Update Report

Period: 2/1/2014 - 1/31/2015

Project: R/SFA-1 - *Impacts of ocean acidification on wild and farmed mussels in Puget Sound, WA*

STUDENTS SUPPORTED

Crosson, Lisa, lisa418@uw.edu, University of Washington, School of Aquatic & Fishery Sciences, status: cont, field of study: Infectious Disease, advisor: Carolyn Friedman, degree type: PhD, degree date: 2016-06-01, degree completed this period: No
Student Project Title:
OA curriculum
Involvement with Sea Grant This Period:
RA
Post-Graduation Plans:
Faculty

Guenther, Rebecca, rebecca.guenther@botany.ubc.ca, University of British Columbia, Botany, status: new, field of study: Marine Botany, advisor: Martone, degree type: PhD, degree date: 2016-06-01, degree completed this period: No
Student Project Title:
Mussel byssal thread strength under OA
Involvement with Sea Grant This Period:
RA
Post-Graduation Plans:
Faculty

Loucks, Hailey, hailey.m.loucks@gmail.com, Friday Harbor High School, *no department*, status: new, *no field of study*, *no advisor*, degree type: High School, degree date: 2015-06-01, degree completed this period: No
Student Project Title:
Lab assistant, seasonal patterns in mussel shell strength
Involvement with Sea Grant This Period:
High School intern
Post-Graduation Plans:
college

Newcomb, Laura, newcombl@uw.edu, University of Washington, BIOLOGY, status: new, field of study: Marine Biology, advisor: Carrington, degree type: PhD, degree date: 2016-06-01, degree completed this period: No
Student Project Title:
Mussel attachment in a warmer, high CO2 world.
Involvement with Sea Grant This Period:
Research Assistant
Post-Graduation Plans:
Faculty

Roberts, Emily, earobert@uw.edu, University of Washington, BIOLOGY, status: new, field of study: Marine Biology, advisor: Carrington, degree type: PhD, degree date: 2019-06-01, degree completed this period: No

Student Project Title:
Mussel Dynamic Energy Budgets
Involvement with Sea Grant This Period:
RA
Post-Graduation Plans:
faculty

CONFERENCES / PRESENTATIONS

Roberts, E.A., O'Donnell, M.J., Murray, J.W. & Carrington E. (2014). Seasonal dynamics of seawater conditions and mussel shell strength in the Salish Sea. Poster presentation at the annual meeting of the Western Society of Naturalists, Tacoma, WA. Nov 13-16., public/profession presentation, 600 attendees, 2014-11-13

Newcomb L.A., Carrington, E., George, M,N., and M.J. O'Donnell. 2014. The effects of elevated temperature and pCO2 on mussel attachment strength in a field and laboratory setting. Oral presentation at the Salish Sea Ecosystem Conference, Seattle, WA, USA. May 7-9., public/profession presentation, 100 attendees, 2014-05-07

Newcomb L.A., George, M,N., M.J. O'Donnell, Carrington, E, (2014). Elevated temperatures and pCO2 alter attachment strength of two Mytilus Species. Oral presentation at the Pacific Coast Shellfish Growers Association Annual Conference, Vancouver, WA. July 6 – 11., public/profession presentation, 150 attendees, 2014-07-06

Newcomb L.A., George, M,N., M.J. O'Donnell, Carrington, E, (2014). Elevated temperatures masks the effects of high CO2 on mussel attachment. Poster presentation at the Gordon Research Conference Ocean Global Change Biology, Waterville Valley, NH. September 23 – 25., public/profession presentation, 120 attendees, 2014-09-23

Carrington, E (2014) Mussel adhesion in a warmer, high-CO2 world: an ecomaterial approach. Keynote speaker for the Marine Bioadhesion session of the 17th International Congress on Marine Corrosion & Fouling (ICMCF). 17th International Congress on Marine Corrosion & Fouling (ICMCF) National University of Singapore, July 6-10, 2014., public/profession presentation, 300 attendees, 2014-07-06

Carrington, E (2014).Effects of Ocean Acidification on Shellfish. Invited talk at the Shellfish and the Environment Research Symposium, St. Martin's University, Lacey WA, Dec 8, 2014., SG-sponsored, 300 attendees, 2014-12-08

