Update Report

KEISTER, Julie

Period: 2/1/2012 - 1/31/2013
Project: R/OCEH-10 - *Effects of ocean acidification on trophically-important crustacean zooplankton of Washington State*

:: STUDENTS SUPPORTED

Ajuogu, Immaculata, immacx@uw.edu, University of Washington, *no department*, status:new, *no field of study*, *no advisor*, *no degree type*, *no degree date*, degree completed this period:No

Student Project Title: *none*

Involvement with Sea Grant This Period:
Hourly paid assistant supported by the Louis Stokes Alliance for Minority Participation program.

Post-Graduation Plans: *none*

Begay, Bridget, bbegay92@gmail.com, Everett Community College, *no department*, status:new, *no field of study*, *no advisor*, *no degree type*, *no degree date*, degree completed this period:No

Student Project Title: *none*

Involvement with Sea Grant This Period:
Intern - assisted with field collection of organisms. Everett Community College

Post-Graduation Plans: *none*

Djundaedi, Audrey, auddju@uw.edu, University of Washington, SAFS and Ocean, status:new, *no field of study*, *no advisor*, degree type:BS, *no degree date*, degree completed this period:Yes

Student Project Title: *none*

Involvement with Sea Grant This Period:
hourly paid post-grad intern - supported field and laboratory experiments

Post-Graduation Plans:
Graduate study in Marine Affairs at Simon Fraser University

Hermann, BethELlee, the1artist@msn.com, University of Washington, Oceanography, status:new, field of study:Biological Oceanography, *no advisor*, degree type:BS, degree date:2013-06-01, degree completed this period:No

Student Project Title: *none*

Involvement with Sea Grant This Period:
Volunteer undergraduate assistant.

Post-Graduation Plans: *none*

Lauzon, Rebecca, Rebecca.Lauzon@noaa.gov, Boston University, *no department*, status:new, *no field of study*, *no advisor*, *no degree type*, *no degree date*, degree completed this period:No

Student Project Title: *none*

Involvement with Sea Grant This Period:
NOAA Hollings scholar (not dedicated to this project) who volunteered in the lab and field for us.

Post-Graduation Plans: *none*

McLaskey, Anna, amclaskey@uw.edu, University of Washington, Oceanography, status:new, 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*

Poinsatte, Natasia, Natasia.Poinsatte@noaa.gov, American University, *no department*, status:new, *no field of study*, *no advisor*, *no degree type*, *no degree date*, degree completed this period:No

Student Project Title: *none*

Involvement with Sea Grant This Period:
NOAA Hollings scholar (not dedicated to this project) who volunteered in the lab and field for us.

Post-Graduation Plans: *none*

Raatikainen, Lisa, lraatika@uw.edu, University of Washington, Oceanography, status:new, 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*

Sandwick, Lyndsey, lyndsey.sandwick@gmail.com, University of Washington, Oceanography, status:new, *no field of study*, *no advisor*, degree type:BS, degree date:2013-06-01, degree completed this period:No

Student Project Title: *none*

Involvement with Sea Grant This Period:
General volunteer - assisted with field collections and experiments.

Post-Graduation Plans: *none*

Thibodeau, Tricia, tricia.thibodeau@noaa.gov, Bowdoin College, *no department*, status:new, *no field of study*, *no advisor*, degree type:BS, degree date:2013-05-01, degree completed this period:No

Student Project Title: *none*

Involvement with Sea Grant This Period:
Hollings Scholar intern, supported by NOAA.

