Completion Report

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

Project: R/OCEH-10 - *Effects of ocean acidification on trophically-important crustacean zooplankton of Washington State*

STUDENTS SUPPORTED

Barber, Tiffany, tiffany.barber@noaa.gov, California State University Monterey Bay, *no department*, status: new, *no field of study*, *no advisor*, degree type: BS, degree date: 2016-06-01, degree completed this period: No
Student Project Title:
Effects of Ocean Acidification on the early life stages of the krill, Euphausia pacifica
Involvement with Sea Grant This Period:
Intern
Post-Graduation Plans: *none*

McLaskey, Anna, amclaskey@uw.edu, University of Washington, Oceanography, status: cont, field of study: Biological Oceanography, advisor: J. Keister, degree type: PhD, degree date: 2019-06-01, degree completed this period: No
Student Project Title:
Effects of ocean acidification on crustacean zooplankton.
Involvement with Sea Grant This Period:
Ph.D. student supported through by WSG through this grant. Anna is the lead student on this project.
Post-Graduation Plans: *none*

Raatikainen, Lisa, lraatika@uw.edu, University of Washington, Oceanography, status: cont, field of study: Biological Oceanography, advisor: J. Keister, degree type: PhD, degree date: 2019-06-01, degree completed this period: No
Student Project Title: *none*
Involvement with Sea Grant This Period:
Assisted in field and lab.
Post-Graduation Plans: *none*

CONFERENCES / PRESENTATIONS

Keister JE, McLaskey AK (2014) Testing the effects of ocean acidification on copepod and krill populations. Poster presentation at the Gordon Conference on Climate Change, Waterville Valley, NH, July 8-10., public/profession presentation, 150 attendees, 2014-07-09

Keister JE, McLaskey AK, McElhany P, Olson B (2014) Testing the effects of ocean acidification on copepod and krill populations. Poster presentation at the Eastern Pacific Ocean Conference (EPOC), Timberline, OR, September 17-19., public/profession presentation, 90 attendees, 2014-09-18

McLaskey, AK (2014) Effects of ocean acidification on crustacean zooplankton. Seminar series, Pontificia Universidad Catolica de Valparaiso, Valparaiso, Chile, September 12., public/profession presentation, 20 attendees, 2014-09-12

McLaskey AK (2014) Effects of ocean acidification on crustacean zooplankton. Seminar series, Universidad de Concepción, Concepción, Chile, September 9., public/profession presentation, 35 attendees, 2014-09-09

McLaskey AK, Keister JE, Winans AK, McElhany P, Busch DS, Maher M, Lambert J (2014) Influence of elevated CO2 on the early life history of Euphausia pacifica and Calanus pacificus. Oral presentation at the Salish Sea Ecosystem Conference, Seattle, WA, April 30-May 3., public/profession presentation, 75 attendees, 2014-05-01

McLaskey AK, Keister JE, Winans AK, McElhany P, Busch DS, Maher M, Lambert J (2014) The effects of elevated pCO2 on the hatching and early development of Euphausia pacifica and Calanus pacificus. Oral presentation at the Joint Aquatic Sciences Meeting, Portland, OR, May 20., public/profession presentation, 65 attendees, 2014-05-20

ADDITIONAL METRICS

P-12 Students Reached:

P-12 Educators Trained:

Participants in Informal Education Programs:

Volunteer Hours:

Acres of coastal habitat protected, enhanced or restored:

Resource Managers who use Ecosystem-Based Approaches to Management:

Annual Clean Marina Program - certifications:

HACCP - Number of people with new certifications:

ECONOMIC IMPACTS

No Economic Impacts Reported This Period

SEA GRANT PRODUCTS

Description	Developed?	Used?	ELWD?	Number of Managers	Names of Managers
Protocols for measuring impact of seawater chemistry on early life stages of crustacean zooplankton.	No	Yes	No	0	
Data on susceptibility of early life stages of crustacean	Yes	Yes	No	3	Paul McElhany, Shallin Busch,

zooplankton to changes in seawater chemistry.	Chris Harvey

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: NOAA

Partner Name: Ocean Inquiry Project

Partner Name: Suquamish Tribe

Partner Name: Western Washington University

IMPACTS AND ACCOMPLISHMENTS

Title: **Worse for krill than for copepods: Washington Sea Grant research reveals new ocean acidification impacts on keystone zooplankton species**

Type: impact

Relevance, Response, Results:

Relevance: Ocean acidification's (OA) harmful effects have been clearly demonstrated in some marine species, but little was known about how acidification affects crustacean zooplankton. Research to date had revealed mixed, highly species-specific responses and no published information on the acidification-impacted waters of Puget Sound. Because crustacean zooplankton are fundamental to marine food webs regionally and worldwide, understanding acidification's effects is critical to marine predictive capacity and management response.

