v.0
Palos Verdes, CA	2197	32.47	119.17	100	6 v.8
Dorado Outcrop	2352	5.17	127.17	107	—

Fig. 1 & 2. Maps showing core collection sites along the continental margins (top) and at Dorado Outcrop (bottom).

Fig. 3. Selected diagnostic characteristics of core collection sites.

Results & Discussion:

Part I: C and Cr:

- There is no significant relationship between %C and [Cr] when %C is less than 2%.
- When %C is greater than 2%, [Cr] and %C covary.
- Data suggest that under anoxic conditions, organic C can reduce Cr(VI) to insoluble Cr(III) which is then buried.

Part II: Mn and Cr:

- There is no significant relationship between [Mn] and [Cr].
- Data suggest that oxidation of Cr by Mn-oxides is not a dominant process or does not leave evidence in the sedimentary record.

Part III: Fe and Cr:

- [Fe-oxide] and [Cr] covary.
- Data suggest that under oxidizing conditions, Cr associates with Fe-oxides which deliver Cr to the sediment layer and control Cr burial.
- Elevated [Cr] occurs at the two anoxic sites — Soledad and San Blas, Mexico.
- Data suggest that under anoxic conditions, Cr(VI) is reduced to insoluble Cr(III), and this process controls burial.

Summary and conclusions:

- Under oxidizing conditions, adsorption onto Fe-oxides is the dominant control over Cr burial.
- Oxidation by Mn-oxides does not have significant control over Cr burial.
- Under anoxic conditions, reduction to insoluble Cr(III) via organic carbon and/or sulfides becomes the dominant control over Cr burial.

Acknowledgments:

We recognize the support of the National Science Foundation (NSF) for the Bigelow Laboratory REU program (NSF Grant OCE 1460861) - REU site: Bigelow Laboratory for Ocean Sciences - Undergraduate Research Experience in the Gulf of Maine and the World Ocean awarded to DMF. Funding for this project was also provided by the NSF under awards 1918061 and 1657832 to JM. Special thanks to Silke Severmann who has contributed to this project both in the field and during development of this project, and to the staff at Bigelow Laboratory for their support during the REU program.

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Fig. 4. Sediment core.

Bigelow's REU Program 2020

Predicting Respiration in Coastal Waters is Complex

Estelle Baldwin^{1,2}, Dr. Patricia Matrai¹; (1) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States, (2) Colby College, United States

Respiration is a process of the carbon cycle that has largely been studied as the complement to photosynthesis. Our study quantifies the effects of environmental factors on respiration alone in Gulf of Maine surface waters (2005 – 2006). Nutrients (PO₄, NO₃ + NO₂) along with seawater temperature, chlorophyll *a* concentration, and primary production (photosynthesis) accounted for significant fractions of the variability in respiration. In this region, salinity, bacterial abundance, and dissolved organic carbon did not significantly impact respiration rates. Two empirical algorithms for respiration were derived using these variables in the training 2005 dataset. These models were applied to a validating 2006 Gulf of Maine dataset as well as to a testing global respiration data set (which did not include nutrients), restricted to temperate, coastal data. Including nutrients in the algorithm accounted for about 7 times more of the variability in the validating dataset. While this algorithm accounted for up to 35% of the variability in the 2006 observed Gulf of Maine data, the applicable algorithm reproduced less than 5% of the global respiration values.

Predicting Respiration in Coastal Waters is Complex

Estelle Baldwin^{1,2}, Dr. Patricia Matrai¹
Bigelow Laboratory for Ocean Sciences¹, Colby College²

Abstract

Respiration is a process of the carbon cycle that has largely been studied as the complement to photosynthesis. Our study quantifies the effects of environmental factors on respiration alone in Gulf of Maine surface waters (2005 – 2006). Nutrients (PO₄, NO₃ + NO₂) along with seawater temperature, chlorophyll *a* concentration, and primary production (photosynthesis) accounted for significant fractions of the variability in respiration. In this region, salinity and dissolved organic carbon did not significantly impact respiration rates. Two empirical algorithms for respiration were derived using these variables in the training 2005 dataset. These models were applied to a validating 2006 Gulf of Maine dataset as well as to a testing global respiration data set (which did not include nutrients), restricted to temperate, coastal data. Including nutrients in the algorithm accounted for about 7 times more of the variability in the validating dataset. While this algorithm accounted for up to 35% of the variability in the 2006 observed Gulf of Maine data, the applicable algorithm reproduced less than 5% of the global respiration values.



Figure 1: (a) Five sampling stations starting in the Kennebec River estuary and moving into saline waters of the Gulf of Maine. (b) Also shown is the location of the testing data set.

Research Questions

- ❑ Q1: Does community respiration have a seasonal cycle in coastal Gulf of Maine waters?
- ❑ Q2: Do the seasonal cycles of community respiration and primary production coincide in coastal waters?
- ❑ Q3: Is temperature a major control of the community respiration cycle in coastal Gulf of Maine waters?
- ❑ Q4: Does aquatic community respiration vary spatially along an estuarine to marine continuum?
- ❑ Q5: Does community respiration in temperate coastal waters of the Gulf of Maine agree with values from other coastal regions?

Seasonality of Respiration (R) and Primary Production (PP)

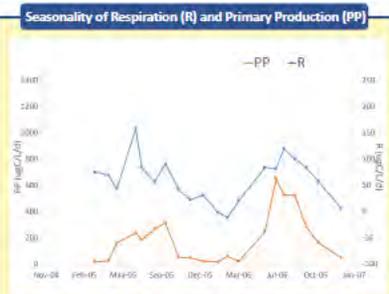


Figure 3: Community respiration (R) and primary production (PP) monthly averages (and standard deviation) in 2005-2006 surface coastal waters of the Gulf of Maine. Surface waters in both regions appear to be net autotrophic given that community PP (0-1700 µgC L⁻¹ d⁻¹) greatly exceeds R (0-200 µgC L⁻¹ d⁻¹) regardless of time. Respiration lagged primary production in 2005 and coincided with it in 2006.

Controls of Respiration

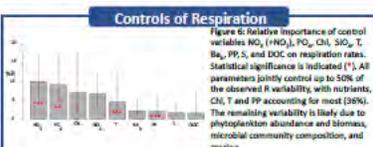


Figure 5: Relative importance of control variables (NO₃, NO₂, PO₄, CHL, SiO₂, T, Ba, PP, S, and DOC on respiration rates. Statistical significance is indicated (*). All parameters jointly control up to 50% of the observed R variability, with nutrients, CHL, T and PP accounting for most (38%). The remaining variability is likely due to phytoplankton abundance and biomass, microbial community composition, and grazing.

$R = 92.386 [234.365] - [0.029 [20.020] PP] - [1.045 [1.983] T] + [17.099 [19.638] CH] - [0.037 [2.452] NO_3 + NO_2] - [40.833 [22.696] PO_4]$
 EQUATION 1: Predicted respiration (R) as a function of primary production (PP, µgC L⁻¹ d⁻¹), temperature (T, °C), chlorophyll (CH, µg/L), nitrate + nitrite concentration (NO₃+NO₂, µM), and phosphate concentration (PO₄, µM); derived using the training dataset.

$R = 23.096 [19.260] - [0.089 [2.050] PP] + [1.566 [1.663] T]$
 + [21.4720 [2.616] CH]

EQUATION 2: Predicted respiration as in EQUATION 1 above, without nutrients.

Methods

- Field data collected monthly in surface waters of the Kennebec River and Gulf of Maine (Figure 1) from March 2005 to December 2006.
- Primary production was determined using standard C-14 technique (Knap et al. 1995).
- Respiration was measured as oxygen consumption by Winkler titrations (Knap et al. 1995).
- Cell counts were measured by flow cytometric analysis (Sizemak et al. 2005).
- Total organic carbon (TOC) and particulate organic carbon (POC) were analyzed according to Qian & Mopper (1996) and Knap et al. (1995), respectively. Dissolved organic carbon (DOC) was estimated by difference.
- A global community respiration dataset was provided by Dr. C. Robinson (University of East Anglia) (https://people.wvu.edu/~carol_robinson/info/type-research-interests)
- Data and statistical analyses, including ANOVA, relative importance, and multiple linear regression, were executed with Excel and R-Studio.
- The model-explained variance was decomposed using the LMG metric (Lindeman et al. 1980).
- Statistical significance between each variable and community respiration is shown by stars (3, 2 and 1 stars correspond to p-values of 0.001, 0.01, and 0.05, respectively).

