Update Report

Period 2/1/2013 - 1/31/2014

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

STUDENTS SUPPORTED

Grodzins, Matthew, matthew6@uw.edu, University of Washington, Oceanography, status new, field of study Oceanography, advisor Julie Keister, degree type BS, degree date 2014-06-01, degree completed this period No Student Project Title none Involvement with Sea Grant This Period assistant Post-Graduation Plans unknown
Herrmann, BethELlee, the1artist@msn.com, University of Washington, Oceanography, status cont, field of study Biological Oceanography, no advisor, degree type BS, degree date 2014-06-01, degree completed this period No Student Project Title none Involvement with Sea Grant This Period Volunteer undergraduate assistant. Post-Graduation Plans none
Lambert, Jonathan, jonathan.e.lambert@noaa.gov, Louisiana State University, Coastal Environmental Science and Marine Biology, status new, field of study Effects of ocean acidification on crustacean zooplankton, advisor Shallin Busch, degree type BS, degree date 2014-05-01, degree completed this period No Student Project Title Effects of Ocean Acidification on a Marine Copepod and Euphausiid Involvement with Sea Grant This Period NOAA Hollings Scholar summer intern Post-Graduation Plans Graduate school at Columbia University
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

Miller, Jason, jason.miller@noaa.gov, University of Washington, SAFS, status new, no field of study, advisor Carolyn Friedman, degree type MS, degree date 2014-08-01, degree completed this period No
Student Project Title OA Effects on Dungeness Crab Larvae

Involvement with Sea Grant This Period Assisted with lab experiments and maintenance of experimental system.

Post-Graduation Plans Will continue work with NOAA.

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

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 S, 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, S (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, A. 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
Anna McLaskey. 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 A, 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. Ocean acidification Causes, ecosystem consequences, research directions. Presentation as part of the Seattle Aquarium's Discover Science Weekend, November 6 2013, public/profession presentation, 100 attendees, 2013-11-06

ADDITIONAL METRICS

K-12 Students Reached	1000	Acres of degraded ecosystems restored as a result of Sea Grant	0

		activities	
Information and personnel from this project were included in a booth organized by the Suquamish Tribe for the Seattle Aquarium's Discover Science weekend which is targeted at families, primarily at the 5th grade level. http //www.seattleaquarium.org/discover-science			
		Resource Managers who use Ecosystem-Based	
Curricula Developed	0	Approaches to Management	0
		HACCP - Number of people with new	
Volunteer Hours	190	certifications	0
Multiple volunteers assisted with field collections of organisms, lab sorting of animals for experiments, conducting lab experiments, and analysis of results.			
Cumulative Clean Marina Program - certifications	0		

PATENTS AND ECONOMIC BENEFITS

Description		Patents	Economic Benefit ($)	Businesses Created	Businesses Retained	Jobs Created	Jobs Retained
None	Actual (2/1/2013 - 1/31/2014)	0	0	0	0	0	0
	Anticipated (2/1/2014 - 1/31/2015)	0	0	0	0	0	0

TOOLS, TECH, AND INFORMATION SERVICES

Description	Developed	Used	Names of Manage	Number of Managers

				rs	
Data on susceptibility of early life stages of crustacean zooplankton to changes in seawater chemistry.	Actual (2/1/2013 - 1/31/2014) Anticipated (2/1/2014 - 1/31/2015)	1 0	1 0	Paul McElhany Shallin Busch Chris Harvey	3
Protocols for measuring impact of seawater chemistry on early life stages of crustacean zooplankton.	Actual (2/1/2013 - 1/31/2014) Anticipated (2/1/2014 - 1/31/2015)	1 0	1 0	Paul McElhany Shallin Busch Chris Harvey	3

HAZARD RESILIENCE IN COASTAL COMMUNITIES

Name of coastal community	County		Number of resiliency trainings / technical assistance services provided	Was community hazard resiliency improved (e.g., via changes in zoning ordinances) ?
None		Actual (2/1/2013 - 1/31/2014) Anticipated (2/1/2014 - 1/31/2015)	0 0	Yes

ADDITIONAL MEASURES

Safe and sustainable seafood

Number of stakeholders modifying practices	Number of fishers using new techniques
Actual (2/1/2013 - 1/31/2014)	Actual (2/1/2013 - 1/31/2014)
Anticipated (2/1/2014 - 1/31/2015)	Anticipated (2/1/2014 - 1/31/2015)