Response: A Washington Sea Grant-supported research team collaborated to examine OA's effects on the early growth, survival, and vertical distribution of two keystone zooplankton species, the copepod Calanus pacificus and the krill Euphausia pacifica. The project combined laboratory experiments with field observations in Puget Sound's Hood Canal.

Results: Field results showed that young copepods stayed near the surface and were not exposed to severely low-pH (acidified) water, but significant numbers of krill larvae inhabit deeper water with a lower pH level. Laboratory experiments showed that copepod-hatching success declines in low-pH water, but variability is high and some broods show strong success despite acidified conditions. The krill larvae were

more severely affected, suffering slower growth and higher mortality at reduced pH levels. This suggests krill populations may decline as acidification progresses, affecting the fish, seabirds, and mammals that depend on them Widely disseminated via media and public forums, these findings are already influencing the acidification policy debate and Washington State's response.
Recap:
Recap: Washington Sea Grant-supported research quantifies differential impacts of ocean acidification on the distribution, growth, and survival rates of Puget Sound zooplankton species essential to the marine food web.
Comments:
Primary Focus Area: OCEH (HCE)
Secondary Focus Area: COCC (HRCC)
Associated Goals: Improve understanding and management of emerging and cumulative threats to ocean and coastal health. (HCE Science)
Improve understanding of coastal hazards and environmental change and develop tools and approaches for observation, prediction, planning and adaptation. (HRCC Capacity)
Partners:
NOAA
Ocean Inquiry Project
Suquamish Tribe
Western Washington University
Related Partners: *none*

PUBLICATIONS

No Publications Reported This Period

OTHER DOCUMENTS

No Documents Reported This Period

LEVERAGED FUNDS

Type: influenced Period: 2014-09-08: : 2014-09-15Amount: $10000
Purpose:
Travel funds for graduate student (Anna McLaskey) to communicate results of research to foreign collaborators.
Source: Universidad de Concepción, Concepción, Chile

COMPLETION NARRATIVE

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Effects of ocean acidification on trophically important crustacean zooplankton of Washington State.
Julie Keister and Paul McElhany
Final Report

Project Goals
This project was a collaboration between the University of Washington and the NOAA NWFSC to investigate the effects of ocean acidification (OA) on zooplankton populations through experimental manipulations and field studies. Compared to most regions of the ocean, Puget Sound waters experience very low pH as a result of the high-CO_2 content of upwelled source waters that enter the Sound, as well as biological activity within the estuary. The goal of this project was to quantify the variation in pH currently experienced by crustacean zooplankton in Hood Canal, and to use this information to test the response of crustacean zooplankton to current and future projected pH levels using laboratory experiments. This project focused on the early life stages of two important crustacean zooplankton—the copepod *Calanus pacificus* and the euphausiid (krill) *Euphausia pacifica*. These are two ecologically important species in food webs of Washington State and throughout much of the North Pacific. The responses of these zooplankton species to ocean acidification is being used to inform existing food web models and to help predict the effects of OA on the regional ecosystem and fish production.

Field Observations
In Year 1 of the project, we completed two research cruises to Hood Canal, WA to characterize the chemistry and zooplankton species distributions in late spring (April) and early summer (June). During each cruise, we sampled two stations in the north end of Hood Canal during the day and night to characterize the diel movements of our target species. We collected physical and chemical data using CTD casts and collected water samples from discrete depths for spectrophotometric pH, Dissolved Inorganic Carbon (DIC), and Total Alkalinity (TA) analyses.

During each sampling we collected zooplankton using two types of nets: a fine-mesh (75 µm), closing ring net lifted vertically to sample the small, early life stages of copepods, and a coarser-mesh (335 µm), 5-net MultiNet® sampling system which was obliquely towed at 1-2 kts to capture the larger, strongly-swimming organisms. Both types of net were sampled across five depth strata (approximately 0-10, 10-20, 20-50, 50-100, and >100 m) at each station to characterize depth distributions.