Nitrate and Chlorophyll

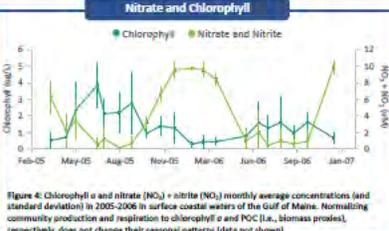


Figure 4: Chlorophyll *a* and nitrate (NO₃) + nitrite (NO₂) monthly average concentrations (and standard deviation) in 2005-2006 in surface coastal waters of the Gulf of Maine. Normalizing community production and respiration to chlorophyll *a* and POC (i.e., biomass proxies), respectively, does not change their seasonal patterns (data not shown).

Algorithms Applied

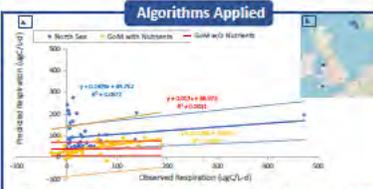


Figure 7: (a) Predicted community respiration in surface waters (using Equations 1 and 2) versus measured respiration rate in the coastal/estuarine Gulf of Maine (GOM, 2005) as well as in the North Sea (using Equation 2) at the locations marked in (b). A larger starting dataset does not significantly improve predictability of R in the North Sea. Also shown are the 95% confidence levels (dashed lines) for each regional prediction. Community PP in the Gulf of Maine surface waters exceeds PP in the North Sea by up to 16-fold. Although R is underestimated, our model is more effective in predicting R in the Gulf of Maine than in the North Sea, emphasizing the uniqueness of each system (e.g., estuarine-based salinity gradient, riverine input of allochthonous materials in the Gulf of Maine).

Annual Station Averages of Respiration-Relevant Variables

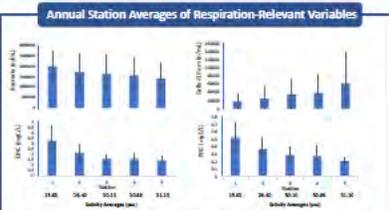


Figure 2: Bacterial count (BA), cell count below 20 µm diameter, dissolved organic carbon (DOC) and particulate organic carbon (POC) concentration annual averages (and standard deviation) for each station (1-5), as shown in Fig. 1. Also shown is the average annual salinity for each station (liver end-member on the left and marine end-member on the right). No significant trends were observed spatially nor with salinity, at any time scale. Bacterial abundance and DOC are not significantly related to respiration (R) and do not show significant temporal or spatial variability. Photograph (>20µm) abundance increases with increasing salinity while POC shows the reverse pattern; neither predicts R.

Respiration and Temperature

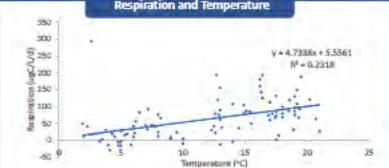


Figure 6: Community respiration as a function of seawater temperature in surface coastal waters of the Gulf of Maine. Respiration rates increase with increasing temperature and this variable accounts for about 23% of the variation seen in respiration rates.

$y = 4.7388x + 5.5561$
 $R^2 = 0.2318$

Conclusions

- Community respiration shows a seasonal cycle that may lag (2005) or coincide (2006) with primary production in the Gulf of Maine.
- Respiration and primary production increased with increasing temperature in these surface waters. This was not observed with salinity.
- Normalizing primary production and respiration to biomass does not change their temporal or spatial patterns.
- Nitrate & nitrite, phosphate, chlorophyll, temperature, and primary production account for most of the seasonal variability of community respiration in these surface waters.
- Nutrients significantly improve the predictive algorithm for respiration.
- The model derived from Gulf of Maine coastal observations does not predict well community respiration in the North Sea.
- Coastal Gulf of Maine and North Sea surface waters are net autotrophic.

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Bigelow's REU Program 2020

Forecasting Whale Populations in the Northwest Atlantic with Machine Learning and Big Data Turner Johnson 1,2, Ben Tupper 2, Nick Record 2, (2) Haverford College, Ardmore, PA, United States (2) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States.

Within the past decade, large swaths of the North Atlantic trophic web have been geographically uprooted due to the effects of climate change. Notably, the right whale (*E. glacialis*) is following its main food source, *C. finmarchicus*, out of historically protected waters and into ship routes and fishing grounds. Similar effects are observed in blue (*B. musculus*), fin (*B. physalus*), humpback (*M. novaeangliae*), and sei whale (*B. borealis*) populations. To gain detailed insight into future whale distribution, we use the machine learning model, MaxEnt, to produce daily encounter-likelihood maps using whale observations, and covariate data layers gathered by the Aqua MODIS satellite. Using data from January 2014 to June 2020, we produced a series of daily predictive models, varying predictor, observational, and model parameters to test the ability of this model to anticipate distributions across two or more trophic levels in the whale food chain. The favorable effect of adding calculated covariate layers (integrated chlorophyll-a, bathymetry gradient, and sea surface temperature gradient) is noted in the strong contribution of integrated chlorophyll to the planktivorous *E. glacialis* model, but not the piscivorous whales, suggesting that chlorophyll-a could be an effective proxy for zooplankton abundance. In a comparison of definite sightings to possible sightings, we find little difference in model output and infer the usability of a range of data scores. A whale distribution forecast on a massive scale is a critical tool in ecosystem conservation, as each whale's actions have resounding effects on both their local food web and the global carbon and oxygen cycles.



Forecasting Whale Populations in the Northwest Atlantic with Machine Learning and Big Data




Turner Johnson^{1,2}, Nicholas R Record¹, Ben Tupper¹
¹Bigelow Laboratory for Ocean Science, ²Haverford College

Introduction

Baliner whales are essential components in the stabilization of marine ecosystems.

In the past 10 years, climate change has gravely affected whale movement patterns in the North Atlantic.

- right whales (*E. glacialis*) follow their main food source, *Calanus finmarchicus*, into unprotected shipping lanes and fishing zones!



- blue whale (*B. musculus*), fin whale (*B. physalus*), humpback whale (*M. novaeangliae*), and sei whale (*B. borealis*) populations are following similar climate shifts, unwittingly subjecting themselves to the same anthropogenic hazards, including noise pollution!

There is a growing need for understanding current and future whale distribution.

- Established whale tagging methods are incompatible with right whale anatomy.
- Machine learning model MaxEnt (Fig 1) compares environmental conditions to observational whale data to produce an encounter-likelihood map (Fig 3).
- Taking the local food web (Fig 3) into consideration.



Figure 1: Basic schematic showing the inputs (blue) and output (orange) of the MaxEnt machine learning model. Predictor (covariate) layers are environmental conditions e.g. sea surface temperature, chlorophyll-a, particulate organic and inorganic carbon, and bathymetry. For a different set of predictors, the model produces a map gauging whale encounter likelihood.

Research Questions:

- Can we predict whale presence using satellite data and a derived *Calanus* proxy data layer?
- How does adding derived predictor layers affect the model's respective reliance on these layers?
- How do observation type and score affect the model?

Testing Data Score and Type

With our optimized configuration, we ran a series of models to test the influence of possible vs. definite data scores and visual vs. acoustic encounter types. Encounters where researchers or algorithms were unable to identify a whale species are marked "possible" while confident encounters are "definite". Our results for data type are inconclusive and require further research. We note little difference in model output between scores, which suggests the model's dexterity in handling data score. If only for the data set we used.