Sustainable Coastal Development
Actual (2/1/2013 - 1/31/2014)
Anticipated (2/1/2014 - 1/31/2015)

Coastal Ecosystems
Actual (2/1/2013 - 1/31/2014)
Anticipated (2/1/2014 - 1/31/2015)

PARTNERS

Partner Name NOAA

Partner Name Suquamish Tribe

IMPACTS AND ACCOMPLISHMENTS

Title Krill cringe but copepods cope Washington Sea Grant research explores ocean acidification effects on crustacean zooplankton

Type impact

Relevance, Response, Results Relevance Crustacean zooplankton are the prey base for most fish, but little is known about how they will be affected by ocean acidification. Research to date has revealed mixed, highly species-specific responses; nothing has been published on effects in the acidification-impacted waters of Puget Sound. Quantifying these effects is critical to fisheries management and predictive ecosystem modeling. At the same time, motivating the changes in thinking and behavior that will lead to effective policies to address the underlying problem requires public education about this and other impacts. Response Washington Sea Grant-supported research combined laboratory experiments and local field observations to investigate acidification's effects on the early growth, survival and vertical distribution of two important zooplankton species, the copepod Calanus pacificus and krill Euphausia pacifica. Species response information from experiments is being used to inform existing regional food web models. Results C. pacificus's hatching success declined significantly in high-CO2 water, but its growth was not significantly affected. E. pacifica showed robust hatching across a wide pH range, but its early development slowed significantly at CO2 levels that occur in Puget Sound's bottom waters during summer. Because these species and their congeners are important in food webs worldwide, the data have broad significance. Researchers engaged legislators, journalists, teachers, and the general public through activities that included speaking at public and private events, involving citizens in the research, and hosting science displays.

Recap Washington Sea Grant-supported researchers quantified the differential growth and survival rates in acidified waters of zooplankton species that are fundamental to the marine food web, and engaged hundreds of citizens, journalists, teachers, legislators and schoolchildren in the issue of ocean acidification.

Comments Primary Focus Area OCEH (HCE) Secondary Focus Area COCC (HRCC) State 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).

Related Partners Suquamish Tribe, NOAA

PUBLICATIONS

Title Ocean Acidification Causes, Consquences, Research Directions.

Type Videos / DVDs Publication Year 2013 Uploaded File none URL http //www.youtube.com/watch?v=_yW1d5XFXRk

Abstract Centers for Ocean Sciences Education Excellence - Ocean Learning Communities (COSEE OLC) and Seattle Aquarium hosted a Lightning Talks program on ocean and marine science. The event was held at Seattle Aquarium on November 6, 2013. Dr. Julie Keister is a biological oceanographer and on faculty at the School of Oceanography and Washington Sea Grant at the University of Washington. Julie presents on ocean acidification and it's effects on the unique Puget Sound ecosystem.

Citation J. Keister. “Lightning Talks Julie Keister - The Effects of Ocean Acidification on the Puget Sound Ecosystem." YouTube. 16 Jan. 2014; 31 March 2013.

Copyright Restrictions + Other Notes

Journal Title none

Title Species diversity in zooplankton responses to hypoxia and elevated pCO2.

Type Internet Resources, Topical Websites Publication Year 2013 Uploaded File none URL http //www.pices.int/publications/presentations/PICES-2013/2013-S4/S4-Day2-1050-Keister.pdf

Abstract The effects of stressors such as hypoxia and ocean acidification on zooplankton are of increasing concern, especially as serious consequences have been demonstrated for many species. But how changes to zooplankton will affect ecosystems as a whole remains largely unknown. We are studying relationships between ocean chemistry and zooplankton in Puget Sound, Washington—a deep fjord in the Pacific Northwest that supports a diverse zooplankton community. In Puget Sound, hypoxia (<2 mg DO l-1) and extremely low pH (<7.5) occur naturally as a result of inputs of upwelled ocean water, high surface production, and restricted circulation; anthropogeniceutrophication and global climate change are increasing the severity of these conditions. In summer and late autumn, when the lowest oxygen and pH occur, conditions are particularly stressful for many organisms, yet abundant zooplankton and fish inhabit the region. How zooplankton behavior, species composition, growth, and energy flow to upper trophic levels are altered by the changing conditions is a focus of our research. Here we will examine zooplankton response to low oxygen and pH from field sampling and laboratory studies. The high variability that we have observed among species indicates that measuring and interpreting the effects on ecosystems will be challenging. Better understanding of

species-level impacts will be necessary to understand how the stressors affect marine ecosystems directly and indirectly.