In the field, we found that pH was >8.1 near the surface, declined sharply to <7.8 by 15-20 m depth, then gradually declined to <7.6 near bottom (Fig. 1). As expected, pH was slightly lower at depth in June than in April. Unexpectedly, day

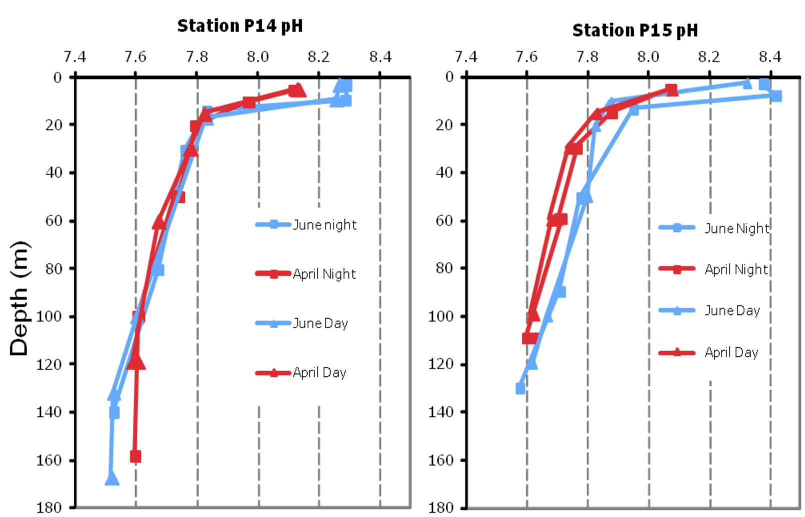

Figure 1. Depth profiles of pH measured by spectrophotometer in northern Hood Canal in April and June, 2012.

and night values at each depth were very similar, even near surface where primary production was expected to cause a large diel decrease in pH. Early life stages (particularly eggs and the youngest nauplii) of both *C. pacificus* and E. *pacifica* were concentrated in the upper layers in both day and night; older stages occupied deeper layers during the day and moved toward surface at night (Fig. 2; night plots not shown). The majority of eggs and nauplii of *C. pacificus* were found in high pH waters above the pycnocline, but a significant portion of euphausiid eggs and nauplii were found in pH 7.7-7.8 (20-50 m depth). Some nauplii of all stages were found at all depths sampled, probably from eggs which sank and hatched at depth.