Figure 3: The North Atlantic Food Web for Baliner Whales.

Constraining Model Parameters

To prepare a group of control models, we regulated parameters as such:

- region: previously North West Atlantic, now only depth >1000m
- why: model relied too heavily on bathymetry
- number of observed presence points: capped at 200
- why: inverse relation affect between presence and AUC²
- number of background points: converges around 1200
- see Figure 2

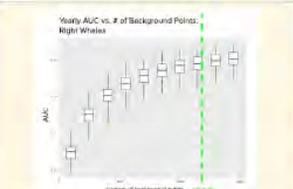


Figure 2: Results of a convergence test for the number of background points going into a right whale model. The x-axis shows the AUC (area under receiver-operator curve) and the y-axis represents a model run at a different number of background points along the x-axis. We ultimately determined the series to converge at 1200 background points, shown by the green dashed line.

Comparing effect of new covariate layers on species

We next ran a set of models to study the effect of supplementing current predictor layers, which are from direct survey data, with derived layers: integrated chlorophyll-a, sea surface temperature slope, and bathymetry slope. The new models, shown in the lower row of Fig. 4, markedly rely on the integrated chlorophyll, which is meant to emulate the total accumulation of energy as the *Calanus* graze on phytoplankton. Notably, the right whale model fits our ecological understanding of the food web (Fig. 3); it relies on this cumulated chlorophyll when *Calanus* begins to enter diapause and aggregate, making it easier for whales to find food on them. This climatological reliance suggests that integrated chlorophyll is a suitable proxy for *Calanus*, for which there is no current method to track directly. We also observe the other predictors assume a certain amount of model contribution.

In Figure 5, the hindcast for fin whales on July 28, 2018 shows the predictive difference of before (a) and after (b) adding the three calculated predictive layers, depicted by the rows in Fig. 4. One main goal of cumulative chlorophyll was to fill in some of the patchiness evident in (a), which is successful on a small scale as seen in (b). Congruent with higher AUC for model (b), we observe low correlation between model prediction and observation (green) in the left plot, whereas the same correlation is higher in the right plot.

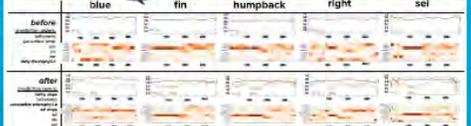


Figure 4: Across five whale species, comparing annual models before and after adding three predictor layers (bathymetry slope, cumulative chlorophyll-a, and sea surface temperature slope). The top graph for each model shows the AUC in black, with a y-axis from 0 to 1, illustrating how well the model fits observation. The x-axis for all charts is time by day of year (DOY), starting on the left in January. The orange lower plot for each model shows the percent contribution each predictor makes to the model; a vertical line across all variables sums to 100% of the model's contribution. Of the new layers, cumulative chlorophyll makes the largest impact, compared to the before counterparts. All other models have higher annual AUCs than their before counterparts.



Figure 5: Output for the MaxEnt model in the form of hindcasts showing likelihood of encountering a fin whale on 2018-07-28. In green as shown the observations from the same day. In (a), the hindcast model predicts out addition of the three predictors mentioned in Fig. 4 and the sections above, and serves as a control for (b). Note addition of cumulative chlorophyll-a, sea surface temperature gradient, and bathymetry gradient. Note the strong contour given by the regional restriction of bathymetry in (a), depths beyond which have been further indicated in (b).

Conclusions

- Initially constraining certain parameters made qualitative analysis of following models easier.
- Integrated chlorophyll-a provides considerable contribution to the planktivorous *E. glacialis*
- chlorophyll-a as an effective proxy for zooplankton abundance.
- Our test for data score indicates that the variety of data scores perform similarly.

Acknowledgements

We recognize the support of the National Science Foundation for the Bigelow Laboratory REU program NSF Grant OCE 1904481. REU site: Bigelow Laboratory for Ocean Sciences - Undergraduate Research Experience in the Gulf of Maine and the World Ocean awarded to DAF. Special thanks to Hunter Johnson of DePaul University for his whale observation dataset and to David Penland of the New England Aquarium.

Future Directions and Implications

- A more thorough investigation of data type and score
- This preliminary model provides incentive for conducting surveys in regions of high likelihood but no efforts made, to contribute to a larger scale, improved model
- Incorporate "opportunistic" data score i.e. from Whale Watch
- Incorporate other predictor layers: particulate inorganic/carbon/diatom

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Bigelow's REU Program 2020

Day and Night Influences on the Zooplankton community in a Coastal Environment

Molly Spencer¹, Maura Niemisto², David M Fields²; (1) University of Southern Maine, Biological Sciences, Portland, ME, United States, (2) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States

Despite zooplankton being a crucial part of every marine ecosystem, there is a lack of data describing day-night changes in their vertical distribution in the Gulf of Maine; more specifically, the population's diurnal vertical migration (DVM). This synchronized vertical movement of zooplankton within the water column is an important behavioral strategy to avoid visual predation. In this study, we analyzed the diversity and abundance of zooplankton species over the course of a diel cycle within the coastal waters of the Damariscotta River. Our data revealed that diversity between day and night samples did not differ, however, certain abundances of specific zooplankton species were significantly higher at night compared to the day. For example, *Acartia tonsa* and *Evadne nordmanni* abundances increased by 238% and 86% during the nighttime. Similarly, barnacle nauplii showed a more than 2 fold increase in abundance at night, a 129% change in size. Diverging from this pattern is the considerably smaller copepod species *Oithona*, which displayed a 20% decrease in abundance during the nighttime. These results suggest that zooplankton predators such as larval fish and other planktivores may benefit from the higher abundances of zooplankton in the upper water column at night. Further research will investigate species-specific migratory behavior and the impact these migrations have on the grazing rates of economically important species that rely on these prey during early developmental stages.

Day and Night Influences on the Zooplankton Community in a Coastal Environment



Molly Spencer¹, Maura Niemisto², David Fields, Ph.D.²
University of Southern Maine¹, Bigelow Laboratory²



Introduction

Despite zooplankton being a crucial part of every marine ecosystem, and subsequently the marine economy, there is a lack of research regarding their patch dynamics off the Gulf of Maine; more specifically, their diel vertical migration (DVM). This synchronized vertical movement of zooplankton within the water column is an important behavioral strategy to avoid visual predation. Several studies of potential influences on DVM in zooplankton communities have been assessed, such as predation¹, light availability², endogenous drive³, and general body condition^{4,5}, but few have studied these dynamics in shallow-bodied environments. Our research proposes a further look into zooplankton populations within the coastal waters of the Damariscotta River with reference to day and night conditions. We are interested specifically in analyzing the change in zooplankton abundance and species diversity in their day-time and night-time presence within a shallow water column.



Fig. 1 Sampling site in the Damariscotta River, off Bigelow Laboratory's Pier: 43°51'37.9"N 69°34'41.5"W

Materials and methods

- Quantitative, vertical net tows taken from Bigelow Laboratory's pier (Fig. 1), located in East Boothbay, Maine. A total of 8 tows were taken for this study; five day-time and three night-time tows.
- Zooplankton were collected with a 1.5m long, 30 cm diameter, 150-µm-conical net. Tows were taken at a depth of 6 meters, approximately 3 meters above the bottom.
- Environmental data collected by CTD profiler
- Samples stored in 10% ethanol preservative, were subsampled into 5 mL aliquots, and ID'd down to the lowest possible taxonomic level.
- Zooplankton abundance expressed as number per liter
- Standard T-test applied for day and night zooplankton abundance, along with the application of Shannon diversity index

Results

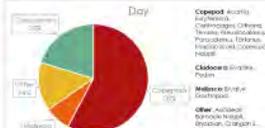


Fig. 2 Diversity of Average Day Samples: Zooplankton abundances were grouped into four separate classes, with Copepods and Cladocera making up over half of the population within this site. The Shannon Diversity Index value for the daytime environment was 2.47, falling in line with typical values seen in ecological studies

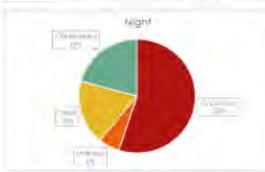


Fig. 3 Diversity of Average Night Samples: This chart shows the average composition of a night sample. Nighttime sample composition did not deviate far from daytime; Copepods and Cladocera accounted for over half of the population within the water column. Shannon Diversity Index value for the nighttime was 2.42, still within average values seen in ecological studies.