Post-Graduation Plans:
Graduate school

:: CONFERENCES / PRESENTATIONS

Conference oral presentation: Julie E. Keister, Anna McLaskey, Lisa Raatikainen, Shallin Busch, Amanda Winans and Paul McElhany. Oxygen and pH conditions experienced by zooplankton in a North Pacific fjord: Impacts on taxonomic composition, distributions, and growth. Oral presentation at the North Pacific Marine Science Organization's PICES 2012 Annual Meeting, Oct. 12-21, Hiroshima, Japan., public/profession presentation, 466 attendees, 2012-10-16

:: ADDITIONAL METRICS

K-12 Students Reached: 0

Acres of degraded ecosystems restored as a result of Sea Grant activities: 0

Curricula Developed: 1

Resource Managers who use Ecosystem-Based Approaches to Management: 0

Incorporated results of experiments into graduate level Zooplankton Ecology 'Ocean change' lecture in OCN 532A.

Volunteer Hours: 100

HACCP - Number of people with new certifications: 0

Undergraduate volunteers:
Lyndsey Sandwick (UW undergraduate, ~20 hrs)
BethElLee Hermann (UW undergraduate, ~10 hrs)

Hollings Scholars:
Tricia Thibodeau (Bowdoin undergraduate, ~50% of summer internship)
Natasia Poinsatte (Boston U undergraduate ~10 hrs)
Rebecca Lauzon (American University undergraduate, ~10 hrs)

Undergraduate supported by LSAMP:
Immaculata Adjuogu (20-40 hrs?)
(Immaculata may have helped start set up before

2/1/12)

Citizen volunteers:
Janice Jensen (~15 hrs)

Cumulative Clean Marina Program certifications: 0

:: PATENTS AND ECONOMIC BENEFITS

No Benefits Reported This Period

:: TOOLS, TECH, AND INFORMATION SERVICES

No Tools, Tech, or Information Services Reported This Period

:: HAZARD RESILIENCE IN COASTAL COMMUNITIES

No Communities Reported This Period

:: ADDITIONAL MEASURES

Safe and sustainable seafood

Number of stakeholders modifying practices
Actual (2/1/2012 - 1/31/2013) :
Anticipated (2/1/2013 - 1/31/2014) :

Number of fishers using new techniques
Actual (2/1/2012 - 1/31/2013) :
Anticipated (2/1/2013 - 1/31/2014) :

Sustainable Coastal Development
Actual (2/1/2012 - 1/31/2013) :
Anticipated (2/1/2013 - 1/31/2014) :

Coastal Ecosystems
Actual (2/1/2012 - 1/31/2013) :
Anticipated (2/1/2013 - 1/31/2014) :

:: PARTNERS

Partner Name: NOAA

Partner Name: Ocean Inquiry Project

Partner Name: Suquamish Tribe

:: IMPACTS AND ACCOMPLISHMENTS

Title: **Washington Sea Grant-supported research shows the impacts of ocean acidification on two keystone zooplankton species**

Type: accomplishment

Description:
Relevance: Ocean acidification's detrimental effects of have been clearly demonstrated in some marine species.

But little is known about how it will affect crustacean zooplankton, the prey base for most fish. Research conducted 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. Because the species studied and their congeners are important elements of food webs worldwide, such an effort also would have broader significance.
Response: This Washington Sea Grant-supported collaborative project examines acidification's effects on the early growth, survival, and vertical distribution of two trophically important zooplankton species, the copepod Calanus pacificus and euphausiid (krill) Euphausia pacifica. It combines field observations in Hood Canal (a sub-basin of Puget Sound) and laboratory experiments.
Results: Field results show that young C. pacificus stay near the surface and are not exposed to severely low-pH (acidified) water, but a significant share of E. pacifica larvae inhabit deeper water with pH under 7.8. Laboratory experiments show that the hatching success of C. pacificus declines in low-pH water and deformation rates increase slightly. But variability is high, and some broods show strong hatching success despite acidified conditions.

Recap:
Washington Sea Grant-supported researchers have quantified for the first time in acidified waters the varying distribution, growth and survival rates of zooplankton species that are fundamental to the marine food chain.

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).