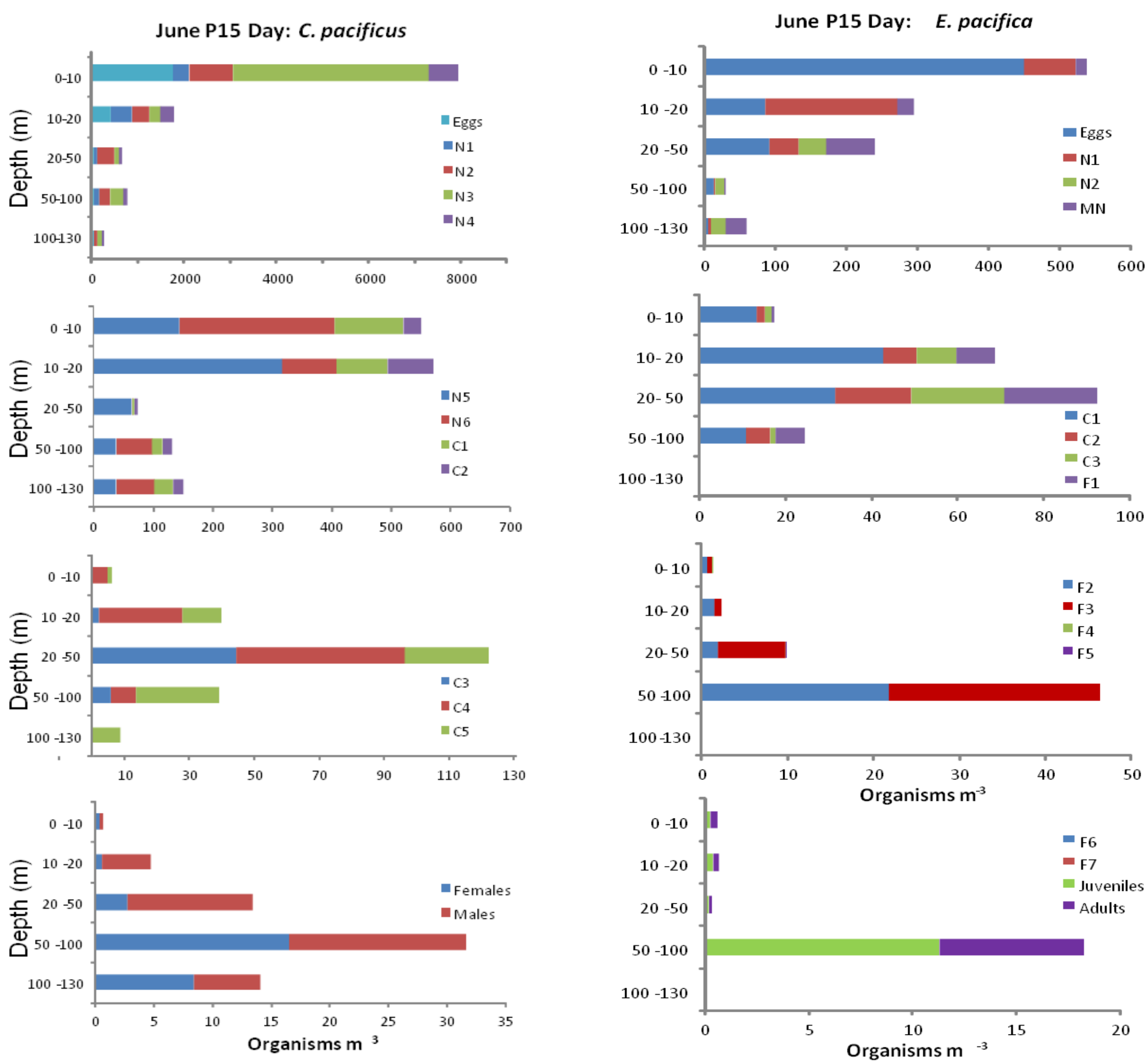

Figure 2. Depth distributions of *Calanus pacificus* and *Euphausia pacifica* in northern Hood Canal during the day in June, 2012. Life stages are ordered from youngest (top) to oldest (bottom) of each panel. Note that widths of the depth bins are not equal.

Experimental Methods and Results

Experiments in 2012 and 2013 were conducted at the NOAA NWFSC OA facility in Montlake, Seattle. The facility consisted of a series of temperature-controlled treatments systems that deliver water with controlled pH/pCO_2. Carbon chemistry was maintained with membrane contactors (LiquiCel) for gas stripping and by controlled bubbling of air, CO_2, CO_2-free air, O_2 and N_2 into a tank dedicated to bubbling. Treated water then moved to a header tank where automated measurements of pH (Durafet® probe), dissolved oxygen, conductivity, and temperature were taken. Water from this tank also flowed through an equilibrator, and the pCO_2 in the equilibrated air was measured with a Licor® gas analyzer. The carbon chemistry was regularly calibrated and verified by spectrophotometric pH, DIC, and TA measurements.

Adult females were collected from Puget Sound for experiments. Healthy females were individually distributed into 125 ml jars (for copepods) or 500 ml jars (for euphausiids) of pre-equilibrated treatment water and held at 12˚C. The following morning, females were removed and her eggs were counted. Copepods were maintained on the flow-through system; euphausiids were maintained in closed jars with water changes each two days. Eggs and larvae were incubated under treatment conditions until approximately half had reached the first feeding stage (Nauplius stage 3 for copepods; Calyptopis stage I for krill). At the end of the experiment, larvae were sorted into live and dead groups and preserved in 5% buffered formalin for counting and staging. Hatching success was calculated from the initial egg counts and the number of hatched larvae found at the end of the experiment, survival from the proportion of live hatched larvae, and development from the proportion of the hatched larvae that had reached first feeding stage.

Calanus pacificus

We tested the copepod *Calanus pacificus* for changes in egg hatching success and timing of development to the 3rd naupliar stage (the 1st feeding stage) as a proxy for growth rate. Four experiments were completed using treatment pCO_2 levels that are commonly found in Washington State marine waters: ~400 (pH 8.0) and 1600 µatm (pH 7.4): a high pCO_2 level found in deep, restricted waters of Puget Sound and predicted for future upwelling conditions 2400 (pH 7.3); and an extreme future deep-water condition 3200 (pH=7.2). Because these experiments were extremely labor-intensive, we were restricted to testing two CO_2 conditions at a time, always testing either 400 or 800 µatm as a control, plus one higher pCO_2 level. We found that hatching was significantly decreased at 2400 and 3200 µatm pCO_2 compared to 400 and 800 µatm controls, but the development rate of nauplii that successfully hatched was not strongly