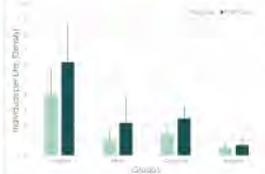


Fig. 4 Average (+/-SD) Concentration for all organisms in Day and Night samples: This graph illustrates the average number of animals perceived (grouped similarly to Fig. 2 and 3) within the water column in both day and night samples. We found no significant difference in the abundance of organisms between day and night samples (t-test; p=0.073)

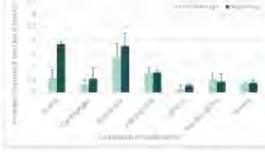


Fig. 5 Average Copepod Concentration (+/-SD) in Day and Night samples: These copepod species made up the majority of copepods seen within our samples. *Acartia* were the only copepod species to show a statistically significant abundance difference (t-value of 0.0005) in day-night variations. *Acartia* exhibited a 238% increase in night sample abundance

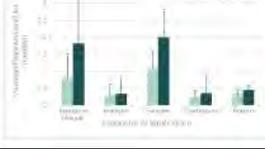


Fig. 6 Average (+/-SD) other specific Organisms of Significance: Densities in Organisms of Significance: These species of zooplankton made up a large portion of what was seen in day and night samples, with *Evadne* (marine cladocera) showing a 16% increase in night time abundance, and barnacle nauplii a 130% increase.

Conclusions

- Species richness and evenness within this coastal environment's day vs night populations are similar given both Shannon diversity values falling in the 2-4 range. Both values exhibit standard diversity.
- Acartia tonsa* exhibit a significant difference in DVM behavior in day and night samples, but this does not seem to be a predominant influence in all copepod species. Other zooplankton observed, such as *Evadne nordmanni* and barnacle nauplii, also displayed a notable DVM behavior influenced by daytime and nighttime periods.
- Zooplankton abundances on average were higher at night compared to during the day, however, the data was not statistically significant under a marginal alpha of 0.05. The collection of more data would likely find a statistical difference in day-night abundances.
- These results have important implications for trophic dynamics and food availability within marine coastal foodwebs. Further research will investigate species-specific migratory behavior and their impact on grazing rates in economically important species that rely on these prey during early developmental stages.

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Acknowledgments

We recognize the support of the National Science Foundation for the Bigelow Laboratory REU program (NSF Grant OCE 1910443) - REU Site: Bigelow Laboratory for Ocean Sciences-Undergraduate Research Experience in the Gulf of Maine and the World Ocean awarded to DMF. Funding for this project was also provided by SeaGrant NA16OAR417038-DCU1233, awarded to DMF. Special thanks to M. Niemisto, Dr. R. Lesley-Rasch, Dr. D. Fields, and the staff at Bigelow Laboratory for their support during the REU program.

Bigelow's REU Program 2020

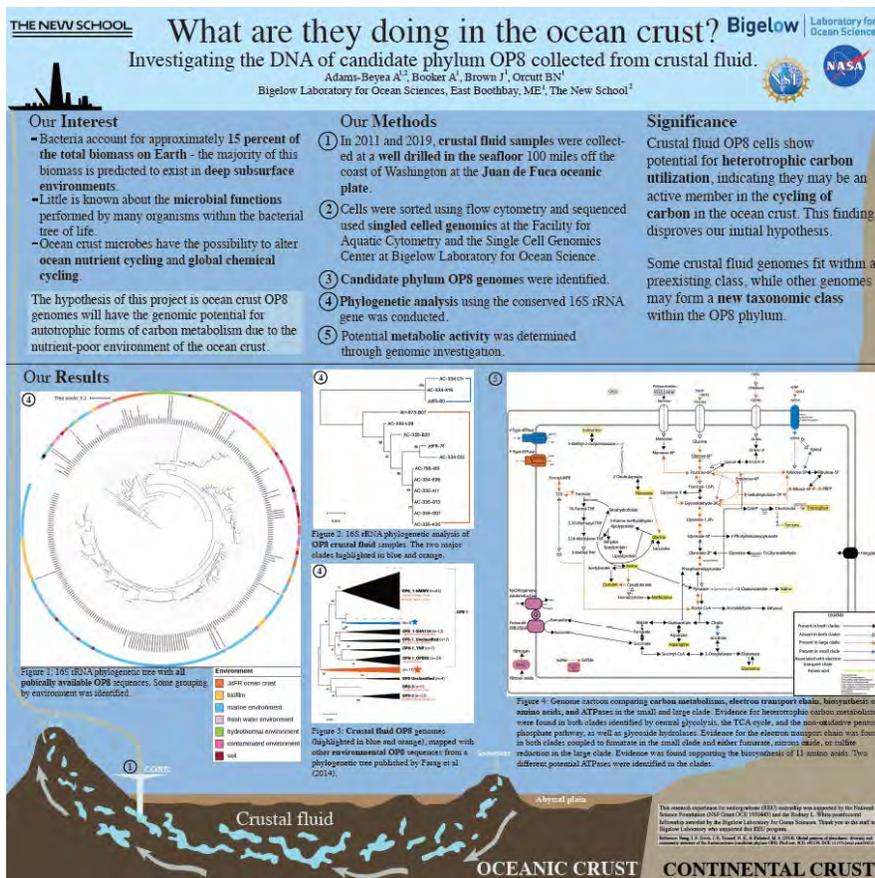
What are they doing in the ocean crust? Investigating the DNA of candidate phylum OP8 collected from crustal fluid.

Adams-Beyea A^{1,2}, Booker A¹, Brown J¹, Orcutt BN¹

Bigelow Laboratory for Ocean Sciences, East Boothbay, ME¹, The New School NYC NY²

Little is known about the microbial life that terrestrial and oceanic subsurface environments support. The subsurface of the ocean, the ocean crust, is composed of porous rock through which seawater circulates. As fluid circulates through the crust, water-rock interactions provide nutrients for the microorganisms that live in this extreme environment. This project aims to study a largely unresearched group of bacteria found in the ocean crust that could contribute to a wealth of undiscovered information including new life strategies, additions to the genomic tree of life, and a deeper understanding of ocean nutrient cycling and global chemical cycling.

Two research cruises in 2011 and 2019 traveled 100 miles off the coast of Washington State in the Pacific Ocean to the Juan de Fuca oceanic plate. There, crustal fluid was accessed through a well drilled into the crust. Cells were isolated from crustal fluid samples using flow cytometry at the Facility for Aquatic Cytometry and genomic DNA was sequenced using single-cell genomic techniques at the Single Cell Genomics Center at Bigelow Laboratory for Ocean Science. Candidate phylum OP8 cells were identified in samples from both research cruises indicating that this bacteria is an active and consistent member of the ocean crust microbial community. This project investigates 16 crustal fluid origin OP8 genomes aiming to learn what types of carbon this organism is utilizing in the ocean crust. The hypothesis of this project was ocean crust OP8 genomes will have the genomic potential for autotrophic forms of carbon metabolism due to the nutrient-poor environment of the ocean crust. However, our searches found compelling evidence that ocean crust OP8 use heterotrophic forms of carbon metabolism, indicating that this bacterial phylum may be an active member in the carbon cycling occurring in the ocean crust. Additionally, this project used 16S rRNA phylogenetic analyses to review all publically available OP8 sequences to determine where the crustal fluid OP8 cells fit within this phylum. Based on this comparison, two of our crustal fluid OP8 genomes fit within a preexisting class, while the other group may form a new class. This research adds to the limited knowledge about the carbon cycling role crustal fluid OP8 may play in the ocean crust environment.