Citation J. E. Keister, A. McLaskey, L. Raatikainen, A. Winans and B. Herrmann. (2013) Species diversity in zooplankton responses to hypoxia and elevated pCO2. North Pacific Marine Science Organization, PICES 2012 Annual Meeting presentation web resources.

Copyright Restrictions + Other Notes

Journal Title none

OTHER DOCUMENTS

No Documents Reported This Period

LEVERAGED FUNDS

Type influenced Period 2013-07-01 2013-09-30Amount $6444

Purpose Graduate student stipend.

Source NSF IGERT Ocean Change fellowship

Type influenced Period 2013-02-01 2014-01-31Amount $3048

Purpose Volunteer hours to support laboratory experiments.

Source Volunteer hours.

Type influenced Period 2013-06-15 2013-09-15Amount $4468

Purpose Graduate tuition support.

Source NSF IGERT Ocean Change program

Type influenced Period 2013-07-01 2013-11-01Amount $1258

Purpose Funds to graduate student for analysis of alkalinity and dissolved inorganic carbon (DIC) samples in support of field observations.

Source NSF IGERT Ocean Change program

Type influenced Period 2013-02-01 2014-01-31Amount $200000

Purpose NOAA NWFSC laboratory facilities, chemical analyses, and personnel support provided by NOAA

Source NOAA NWFSC

UPDATE NARRATIVE

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

Project Goals

This project is 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 is 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 focuses 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.

Experimental Methods and Results

In 2013, we completed 12 laboratory experiments on *Euphausia pacifica* to test egg hatching success and development rate under pCO_2 levels that are commonly found in Washington State marine waters (400, 800, 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 show that *Euphausia pacifica* hatching success is not significantly affected by pCO_2 levels up to 3200 μatm (Fig. 1). However, growth is slowed at high 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. There was also a trend of increasing mortality with increased pCO_2 (Fig. 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.

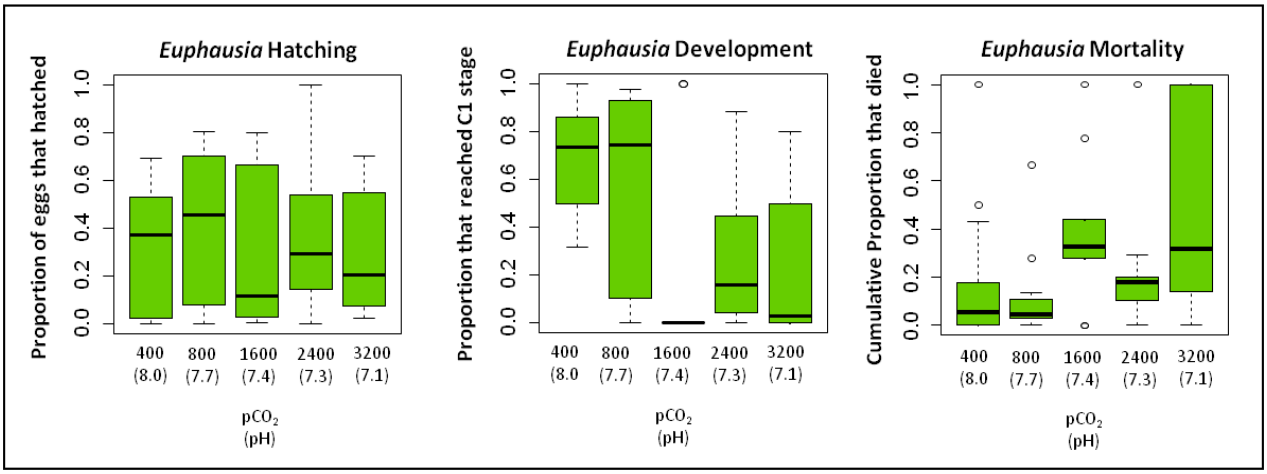

Fig. 1. The relationship between experiment pCO_2 level and *E. pacifica* hatching success, development, and mortality. Each bar shows the distribution of average brood responses within a treatment condition. The thick line represents the median, the box represents the 25th through the 75th percentile, 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.*

We conducted four experiments on *Calanus pacificus* in 2013. Treatments for the *C. pacificus* experiments were 400 (pH 8.0), 1600 (pH 7.4), and 2400 (pH 7.3) µatm. The data from the 2013 experiments are still being compiled, but initial analysis indicates that hatching was significantly decreased at 2400 and 3200 µatm pCO_2 compared to controls, but development rate of nauplii that had successfully hatched was not strongly affected. 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.