ADDITIONAL METRICS

P-12 Students Reached:	72	**P-12 Educators Trained:**	0

Private Eye Science Outreach. Friday Harbor Elementary School and

UW Friday Harbor Labs students. Oct-Nov 2014 (60 students, E. Carrington) Spring Street International School Summer Camp, lecture and advised for Salish Sea cruise activity of water sampling for salinity, temperature and pH, Summer 2014 (12 students, C. Friedman)			
Participants in Informal Education Programs: Informal coaching for Friday Harbor High School National Ocean Science Bowl teams.	10	**Volunteer Hours:**	0
Acres of coastal habitat protected, enhanced or restored:	0	**Resource Managers who use Ecosystem-Based Approaches to Management:**	0
Annual Clean Marina Program - certifications:	0	**HACCP - Number of people with new certifications:**	0

ECONOMIC IMPACTS

Description	Patents	Market Impacts ($)	Non-Market Impacts ($)	Businesses Created	Businesses Retained	Jobs Created	Jobs Retained
None	0	0	0	0	0	0	0

SEA GRANT PRODUCTS

Description	Developed?	Used?	ELWD?	Number of Managers	Names of Managers
Summer field camp curriculum on ocean acidification for high school	Yes	Yes	Yes	0	

students.

HAZARD RESILIENCE IN COASTAL COMMUNITIES

No Communities Reported This Period

ADDITIONAL MEASURES

Number of stakeholders modifying practices:	Sustainable Coastal Development **# of coastal communities:**

PARTNERS

Partner Name: National Science Foundation, type: Government, scale: Federal or National
Partner Name: NOAA
Partner Name: Penn Cove Shellfish, type: Industry and Business, scale: Regional
Partner Name: Taylor Shellfish, type: Industry and Business, scale: Regional
Partner Name: Washington Department of Natural Resources, type: Government, scale: State
Partner Name: Westcott Bay Shellfish, type: Industry and Business, scale: Local

IMPACTS AND ACCOMPLISHMENTS

Title: **Washington Sea Grant research probes effects of ocean acidification and warming on farmed and wild mussels in Puget Sound**
Type: impact
Relevance, Response, Results:
Relevance: Valued for culture worldwide, mussels are keystone species, dominating rocky temperate shorelines where they anchor by means of strong byssal threads. Coastal managers and shellfish growers urgently need to understand how acidification and other ocean changes will affect byssal strength and mussel survival.
Response: Washington Sea Grant-supported researchers are studying the interaction, in both laboratory and natural settings, of rising temperature and falling pH on byssal strength in two native mussel species, Mytilus trossulus and M. californianus, and the naturalized M. galloprovincialis. Ongoing research explores the outcome of varying food supply in combination with pH and temperature on byssal strength, and future trials will add low dissolved oxygen to the experimental recipe. The researchers also participate in public and educational outreach, including high school and summer camp curricula on acidification.
Results: The response of each mussel species to acidification varied seasonally with their diverse breeding schedules; effects on byssal strength were less obvious during

breeding, when the animals were already nutritionally stressed. M. galloprovincialis adapted better than M. trossulus in higher salinity. When the temperatures exceeded 20 degrees Celsius, M. trossulus produced fewer byssal threads, M. californianus's production held steady, and M. galloprovincialis produced more threads, giving it a competitive advantage in warmer climates. Additional field tests found that mussels' shells become thinner in summer, when pH drops and metabolism rises.
Recap:
Recap: Washington Sea Grant-supported research on three mussel species investigates the effects of acidification and other ocean changes on mussel attachment strength, which is essential to their survival.
Comments:
Primary Focus Area – SFA
Secondary Focus Area – HCE
Associated Goals: Aquaculture operations and shellfish harvests are safe, environmentally sustainable, and support economically prosperous businesses. (SFA) Ocean and coastal resources are managed using ecosystem-based approaches. (HCE)

Partners:
National Science Foundation
NOAA
Penn Cove Shellfish
Taylor Shellfish
Washington Department of Natural Resources
Westcott Bay Shellfish
Title: Washington Sea Grant research probes effects
Related Partners: *none*

PUBLICATIONS

Title: **Mussels don't stick around in acidic ocean water.**
Type: Reprint from a Newsletter, Magazine, or Other Periodical (not peer reviewed; see RR for peer-reviewed reprints) Publication Year: 2014
Uploaded File: *none*
URL: http: //www.dailyclimate.org/tdc-newsroom/2014/09/acidification-mussels
Abstract:
Ocean acidification impairs mussels' ability to attach to surfaces – alarming commercial growers farming the waters around Puget Sound. If you like your moules marinieres, this is bad news.
Citation:
Llanos, Miguel, 2014. Mussels don't stick around in acidic ocean water. The Daily Climate, September 9 2014.
Copyright Restrictions + Other Notes:
Journal Title: *none*