Bigelow's REU Program 2020

Thursday, July 30

Bigelow's REU Program 2020

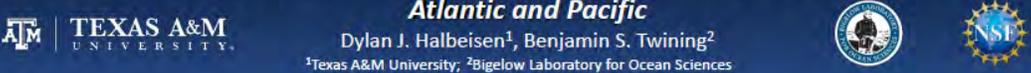
The Power of Three: Comparing Upper Ocean Dissolved, Particulate, & Phytoplankton Trace Metal Micronutrient Stoichiometries Within and Between the Atlantic and Pacific.

Dylan J. Halbeisen¹, Benjamin S. Twining², (1)Texas A&M University, College Station, TX, United States; (2)Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States.

Macro & micronutrient stoichiometries are considered to occur in a relatively consistent ratio, the “Extended Redfield ratio”, throughout the dissolved, particulate, and cellular nutrient pools of the ocean [Bruland et al 1991; Sunda 1997]. The presumed Extended Redfield Ratio is important because it is used to approximate cellular metal quotas. In this study we investigated the presumed consistent ratio between macro & micronutrient stoichiometries to evaluate the extent of presumed consistency. We used data collected on two U.S. GEOTRACES cruises (Pacific: EPZT; Atlantic: NAZT) and the programming language R, to compare dissolved, particulate, and phytoplankton stoichiometries, and calculate basin-scale particle fraction percentages to provide biogeochemical context to departures in the Extended Redfield Ratio. We found that dissolved stoichiometries are consistently lower than biogenic stoichiometries and are offset by a factor of 1-5 both amongst metals and between basins. There is a distinct difference in metal particle fraction distribution between the Atlantic (lithogenic) and Pacific (biogenic). Stoichiometric decoupling likely occurs due to scavenging and varying labilities of authigenic and lithogenic fractions. The Extended Redfield Ratio was found to decouple in the Atlantic and Pacific. For these reasons, the lithogenic and authigenic particle fractions should be considered when inferring controls on micronutrient cycling and equating biogenic with dissolved and particulate stoichiometries.

The Power of Three: Comparing Upper Ocean Dissolved, Particulate, & Phytoplankton Trace Metal Micronutrient Stoichiometries Within and Between the Atlantic and Pacific

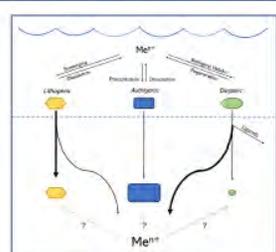
Dylan J. Halbeisen¹, Benjamin S. Twining²
¹Texas A&M University; ²Bigelow Laboratory for Ocean Sciences



Introduction

- Micronutrient trace metals (Fe, Mn, Co, Cd, Ni, Cu, & Zn) are essential cofactors in many biomolecules crucial for phytoplankton development and sustenance (Morel & Price 2003).
- Phytoplankton require different metals to build biomolecules and carry out biochemical reactions (Twining & Behren, 2013).
- It is generally accepted that Macro & micronutrients follow a relatively consistent ratio, “Extended Redfield Ratio” (Redfield 1958, Bruland et al. 1991).
- Terrestrial dust is deposited by global wind patterns, and supplies ocean basins with varying concentrations of particles containing metals (Jickells et al. 2005).
- The varying concentration of metals deposited by these global wind patterns helps make the biogeochemistry of each ocean basin uniquely different.
- Furthermore, the varying concentration of surface and upper ocean micronutrient trace metals influence the rate and productivity of phytoplankton (Froelich et al. 2003).
- Phytoplankton are essential as they serve both as the base of the marine food-web and key contributors to the Earth's Carbon and Nitrogen Cycles.

The Power of Three: Particle Fractions



Hypotheses:
 We hypothesize that there is a consistent decoupling between macro and micronutrient stoichiometries within and between the Atlantic and Pacific for:

- These particles are more than plankton
- These particles undergo different rates of remineralization/regeneration.
- Regenerated/Remineralized metals are scavenged

All of which influence the concentration of micronutrients in the water-column and phytoplankton biomass, respectively.

Element Stoichiometries

Deviations between Metal:P boxplots and the dashed blue line indicate decoupling of macro and micronutrient stoichiometries.

Note: Iron and Manganese scales vary between basins.

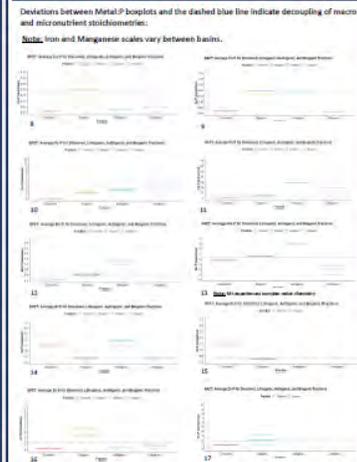


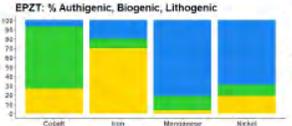
Figure 9-13 Pacific: EPZT (R, S, L, J, A, U, S), NAZT (R, J, L, S, L, S, L, S). Average Metal:P (Phytoplankton ratio (nmol/mol) for dissolved and particulate (Biogenic, Authigenic, Lithogenic) metal stoichiometries. The dashed blue line depicts the proposed “Extended Redfield Ratio” presented in work by Bruland et al. 1991, Sunda et al. 2003.

- Except for Nickel, dissolved stoichiometries are consistently lower than biogenic stoichiometries amongst metals and between basins.
- Biogenic and dissolved stoichiometries are offset by a factor of 1-5 between metals and basins.

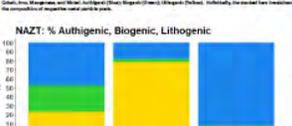
Methods

- Full water-column samples were collected on two U.S. GEOTRACES cruises: Pacific: EPZT GPS; Atlantic: NAZT GADL.
- Dissolved and particulate macro & micronutrients were collected, filtered, and analyzed under standard GEOTRACES procedures.
- The Twining lab collected surface phytoplankton samples during both cruises and measured plankton Metal : Carbon by synchronous X-ray fluorescence.
- Using R, we compared stations three ways to estimate the influence of biological uptake and remineralization in TP, TPL, and dissolved Metal:P stoichiometries.
 - We calculated the mean TP & TPL Metal:P ratio for the suite of bioactive trace metals in the surface mixed layer (0-100m).
 - and calculate the dissolved ratio of Metal:P for the surface mixed depths (250-1000m) via linear regression.
- We will analyze phytoplankton metal species, measured directly by Synchrotron X-ray fluorescence, to compare across basins and depths.
- Finally, Using the total particulate / Labile, and phytoplankton data, we calculated the % size fraction for each metal in both basins.

EPZT: % Authigenic, Biogenic, Lithogenic



NAZT: % Authigenic, Biogenic, Lithogenic



Conclusions

- Lithogenic and authigenic particle fractions should be considered when inferring controls on micronutrient cycling and equating biogenic with dissolved and particulate stoichiometries.
- There is a distinct difference in metal particle fraction distribution between the Atlantic (lithogenic) and Pacific (biogenic).
- Unlike N:P, Dissolved and micronutrient stoichiometries are often decoupled, likely due to scavenging and different labilities of authigenic and lithogenic fractions.

Acknowledgements

We would like to thank the crew of R/V Thomas G. Thompson and R/V Knorr for their leadership at sea. We also thank those in the GEOTRACES community for their contribution towards the EPZT17 data product. We would like to thank Dr. Alessandro Tagliabue for his contribution and preliminary collaboration. Support for this project was provided by NSF Grant 1550443 (REU) Site: Bigelow Laboratory for Ocean Sciences – Undergrad Research Experience in the Gulf of Maine and the World Ocean. Lastly, we would like to thank the faculty & staff of Bigelow for their committed effort towards hosting the Summer 2020 REU program.