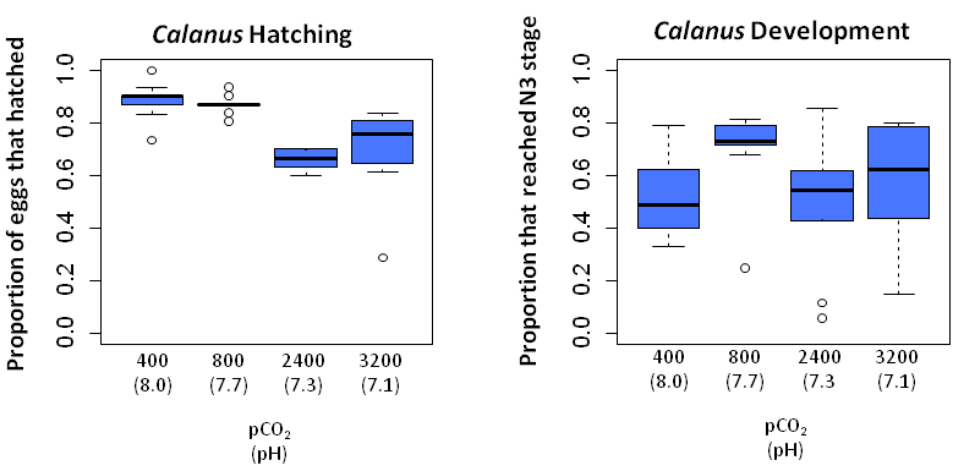

Figure. 3. The relationship between experiment pCO_2 level and *Calanus pacificus* hatching and development in laboratory experiments.

affected by pCO_2 (Fig. 3). We did not directly assess mortality in these experiments because loss of the tiny nauplii in the flow-through system may have occurred which would bias those results.

Euphausia pacifica

We completed 12 laboratory experiments on *Euphausia pacifica* over two years (2013 and 2014) to test egg hatching success and development rate under pCO_2 levels that are commonly found in Washington State marine waters (400, 800, 1200, and 1600 µatm); a high pCO_2 level found in deep, restricted waters of Puget Sound and predicted for future upwelling conditions (2400 µatm), and an extreme future deep-water condition (3200 µatm). Because it was difficult to collect sufficient spawning females from the field to test more than two pCO_2 levels in any particular experiment, comparisons were run in pairs (i.e., statistical comparisons are only valid across pairs tested). Hatching success was calculated as the percent of eggs that had successfully hatched in each brood by the end of the 6-day experiments. Development (growth) was determined from the proportion of the hatched larvae that reached the first feeding stage (Calytopis 1) over the experiment.

Results of our 2013 experiments revealed that *Euphausia pacifica* hatching success was not significantly affected by pCO_2 levels up to 3200 µatm, but growth was slowed at high pCO_2 levels—the proportion of larvae that reached the first feeding stage over the six-day experiments was significantly reduced at pCO_2 levels of 1600 µatm and higher (Fig. 4). There was also a trend of increasing mortality with increased pCO_2. We noted a significant increase in mortality at 1600 µatm (42.5% mortality) compared to 400 µatm (11.8%) and at 2400 µatm (16.2%) compared to 800 µatm (5.5%). There was also a non-significant increase in mortality at 3200 µatm (18.8%) compared to 400 µatm (9.2%). Because 1600 µatm pCO_2 occurs in the bottom waters of Puget Sound in summer, these effects on growth and survival are likely to impact regional populations.

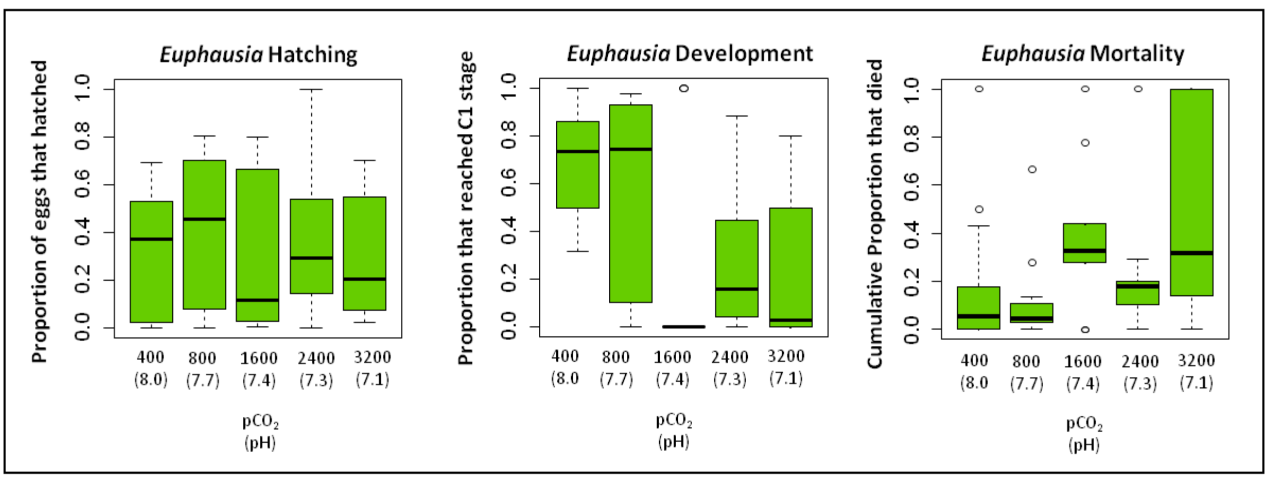

Figure. 4. The relationship between experiment pCO_2 level and *E. pacifica* hatching success, development, and mortality. Each bar shows the distribution of average brood responses within a treatment condition. The thick line represents the median, the box represents the 25th through the 75th percentile, the dashed lines show the range of data excluding any outliers, and circles show outliers. ***Note: these experiments were run in the following pairs: 400v1600, 800v2400, and 400 v3200, therefore direct comparison between 1600 and 2400 µatm is not possible because natural temporal variability in the condition of test animals collected from the field was not controlled for.***