Related Partners: Ocean Inquiry Project
Northwest Fisheries Science Center (US DOC, NOAA, NMFS, NWFSC)
Suquamish Tribe

:: PUBLICATIONS

Title: **Oxygen and pH conditions experienced by zooplankton in a North Pacific fjord: Impacts on taxonomic composition, distributions, and growth.**

Type: Internet Resources, Topical Websites Publication Year: 2012
Uploaded File: *none*
URL: http://www.pices.int/publications/presentations/PICES-2012/2012-S14/S14-1710-Keister.pdf

Abstract:
We are studying relationships between ocean chemistry and zooplankton distributions in Puget Sound, Washington as a model of future coastal ocean ecosystems. Puget Sound is a deep fjord that connects to the North Pacific between the U.S. and Canada through the Strait of Juan de Fuca. Hypoxia (<2 mg DO l-1) and extremely low pH (<7.5) occur naturally in Puget Sound as a result of inputs of upwelled ocean water, high surface production, and restricted circulation; anthropogenic eutrophication and global climate change are increasing the severity of conditions. In Summer and late Autumn, when the seasonally lowest oxygen and pH

occur, conditions are particularly stressful for many organisms, yet abundant zooplankton and fish inhabit the region. How these organisms tolerate the conditions and whether their behavior, growth, taxonomic composition, and energy flow through trophic webs are altered is a focus of our research. Here we will examine shifts in zooplankton community structure and vertical distributions in relation to oxygen and pH in the field as well as results from laboratory experiments on changes in growth and survival to begin to understand how the interacting stressors affect marine ecosystems through direct and indirect effects. Because oxygen and pH are predicted to decline throughout the North Pacific, understanding controls on zooplankton will be necessary to predict future fisheries and ecosystem status.

Citation:
Keister, J.E., A. McLaskey, L. Raatikainen, S. Busch, A. Winans, and P. McElhany. 2012. Oxygen and pH conditions experienced by zooplankton in a North Pacific fjord: Impacts on taxonomic composition, distributions, and growth. North Pacific Marine Science Organization, PICES 2012 Annual Meeting presentation web resources.

Copyright Restrictions + Other Notes:
http://www.pices.int/publications/presentations/PICES-2012/2012-S14/S14-1710-Keister.pdf

Journal Title: *none*

:: OTHER DOCUMENTS

No Documents Reported This Period

:: LEVERAGED FUNDS

Type: Period: ::Amount: $

Purpose:

Source:

Type: influenced Period: 2012-02-15::2012-10-15Amount: $200000

Purpose:
NOAA NWFSC laboratory facilities, chemical analyses, and personnel support provided by NOAA, 15 Feb. - 15 Oct. 2012.

Source: NOAA NWFSC

Type: influenced Period: 2012-02-16::2012-09-25Amount: $7286

Purpose:
Lab technician salary provided to support lab work on WSG project. $7286 provided by the University of Washington School of Oceanography, 16 Feb. - 25 March, 16-25 Sept.

Source: University of Washington School of Oceanography

Type: influenced Period: 2012-02-16::2012-03-10Amount: $1580

Purpose:
Undergraduate students supported hourly to provide general assistance with lab and field work on WSG project, $1580 provided by the University of Washington School of Oceanography, Feb 16, 2012 to May 15, 2012.

Source: University of Washington School of Oceanography

Type: influenced Period: 2012-04-09::2012-06-17Amount: $15536

Purpose:
R/V Clifford A. Barnes ship time supported by the University of Washington School of Oceanography, April 9-11, June 16-17, 2012.

Source: University of Washington School of Oceanography

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 sources 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 early life stages to current and future projected pH levels using laboratory experiments. This project focuses on the early life stages of two important crustacean zooplankton—the large-bodied copepod *Calanus pacificus* and the euphausiid (krill) *Euphausia pacifica*. These are two ecologically important species in the food webs of Puget Sound and throughout much of the North Pacific. The responses of these zooplankton species to ocean acidification will be 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 2012, we completed two very successful 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 capture 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.