Bigelow's REU Program 2020

Simulating hydrocarbon gradients in the water column with mesocosms

Cameron Carlson^{1,2}, Dr. Christoph Aeppli², David Fields²

University of Alaska Anchorage¹, Bigelow Laboratory for Ocean Sciences²

To conduct experiments on zooplankton response to oil spill treatments, we need a laboratory system which can simulate the gradient of hydrocarbon concentration down a water column. For this purpose, we constructed two-meter-tall tanks to hold marine water and copepods, to which treatments of undispersed and dispersed oil are added. These mesocosms simulated the expected small gradient of undispersed oil and more pronounced gradient of dispersed oil. Additionally, the system corroborated the increased concentration of crude oil hydrocarbons in seawater exposed to dispersed oil, as compared to undispersed oil.



Simulating hydrocarbon gradients in the water column with mesocosms

Cameron Carlson^{1,3}, Dr. Christoph Aeppli³, Dr. David Fields³, Sam McNeely^{2,3}
University of Alaska Anchorage¹, University of North Carolina Wilmington², Bigelow Laboratory for Ocean Sciences³



Abstract

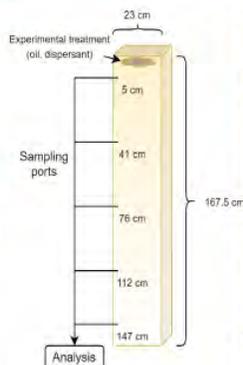
To conduct experiments on zooplankton response to oil spill treatments, we need a laboratory system which can simulate the gradient of hydrocarbon concentration down a water column. For this purpose, we constructed two-meter-tall tanks to hold marine water and copepods, to which treatments of undispersed and dispersed oil are added. These mesocosms simulated the expected small gradient of undispersed oil and more pronounced gradient of dispersed oil. Additionally, the system corroborated the increased concentration of crude oil hydrocarbons in seawater exposed to dispersed oil, as compared to undispersed oil.

Introduction

In the event of an oil spill in a marine environment, a common technique for remediation is the application of chemical dispersants: surfactants which disperse the oil into droplets in the water column. This technique is effective at removing most of the spilled oil by increasing the rate of biodegradation, a consequence of the dispersion and increased surface area of the lipid-aqueous interface. At the same time, this remediation technique could potentially be posing a greater risk to marine life than untreated oil. Dispersed oil is more likely to impart toxic effects to plankton such as copepods. When dispersed, oil more easily releases toxic hydrocarbon compounds, such as polycyclic aromatic hydrocarbons (PAHs) into the water. Additionally, the reduced size of oil droplets increases the risk of oil being directly ingested by copepods (such as *Calanus finmarchicus*). This risk suggests that application of chemical dispersants may not be the most ecologically friendly technique. However, the ability of *Calanus spp.* to dive several hundred meters in the water column in a single day potentially mitigates this risk. If *Calanus spp.* can detect crude oil gradients in the water column and respond by diving, then it may be appropriate to apply dispersants to oil spills even during the active season of copepods. This interaction is difficult to simulate in normal toxicity experiments, which are performed in shallow systems.

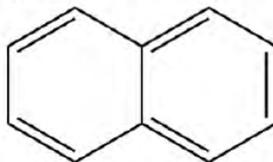
We are testing the potential for copepod oil detection and vertical movement by simulating oil gradients in the marine environment with mesocosms. These mesocosms are two meters tall aquaria, to which *C. finmarchicus* are added, and at the top of which oil and dispersants are applied.

Methods



Experimental treatments: We added 300 *C. finmarchicus* to the mesocosm for each experiment. Four experiments received crude oil to the surface of the water, and one experiment received a mixture of crude oil and dispersant.

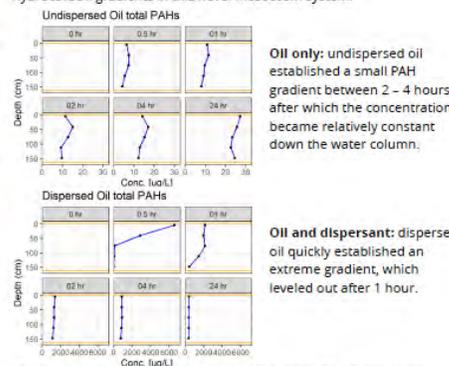
Data collection: Sample ports collected water at each depth at timepoints of 0, 0.5, 2, 4, and 24 hours. Additionally, cameras constantly captured images of copepods to observe vertical movement.



Analysis of PAHs: A fluorometer quantified the concentration of PAHs for each sample.

Results and Conclusion

As of July 24, 2020, we have performed four replicates of mesocosms tested with oil and no dispersant, as well as one experiment of a mesocosm tested with oil and dispersants. One of the replicates of oil only is an outlier, probably due to insubstantial air flow mixing. While this replicate will be revelatory when compared with copepod vertical distribution data, it is unimportant for evaluating the establishment of hydrocarbon gradients in this novel mesocosm system.



Oil only: undispersed oil established a small PAH gradient between 2 - 4 hours, after which the concentration became relatively constant down the water column.

Oil and dispersant: dispersed oil quickly established an extreme gradient, which leveled out after 1 hour.

The mesocosm apparatus was capable of simulating a hydrocarbon gradient, although, as expected, at a shorter timescale than would be expected in a true marine environment. The gradient, as well as the overall concentration of PAHs, was much more pronounced for the samples of dispersed crude oil, as compared to undispersed crude oil.

Acknowledgments

We recognize the support of the National Science Foundation for the Bigelow Laboratory REU program (NSF Grant OCE 1950443) - REU Site: Bigelow Laboratory for Ocean Sciences - Undergraduate Research Experience in the Gulf of Maine and the World Ocean awarded to DMF. Funding for this project was also provided by ADAC awarded to CA and DMF. Special thanks to Erin Belme, Maura Niemisto, and the staff at Bigelow Laboratory for their support during the REU program.