In 2014, we leveraged NSF and Washington Ocean Acidification Center (WOAC) funded research to build on the results obtained on this WSG-funded grant. Our 2013 results had suggested that *Euphausia pacifica* growth is significantly reduced at pCO_2 levels of ≥1600 µatm compared to 800 µatm pCO_2, but we had not tested intermediate levels. Leveraging WOAC funding, we conducted experiments at Western Washington University's Shannon Point Marine Center (SPMC) in 2014 to refine the pCO_2 at which effects on larval krill occur since those intermediate levels are very common in Puget Sound, so are very relevant to population dynamics. We completed three experiments to test egg hatching success and development rate under pCO_2 levels of ~400, 950, and 1300 µatm. We confirmed that *E. pacifica* hatching success is not significantly affected at the pCO_2 levels used in these experiments, and found that development rate is significantly slowed by 1200 µatm pCO_2 (Fig. 5).

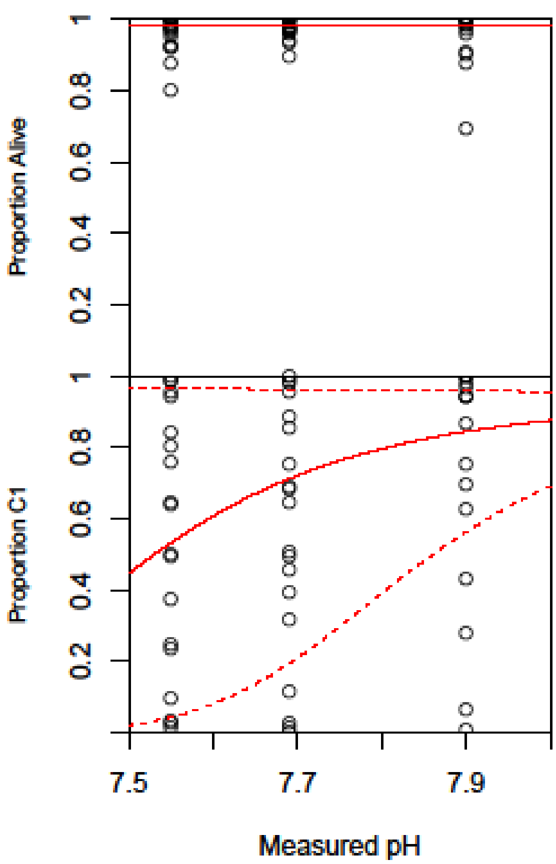

Figure 5. Results of experiments run in 2014 showing the relationship between experiment pCO_2 level and *E. pacifica* survival and development (as proportion that had reached the C1 stage) at ~400, 950, and 1300 µatm pCO_2 . Each point shows the average response of one female's brood within a treatment condition. Solid red lines show the best fit model of survival or development with pH; dashed lines show the 95% CI for the effect of pH on survival and development.

Implications

As trends in OA sensitivity across taxonomic groups are being summarized in the literature, a general idea that crustaceans are broadly tolerant to OA has emerged. However, that idea has been developed based on testing of a small number of different species and life stages. Our results indicate that this idea should be carefully considered and re-examined through broader testing. Our results lend support to that idea that copepods are not highly susceptible to OA, but the negative response of *E. pacifica* larvae to reduced pH that we observed in this study indicates that krill populations that currently inhabit Puget Sound and the California Current are significantly affected by the water chemistry they currently experience, and may be more affected under future conditions. The large, nearly opposite, response to OA between the copepods and krill is interesting, and points to the problem of extrapolating results across taxonomic groups.

In Washington, krill are often concentrated in highly productive areas that are also acidified due to the respiration of organic matter or the upwelling of high-pCO_2 deep waters. This could lead to tradeoffs between habitat where food availability is high versus where suitable pH conditions for larvae occur. The CO_2 levels at which we found significant impacts on krill (1200 μatm and above) currently occur in the bottom waters of much of Puget Sound and in upwelling regions of the Washington coast in summer—so our results are somewhat surprising given that Puget Sound has likely experienced high CO_2 levels during the spring and summer breeding season for 100's of years. These effects on growth are likely to impact regional krill populations, with resultant impacts on the fish and upper food web organisms that depend on them.