Title: **Naturally acidic waters of Puget Sound surround UW's Friday Harbor Labs**
Type: Reprint from a Newsletter, Magazine, or Other Periodical (not peer reviewed; see RR for peer-reviewed reprints) Publication Year: 2015

Uploaded File: *none*
URL: http: //www.washington.edu/news/2015/03/12/naturally-acidic-waters-of-puget-sound-surround-uws-friday-harbor-labs/
Abstract:
N/A
Citation:
Hickey H (2015) Naturally acidic waters of Puget Sound surround UW's Friday Harbor Labs. UW Today, March 12.
Copyright Restrictions + Other Notes:
Journal Title: *none*

Title: **Detecting the unexpected: a research framework for ocean acidification.**
Type: Reprints from Peer-Reviewed Journals, Books, Proceedings and Other Documents Publication Year: 2014
Uploaded File: Pfister_etal2014.pdf
URL: *none*
Abstract:
The threat that ocean acidification (OA) poses to marine ecosystems is now recognized and U.S. funding agencies have designated specific funding for the study of OA. We present a research framework for studying OA that describes it as a biogeochemical event that impacts individual species and ecosystems in potentially unexpected ways. We draw upon specific
lessons learned about ecosystem responses from research on acid rain, carbon dioxide enrichment in
terrestrial plant communities, and nitrogen deposition. We further characterize the links between carbon chemistry changes and effects on individuals and ecosystems, and enumerate key hypotheses for testing. Finally, we quantify how U.S. research funding has been distributed among these linkages, concluding that there is an urgent need for research programs designed to anticipate how the effects
of OA will reverberate throughout assemblages of species.
Citation:
Pfister CA, Esbaugh AJ, Frieder CA, Baumann H, Bockmon EE, White MM, Carter BR, Benway HM, Blanchette CA, Carrington E, McClintock JB, McCorkle DC, McGillis WR, Mooney TA, Ziveri P (2014) Detecting the unexpected: a research framework for ocean acidification. Environmental Science & Technology 48: 9982−9994.
Copyright Restrictions + Other Notes:
Journal Title: Environmental Science and Technology

Title: **Mussels as a model system for integrative ecomechanics**
Type: Reprints from Peer-Reviewed Journals, Books, Proceedings and Other Documents Publication Year: 2015
Uploaded File: Carrington_et_al_2015_ARMS.pdf
URL: 10.1146/annurev-marine-010213-135049
Abstract:
Mussels form dense aggregations that dominate temperate rocky shores, and they are key aquaculture species worldwide. Coastal environments are dynamic across a broad range of spatial and temporal scales, and their changing abiotic conditions affect mussel populations in a variety of ways, including altering their investments in

structures, physiological processes, growth, and reproduction. Here, we describe four categories of ecomechanical models (biochemical, mechanical, energetic, and population) that we have developed to describe specific aspects of mussel biology, ranging from byssal attachment to energetics, population growth, and fitness. This review highlights
how recent advances in these mechanistic models now allow us to link them together across molecular, material, organismal, and population scales of organization. This integrated ecomechanical approach provides explicit and sometimes novel predictions about how natural and farmed mussel populations will fare in changing climatic conditions.
Citation:
Carrington E, Waite JH, Sara G, Sebens K (2015) Mussels as a model system for integrative ecomechanics. Annual Review of Marine Science 7: 443-469.
Copyright Restrictions + Other Notes:
Journal Title: Annual Review of Marine Science

OTHER DOCUMENTS

No Documents Reported This Period

LEVERAGED FUNDS

Type: influenced Period: 2014-04-01: : 2015-03-30Amount: $35000
Purpose:
Graduate student fellowship
Source: National Science Foundation

UPDATE NARRATIVE

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Year 1 Progress Report
March 23, 2015

Impacts of ocean acidification on wild and farmed mussels in Puget Sound, WA

Emily Carrington[1] and Carolyn Friedman[2]
[1] Department of Biology and Friday Harbor Laboratories, University of Washington, Friday Harbor, WA
[2]School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA

Project Goal: We hypothesize that high temperature and ocean acidification are key stressors to mussels, and that these external stressors represent a significant energetic demand that can be modulated by food supply and seasonal spawning cycles. Mussel species that differ in reproductive timing (e.g., the native spring spawner *Mytilus trossulus*, the naturalized winter spawner *M. galloprovincialis* and the native continuous spawner *M. californianus*) will have different responses to environmental perturbations. The project will link laboratory studies and field observations to test for causes of seasonal weakening of mussel attachment, which in turn causes substantial mortality due to fall-off (also known as "dislodgment" or "sloughing"). Our results are important in identifying the mechanisms by which natural mussel distributions and aquaculture yields are dependent on local changes in environmental conditions, of either natural or anthropogenic origin.