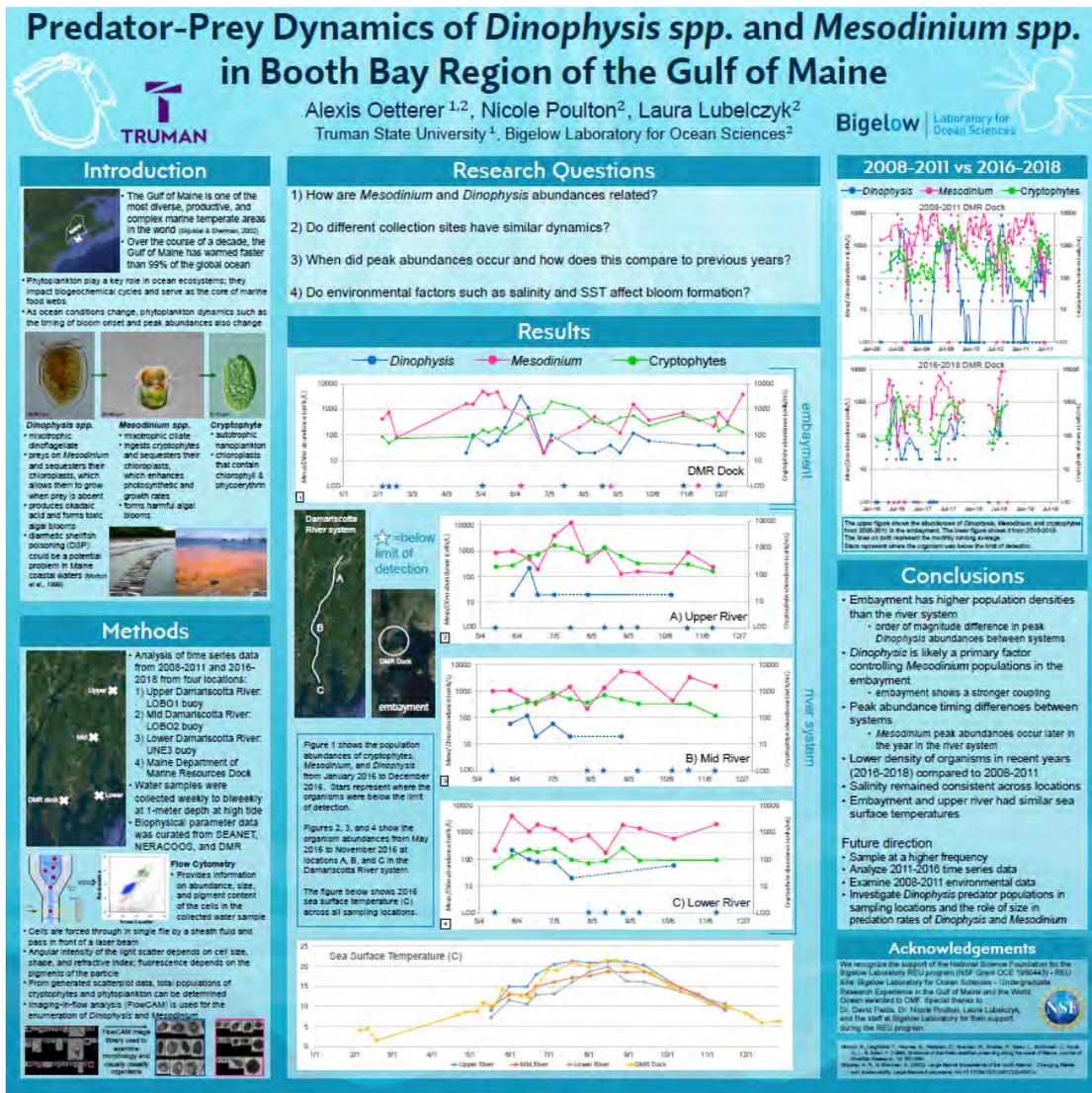
Bigelow's REU Program 2020

Predator-prey dynamics of *Dinophysis* spp. and *Mesodinium* spp. in Booth Bay region of the Gulf of Maine

Alexis Oetterer¹, Laura Lubelczyk², Nicole Poulton²

Truman State University, Kirksville, MO, United States¹, Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States²

Many dinoflagellates and ciliates are known for their ability to use chloroplasts from ingested prey. The toxic dinoflagellate *Dinophysis* and the ciliate *Mesodinium* are two genera of mixotrophic phytoplankton known to form harmful algal blooms and can acquire phototrophy. These harmful blooms can negatively impact other organisms and the aquaculture industry through the production of toxins. Over the course of a decade, the Gulf of Maine has warmed faster than 99% of the global ocean. As ocean conditions change, phytoplankton dynamics such as the timing of bloom onset and peak abundances also change. In this study we investigated the predator-prey dynamics of *Dinophysis* and *Mesodinium* spp. Both are known to possess plastids of cryptophyte origin. *Dinophysis* preys on *Mesodinium* and sequesters its chloroplasts. *Mesodinium* preys on cryptophytes and retains its chloroplasts. Water samples were collected weekly to biweekly at three sites in the Damariscotta River and one site in Booth Bay Harbor. Traditional flow and imaging cytometry were used to enumerate these organisms. Time series population data from 2008-2011 and 2016-2018 was analyzed in conjunction with physical data. Our results show that the embayment had higher population densities than the river system, up to an order of magnitude difference for *Dinophysis* peak abundances. The embayment has a more coupled system and *Dinophysis* is likely a primary factor controlling *Mesodinium* populations. Analysis of 2016-2018 populations compared to 2008-2011 populations revealed lower densities of these organisms in recent years.



Bigelow's REU Program 2020

An Analysis of the Trends of Phytoplankton Fluorescence along the Maine Coast

Allegra Y Rocha¹, Abigail S Tyrell² and David M Fields², (1) University of the Pacific, Stockton, CA, United States (2) Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, United States.

Over the past century, both sea surface temperatures and precipitation have increased in the Gulf of Maine, which could potentially disrupt the growth and reproduction of phytoplankton over time. In this study, we analyzed data from the Damariscotta River Estuary and Gulf of Maine to determine whether there were any changes in the amount of phytoplankton in this region. Trends of phytoplankton were quantified using *in vivo* fluorescence as a proxy for plankton biomass. Fluorescence was measured at four sampling sites during Sept.-Nov. from 2012 through 2019. Although there were no statistically significant trends in fluorescence over time, there was an increasing trend in chlorophyll concentration at one location during this sampling period. Warming temperatures and increased precipitation appear to be potentially fueling shorter and higher biomass blooms in the phytoplankton population. These results suggest that greater secondary production, including important aquaculture species, may be influenced by changes in climate during this period. Further research is necessary to determine how these important Maine ecosystems may be influenced by climate change.

An Analysis of the Trends of Phytoplankton Fluorescence along the Maine Coast

Allegra Y Rocha¹; Abigail S Tyrell²; David M Fields²
¹University of the Pacific, ²Bigelow Laboratory for Ocean Sciences

Background

Phytoplankton

- Phytoplankton serve as primary producers making up the base of the aquatic food web and contribute to over 50% of global oxygen production. Their populations can be tracked over time by measuring *in vivo* fluorescence, which serves as a proxy for phytoplankton biomass by measuring the amount of chlorophyll-a in a water sample.
- Rise in Sea Surface Temperatures
 - The sea surface temperatures in the Gulf of Maine have been rising at a rate faster than 99% of the world's oceans¹. Rises in SST can cause increased stratification which can limit primary productivity.
- Increase in Precipitation
 - Maine has been experiencing a rise in the amount of precipitation recorded annually over the past century². Precipitation leads to nutrient runoff, influencing the growth and reproductive patterns of phytoplankton.

Results

Figure 1. Mean fluorescence across the fall months from 2012-2019. All months were statistically significantly different (Tukey's HSD, $p < 0.05$, following two-way ANOVA, $F_{(1,1)} = 23.94$, $p < 0.001$). Station had no effect on the mean fluorescence (two-way ANOVA, $F_{(3,1)} = 1.17$, $p = 0.32$), and there was no interaction ($F_{(3,1)} = 0.31$, $p = 0.80$).

Results (cont.)

Figure 3. Depth profile of CHL at the Station 4 sampling site from Sept.-Nov. in 2016.

Depth Profile

- ~70% of the measured fluorescence occurs in the upper water column, above 30m
- Fluorescence decreases after the beginning of the seasonal phytoplankton bloom in September

Objective

- How has the measured phytoplankton fluorescence changed over time along the Maine Coast?

Materials and Methods

- Data was collected from 2012-2019 at four sampling sites off the coast of Maine, each with a different ecological profile; stations 1-3 being more greatly influenced by the profile of the Damariscotta River.
- A Seabird SBE - 55 Frame ECO Water Sampler, equipped with an ECO FL fluorometer was deployed at each of the four sampling sites various days across the years of data collection.
- Analysis of the data was performed using R

Conclusions

Despite the short time period, the data show a 67% increase in CHL concentration over the 8 years of measurements. Warmer temperatures and increased precipitation appear to be potentially fueling shorter and higher phytoplankton biomass blooms. These results suggest that greater secondary production, including important aquaculture species, may be influenced by changes in climate during this period.

Station 2 - Sept. Mean Chlorophyll Concentration

Figure 2. Chlorophyll concentration from 2012-2019 in the month of September at the Station 2 sampling site. The equation of the line was Fluorescence = Date * 0.000422 - 5.24, $F_{(1,1)} = 1.33$, $p = 0.27$.