Management implications
Through the NOAA PIs on this project, our results have been communicated to fisheries managers for use in ecosystem models of Washington State marine waters. Our study was influential in the development of the Washington State Blue Ribbon Panel on Ocean Acidification's Strategic Response to the developing problem of OA, which recommended expanded funding of laboratory experiments and field studies of the effects of OA on zooplankton. Results of our studies were broadly communicated through a series of talks given by NOAA collaborator Dr. Shallin Busch in events surrounding the WA Blue Ribbon Panel on Ocean Acidification.

Outreach Our research group participated in numerous public and private events that communicated implications of our research to the public, State Legislators, journalists, teachers, and school children. The Ph.D. student supported by this project, Anna McLaskey, gave public presentations on ocean acidification at the Sound Living Communiversity at Everett Community College in Nov., 2013 and to the Camano Island Beach Watchers in March 2014. She presented this research at several conferences and invited lectures (listed below).

PIs Keister and McElhany participated in the Seattle Aquarium's Discover Science events which included a public "Lightening" talk and a booth on ocean acidification co-hosted with Paul Williams from the Suquamish Tribe.

- McLaskey AK, Keister JE, Winans AK, McElhany P, Busch DS, Maher M, Lambert J (2014) The effects of elevated pCO2 on the hatching and early development of Euphausia pacifica and Calanus pacificus. Oral presentation at the Joint Aquatic Sciences Meeting, Portland, OR, May 20.
- McLaskey AK, Keister JE, Winans AK, McElhany P, Busch DS, Maher M, Lambert J (2014) Influence of elevated CO2 on the early life history of Euphausia pacifica and Calanus pacificus. Oral presentation at the Salish Sea Ecosystem Conference, Seattle, WA, April 30-May 3.
- McLaskey AK (2014) Effects of ocean acidification on crustacean zooplankton. Seminar series, Universidad de Concepción, Concepción, Chile, September 9.
- McLaskey, AK (2014) Effects of ocean acidification on crustacean zooplankton. Seminar series, Pontificia Universidad Catolica de Valparaiso, Valparaiso, Chile, September 9

- Keister JE, McLaskey AK, McElhany P, Olson B (2014) Testing the effects of ocean acidification on copepod and krill populations. Poster presentation at the Eastern Pacific Ocean Conference (EPOC), Timberline, OR, September 17-19.
- Keister JE, McLaskey AK (2014) Testing the effects of ocean acidification on copepod and krill populations. Poster presentation at the Gordon Conference on Climate Change, Waterville Valley, NH, July 8-10.
- Busch DS. Ocean acidification and its impacts on commercially important species. Presentation at the Whatcom County Water Information Network Climate Change Symposium, Bellingham, Washington, October 25 2012, public/profession presentation, 80 attendees, 2012-10-25
- Busch DS. The science of ocean acidification. Presentation at the 2012 Marine Resource Committee Coastal Forum and Science Summit. Long Beach, Washington, December 6-8 2012, public/profession presentation, 60 attendees, 2012-12-07
- Busch DS. Ocean acidification and its biological impacts. Presentation at the Snohomish Marine Resource Committee Event, Everett, Washington, January 24 2013, public/profession presentation, 40 attendees, 2013-01-24
- Busch DS. Ocean acidification and its biological impacts. Invited lecture at the University of Idaho, Moscow, Idaho, February 7 2013, public/profession presentation, 100 attendees, 2013-02-07
- Busch DS. Ocean acidification and its biological impacts. Presentation at the San Juan Marine Resource Committee Event, Friday Harbor, Washington, February 27 2013, public/profession presentation, 40 attendees, 2013-02-27
- Busch DS. Ocean acidification in Washington State: from knowledge to action. Presentation at San Juan Marine Managers Workshop, Friday Harbor, Washington, February 27-March 1 2013, public/profession presentation, 40 attendees, 2013-02-28
- Busch DS. Ocean acidification and its biological impacts. Presentation at South Sound GREEN’s Summer Teacher Institute, Olympia, WA, June 19-21 2013, public/profession presentation, 25 attendees, 2013-06-20
- Busch DS. Ocean acidification and its biological impacts. Presentation at the Port Townsend Marine Science Center, Seattle, WA, June 15 2013, public/profession presentation, 60 attendees, 2013-06-15
- Busch DS. Ocean acidification and its biological impacts. Presentation to the King County Regional Water Quality Committee, Seattle, WA, September 4 2013, public/profession presentation, 20 attendees, 2013-09-04
- Busch DS. Biological impacts of ocean acidification. Presentation at Metcalf Institute Climate Change Science Seminar for Journalists, Seattle, WA, September 6-7 2013, public/profession presentation, 40 attendees, 2013-09-06
- McElhany, P (2013) Ecological effects of ocean acidification along the U.S. west coast: Integrating experiments and models. Poster presentation at the 2013 U.S. Ocean Acidification Principal Investigators' Meeting, Washington, D.C., September 18-20, public/profession presentation, 190 attendees, 2013-09-18
- Busch DS, Norberg S, Maher M, Miller J, Reum J, McElhany P (2012) Using experiments and models to address the response of an estuarine food web to ocean acidification. Oral presentation at the Third International Symposium on the Ocean in a High-CO2 World, Monterey, CA, September 24-27, public/profession presentation, 50 attendees, 2012-09-26