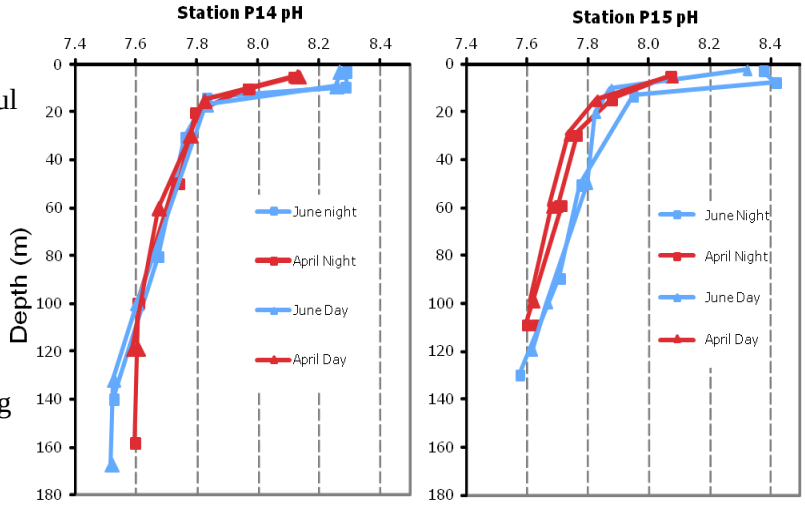

Figure 1. Depth profiles of pH measured by spectrophotometer in northern Hood Canal in April and June, 2012.

During each sampling we collected the 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.

Our field observations show that pH was >8.1 near the surface, declining sharply to <7.8 by 15-20 m depth, then gradually declined to <7.6 near bottom. As expected, pH was slightly lower at depth in June than in April. Unexpectedly, day and night values at each depth were very similar, even near surface where primary production was expected to cause a diel change 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 (night plots not shown). 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.

Experimental Methods

We conducted 10 laboratory experiments on *C. pacificus* and attempted 7 with *E. pacifica* (see Challenges below) to test the effects of elevated pCO_2 on hatching and development. Females were