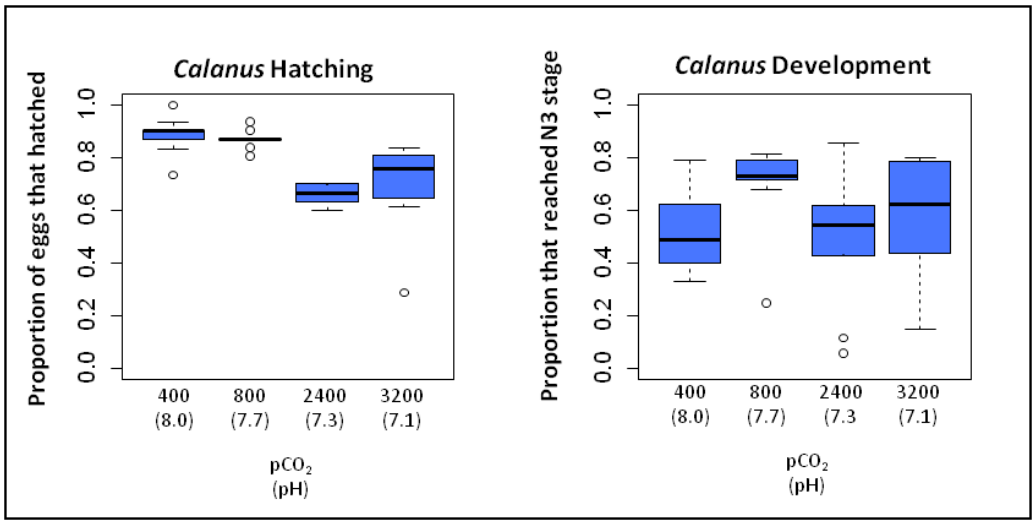

Fig. 2. The relationship between experiment pCO_2 level and *Calanus pacificus* hatching and development in laboratory experiments.

Outreach In 2013, 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 a public presentation on ocean acidification at the Sound Living Communiversity at Everett Community College in Nov., 2013. 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. Results of our studies were broadly communicated through a series of talks given by collaborator Dr. Shallin Busch in events surrounding the WA Blue Ribbon Panel on Ocean Acidification.

Challenges encountered In Year 1 of the project (2012), we had encountered significant problems with high mortality of our text organisms in the NOAA OA lab. We conducted numerous tests to trouble-shoot the problem including tests of handling protocols, types of materials, and the water used in the experiments which eventually revealed that the NOAA OA system water was contaminated from a chemical in the system. Over Winter 2012-13, NOAA conducted a partial re-build and complete clean of the system. Subsequent copepod survival was greatly improved, but we continued to have high mortality of euphausiids, so moved those experiments to an isolated system without flow-through capabilities. We were able to successfully conduct our basic experiments in that manner, but were not able to conduct time-varying pCO_2 experiments as proposed. We hope to be able to piggy-back on upcoming experiments with the Shannon Point Marine Center to conduct those tests this spring.

Continuing plans We have requested a no-cost extension to continue work on this project. This spring and summer, we will continue lab experiments on both *C. pacificus* and *E. pacifica*. We will opportunistically conduct additional experiments in conjunction with newly-funded projects supported by NSF and the Washington Ocean Acidification Center (WOAC). Our priority will be to replicate experiments that we have conducted at pCO_2 level of 400 vs 1600 and 2400 μatm and to fill in lower levels of 400 vs. 1000 and 1200 for C. pacificus since they appear to largely live in ocean surface waters, which are not expected to experience very high pCO_2 levels. If time permits after completing our obligation to our new grants, we will conduct 'time-varying' experiments on krill in which we mimic the slowly decreasing pCO_2 experienced by eggs and nauplii in the field as they sink from near-surface to below the pycnocline.

Participants Dr. Paul McElhany's OA staff at NOAA NWFSC continued to be heavily involved in this project, particularly Michael Maher who assisted with sampling and experiment set-up and who has 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 technician Amanda Winans conducted field collections and assisted with all experiments. Numerous undergraduate students and citizen volunteers assisted with field collections and experiments, and a NOAA Holllings Scholar, Jonathan Lambert, assisted with krill experiments as part of his 2013 summer internship.