Our four specific objectives, with our activities to date listed below, are presented here:

1) **Examine the influence of food supply and reproductive state on the independent and combined effects of OA and temperature on mussel attachment in native and naturalized mussel assemblages, identifying the physiological and environmental conditions that lead to mussel fall-off.**
   Progress to date:
   a. Two laboratory experiments have been conducted by graduate student Laura Newcomb, comparing the response of three mussel species to low pH and high temperature in two seasons, spring and winter. Preliminary analyses confirm our previous observations of the negative effects of low pH and high temperature on byssal thread strength. However, the negative effects are less evident during spawning season (spring for *M. trossulus*, winter for *M. galloprovincialis*), presumably because threads in all treatments were already poor quality due to nutritional stress and could not be damaged further by additional external stressors. These and other observations strongly support a dependence of byssus production on energetic state; we are currently seeking separate funding to pursue this idea further.
   b. Laura Newcomb has also explored in some detail the effects of increased temperature on the rate byssus production, showing the response differs among the three species tested. When seawater is warmed above 20°C, the native *M. trossulus* produces fewer threads, the nonnative *M. galloprovincialis* produces more threads, while the native *M. californianus* produces threads at the same rate. The

implication for future warmer climate is a competitive advantage (stronger attachment) for the nonnative species, *M. galloprovincialis*.

c. We are in the midst of another laboratory experiment with the same three species, this time manipulating food supply with different combinations of OA and warming conditions. We do not have any results to report at this time.
d. Future experiments are planned to explore the effects of low dissolved oxygen on byssal thread strength. This line of research is in part based on our observations in objective 2 (below).

2) Quantify the environmental conditions native and naturalized mussels encounter in wild and farmed habitats, at both the macro and microhabitat scale (e.g., near the mussel where their attachment structures are formed).

Progress to date:

a. Partnering with Penn Cove Shellfish, we have deployed two YSI data sondes near mussel rafts in Penn Cove, WA (*M. trossulus*). We partnered with NANOOS (NOAA) to live-stream these data to a public visualization platform. Our preliminary monitoring (since August 2014) indicates threshold values known to weaken byssus (pH < 7.6, temp > 20°C) are exceeded for periods of up to two weeks. We also see that low pH events are coupled with reduced DO and, in some cases, hypoxia. In addition, seasonal freshet events reduce surface salinity and often co-occur with warming in summer and cooling in winter.
b. We have expanded our observation network to Quilcene Bay WA, a site where Penn Cove Shellfish grows *M. galloprovincialis*, partnering with the WA Department of Natural Resources. WA-DNR provided funds to purchase two more YSI data sondes for this site; these data will also be live-streamed to NANOOS and should be available by May 2015.
c. We are developing a partnership with Westcott Bay Shellfish on San Juan Island and hope to secure funding to add this location to our observation network.
d. Due to time and budgetary constraints, we have not monitored conditions for wild mussel populations.

3) Assess the field performance and retention of mussels in both natural and farmed populations.

Progress to date:

a. We now have over one year of monthly mussel attachment and condition measurements at Penn Cove (Laura Newcomb). Mussels show a strong seasonal cycle in attachment strength and preliminary analyses suggest water warming is the best predictor of weak attachment.
b. Two years of observations at Friday Harbor Labs show similar patterns in wild mussels. In addition to weak attachment in summer months, we also observed shell thinning and weakening (Molly Roberts).
c. In October 2014 added two more sites for these monthly monitoring efforts, at Quilcene Bay (Penn Cove Shellfish) and Totten Inlet (Taylor Shellfish). These data are too preliminary to report at this time.
d. Field retention experiments are planned for summer 2015.

4) **Outreach—Develop a high school chemistry curriculum and summer field camp curriculum on ocean acidification.**

Progress to date:

a. We have started on developing the chemistry curriculum, testing pH probes and running salinity-alkalinity curves. This work will be continued in summer 2015.
b. Students participated in a week-long cruise around the Salish Sea and compared water chemistry among sites. They learned how to use Van Dorn water samplers, salinity refractometers, digital thermometers and use and calibrate pH meters. The ~12 students who participated in the project indicated that they enjoyed the exercise and the instructor indicated that they are interested in further exploring this type of research.
c. In Autumn 2014, Emily Carrington continued her science outreach activity with UW FHL students, mentoring 1st grade students at Friday Harbor Elementary School.
d. We have engaged the scientific community and general public through scientific presentations, public talks and workshop participation. We have also shared our results with media outlets. These activities are outlined in the Project Documents and Publications section of this report.