- Lambert, J. Effects of ocean acidification on a marine copepod and euphausiid. Presentation to NOAA as part of Hollings Scholarship Program, Washington, D.C., July 30 2013, public/profession presentation, 100 attendees, 2013-07-30
- Busch, DS (2014) Ocean acidification and its biological impacts. Oral presentation at the Island Institute's Marine Ocean Acidification Meeting, Augusta, ME, January 16, public/profession presentation, 72 attendees, 2014-01-16
- McLaskey, AK. The Global Fish Tank: How CO2 emissions are throwing ocean chemistry out of balance. Presentation as part of WSU Snohomish County Extension Beach Watchers' Sound Living 2013, Everett Community College, Everett, WA, November 9 2013, public/profession presentation, 35 attendees, 2013-11-09
- McLaskey AK. Influence of seawater pH on the early life history of the copepod Calanus pacificus and the krill Euphausia pacifica. Biological Oceanography Seminar Series, University of Washington, Seattle, WA, November 5 2013, public/profession presentation, 25 attendees, 2013-11-05
- Keister JE, Tuttle L, McLaskey A, Raatikainen L, Winans A (2013) Zooplankton species diversity complicates measurement and understanding the effects of decreasing oxygen and pH on ecosystems. Oral presentation at the ASLO 2013 Aquatic Sciences Meeting, New Orleans, LA, February 17-22, public/profession presentation, 200 attendees, 2013-02-18
- Keister JE, McLaskey AK, Raatikainen L, Winans A, Herrmann B. (2013) Species diversity in zooplankton responses to hypoxia and elevated pCO2. Oral presentation at the PICES 2013 Annual Meeting, Nanaimo, B.C., Canada, October 11-20, public/profession presentation, 366 attendees, 2013-10-16
- Keister JE. (2013) Ocean acidification: Causes, ecosystem consequences, research directions. Presentation as part of the Seattle Aquarium's Discover Science Weekend, November 6, public/profession presentation, 100 attendees, 2013-11-06

Participants Dr. Paul McElhany's OA staff at NOAA NWFSC were heavily involved in this project, particularly Michael Maher who assisted with sampling and experiment set-up and who had primary responsibility for maintaining the OA lab facilities. Dr. Shallin Busch provided oversight and assistance with statistical analyses and disseminated results and implications of our research to broad audiences; Erin Bohaboy helped maintain the facilities and ran many chemical analyses; Jason Miller helped with routine chemical analyses. The project provided full support for an Oceanography Ph.D. student, Anna McLaskey at the University of Washington. UW Lab technicians Amanda Winans, Rachel Wilborn, and Robin Green conducted field collections and assisted with all experiments. Dr. Brady Olson (Western Washington University) provided the OA facilities at the Shannon Point Marine Center in 2014. Catherine Matson was a long-term citizen volunteer on the project.

Students supported

Numerous graduate and undergraduate students were supported by this project or assisted with field collections and experiments:

- Anna McLaskey, University of Washington, Ph.D. student
- Jason Miller, University of Washington, M.S. student
- Jonathan Lambert, Louisiana State University, B.S. student, NOAA Holllings Scholar
- Tricia Thibodeaux, Bowdin College, B.S. student, NOAA Holllings Scholar
- Bridget Begay, Everett Community College, summer intern

- Tiffany Barber, California State University Monterey Bay, B.S. student, NOAA Office of Education EPP Scholar
- Matthew Grodzins, University of Washington, B.S. student volunteer
- Rebecca Lauzon, Boston College, B.S. student volunteer
- BethElLee Herrmann, University of Washington, B.S. student volunteer
- Immaculata Ajuogu, University of Washington, B.S. student hourly assistant
- Lindsey Sandwick, University of Washington, B.S. student volunteer
- Audrey Djunaedi, University of Washington, B.S. capstone student
- Lisa Raatikainen, University of Washington, Ph.D. student
- Natasia Poinsatte, American University, B.S. student volunteer