Future Research

- Data can be collected daily at Station 2 over the course of several weeks to develop a closely observed time frame
- The construction of a mesocosm will allow for a closer look at how phytoplankton directly respond to changes in variables in water condition
- Collecting previous years' weather patterns may offer insight into whether temperature or nutrient availability along the Gulf of Maine may be more closely correlated to influencing the trends of phytoplankton observed

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Bigelow's REU Program 2020

The Hunt for Carnivorous Algae and Solar-Powered Sea Creatures: Creating Gene-Based Predictive Trophic Models for Unicellular Mixotrophic Organisms

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The term “phago-mixotroph”, in the context of unicellular life, describes an organism that is capable of both photosynthesis and phagocytosis. Historically viewed as biological anomalies, mixotrophs (specifically mixotrophic plankton) are now understood to be extraordinarily common in the upper water column, with an estimated 50% of protozooplankton having the potential to photosynthesize [Flynn, 2019]. In order to gain a greater understanding of the trophic composition of aquatic communities, we created a new gene-based predictive trophic model using the Burns 2017 Trophic Mode Prediction Tool. Phago-mixotrophic organisms were represented by genome and transcriptome data from 14 phylogenetically diverse organisms observed to have a phago-mixotrophic lifestyle. Our outgroup of organisms lacking phago-mixotrophy was composed of 29 eukaryotes from groups as diverse as animals, plants, fungi, and photo-autotrophic green and red algae. After training the predictive model on those two groups, our results suggest there may be a common set of proteins linking phago-mixotrophic organisms, despite independent origins of the trait in different lineages. Further analysis of the molecular functions identified by the model may provide clues to genes relevant for maintaining a phago-mixotrophic lifestyle. This new predictive gene set may also help us assess the trophic composition of any mixed DNA sample.

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Creating Gene-Based Predictive Trophic Models for Unicellular Mixotrophic Organisms

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Background

- **Phago-mixotroph** – an organism capable of both photosynthesis and phagocytosis
- Trophic composition of unicellular communities is **difficult** to assess using **traditional lab techniques**
- Current gene-based predictive tools are **limited** in phago-mixotroph prediction capabilities.

Goal

Create a model to predict the trophic lifestyle of **any** unicellular organism.

Methods

1. Train

- 14 known phago-mixotrophs
- 29 known non-mixotrophs

2. Run

- Identify shared proteins within training sets
- Create groupings

3. Test

- 66 genomes with unknown trophic modes
- Run in both new and current models

4. Compare

- Analyze and compare the results of the 2 separate runs.

Figure 1. PCA plot placing the training sets into groupings based on common proteins.

Results

Figure 2. Gene ontology heat map for mixotrophs and non mixotrophs.

There is a set of **common proteins** linking phago-mixotrophic organisms together despite independent origins of the trait.

The new model could assess the trophic composition of **any mixed DNA sample.**

Figure 3. Current model's phagotroph PCA plot of the 66 test genomes.

Figure 4. New mixotroph model's mixotroph PCA plot of the 66 test genomes.

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Bigelow's REU Program 2020

Global Trends in the Biogeography of Coral Recruitment

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Coral reefs are increasingly threatened by large scale disturbances such as prolonged and severe heat waves which induce bleaching, especially in the last two decades. A recent meta-analysis revealed that, from 1970 to 2014, coral recruitment on standardized settlement tiles has shifted poleward. This study aims to augment the database and compare global trends in the biogeography in coral recruitment from the temporal periods 1970-1999 and 2000-2019. Coral recruit densities on tiles and associated metadata were extracted from 40 peer-reviewed journal articles using Webplotdigitizer, adding 910 unique data points and 153 new sites to the database. From 1970 to 2000, peak recruit densities occurred at 15° latitude. However, the lack of deployments of settlement tiles in equatorial regions before 1990 may influence this value. After 2000, the geographic extent of tile deployments was distributed more evenly across latitudes. Peak recruit densities shifted poleward to greater than 20° latitude, with unusually high recruit densities occurring even as high as 30° latitude. Using a 20° latitude inflection point, we also explored temporal trends in recruitment in the tropics and subtropics: in both regions, recruit densities have remained below 160 ind./m² since the last major El Niño in 2015, and the original trend of increasing recruitment at higher latitudes has ceased. Further study of larval supply and coral recruitment rates at high latitudes during this intensifying warming period will clarify to what extent reefs can escape the heat and recolonize in subtropical refugia.



Global Trends in the Biogeography of Coral Recruitment

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Introduction

- Coral reefs are increasingly being threatened by large-scale disturbances such as coral bleaching, which contributes to a global decline in coral density and cover.
- Coral recruitment, the process by which coral larvae settle and establish themselves on the reef, is one of the key mechanisms that determines the recovery of a reef after disturbances.
- Sexual reproduction is the only means through which decimated coral colonies can be rejuvenated, either by quickly re-establishing a once heavily-populated reef with new recruits, or through building colonies outside of their original range.
- Settlement plates or tiles are a popular method used to measure coral recruitment density due to their low cost, decreased impact, and highly replicable nature.



Annual coral spawning in the Maldives | Temecotta settlement plates

- From the 1970s to 2014, corals have been recruiting at slower rates in the tropics and establishing new reefs in the subtropics, indicating a slight poleward shift in latitude.
- However, in the last twenty years some of the worst bleaching events have occurred, and there has been an increased interest in conducting coral recruitment studies from 2012 onwards (Figure 1).
- Gaining a better understanding of biogeographic trends in coral recruitment during this intensifying warming period will provide better insight regarding the extent to which sexual reproduction has continued to aid coral reef recovery and if and how reefs can be recolonized by hard corals.

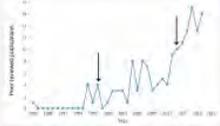


Figure 1. Number of peer-reviewed papers involving "coral settlement" and "tiles" published each year from 1970 to 2020. Arrows mark years in which major El Niño events occurred (1998-1999, 2014-2016).

Methods

Literature Search:

- Identify relevant peer-reviewed papers using various qualifications
- Papers/data found using:



Data Extraction:

- Use Webplotdigitizer to extract data
- Enter coral recruit densities and related meta-data into database

Data Analysis:

- Use scatter plots and regressions

Results

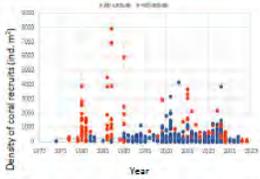


Figure 4. Density of coral recruits (ind./m²) over time with outliers removed

Coral recruit density over time:

- There is a general trend over time of coral recruitment severely declining below 20 degrees latitude, and coral recruitment increasing above 20 degrees latitude (Figure 4)
- Trend of increasing recruitment at higher latitudes is short-term: ceases after 2015, when a large El Niño event occurred (Figure 4)
 - Since 2015, recruit densities have remained below 160 ind./m² in both regions (Figure 4)
- Outliers: densities from Hawaiian islands have low influence on dataset, so were removed from Figure 4

Results

Summary of database additions:

- 40 papers identified
- 910 new recruit densities extracted from 153 new sites
- Doubled the database in 3 weeks



Figure 2. Global map of study sites (n=301) created using ArcGIS, with orange dots representing sites sampled from 1970-1999 and blue dots representing sites sampled from 2000-2020

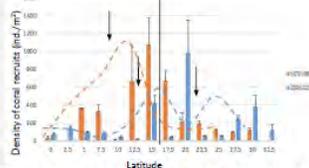


Figure 3. Average coral recruit density (ind./m²) across latitude for the time periods: 1970-1999 (orange) and 2000-2020 (blue)

Discussion

- There is a definitive and continual trend in the reduction of coral recruits below 20° and a periodic spike in the number of recruits above, but it still does not compensate for the major loss in coral recruits occurring across all latitudes.
- While it is expected that coral recruitment would be the highest at even lower latitudes in the 1970s-1999, this can be explained by the lack of studies happening at the equator during early coral reef research.
 - If more research had been conducted in the coral triangle earlier, a more dramatic latitudinal shift might have been observed over time
- Further research includes:
 - Investigate if trends in coral recruitment are consistent across reproductive strategy
 - Conduct fieldwork in unstudied sites by measuring coral recruitment densities to continue compiling the global database

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Project Goals

- Augment the global database
- Compare trends from 2000-2020, a period of bleaching events unprecedented in both number and intensity and midpoint for the time series, to coral recruitment trends in the 1970s-2014.

Hypothesis:

In 2000-2020, coral density will continue decreasing in tropical regions, but increase in sub-tropical regions and these rates are similar to those found in the Price et al. study

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