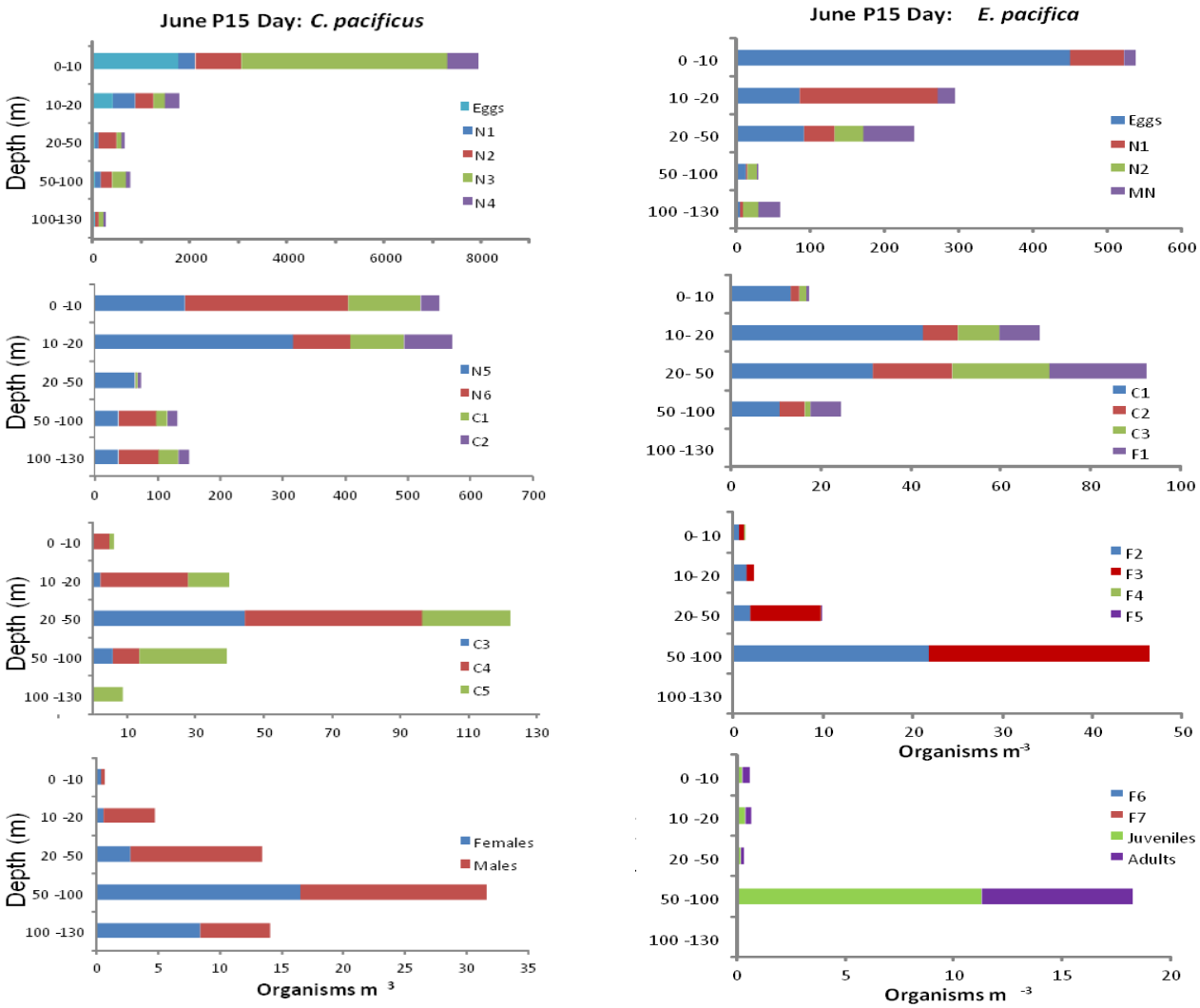

Figure 2. Depth distributions of *Calanus pacificus* and *Euphausia pacifica* in northern Hood Canal during the day in June, 2012. Life stages are ordered from youngest (top) to oldest (bottom) of each panel. Note that widths of the depth bins are not equal.

collected from the field and placed individually in experimental containers connected to NOAA's flow-through system at several levels of pCO_2 and left to spawn overnight. Text levels were usually 400 (pH=8.0), 800 (pH=7.8), 2400 (pH=7.3), and 3200 (pH=7.2) µatm CO_2. Broods were counted and either returned intact to their treatment conditions for the remainder of the experiment to test variability among females ('individual brood' experiments) or were evenly split among all containers and mixed with other broods to test the effect of jar position in the system ('mixed brood experiments'). Containers were then left on the system for four days until approximately half of the organisms had reached the first feeding stage (N3). At the end of each experiment, dead and live nauplii were preserved separately and returned to the lab where they were counted and their life stage determined. Water chemistry was continuously monitored and verified by discrete sampling at the beginning and end of each experiment.

Preliminary results from experiments indicate a reduction of, and higher variability in, hatching success of *C. pacificus* at 2400 and 3200 compared to 400 and 800 µatm CO_2. There was not a strong effect on development rate once eggs hatched, but variability appeared to increase with increased pCO_2. No significant effect on post-hatch survival was found, but a higher number of deformities occurred in the developing swimming appendages of nauplii at 2400 and 3200 compared to 400 and 800 µatm pCO_2.

Challenges encountered

We encountered a significant challenge in the first quarter of this project which we are not certain has been resolved. We did not have successful euphausiid egg hatching during our experiments, even at

control pCO_2 and pH levels. Hatching has not been a problem in previous experiments at UW, so we suspected an issue with handling or contamination in the NOAA lab. We conducted numerous tests to trouble-shoot the problem including tests of handling protocols, the type of containers (i.e., materials) used in experiments, and the water used in the experiments. Concurrently, euphausiid spawning was atypically low for Puget Sound, so getting sufficient experimental animals to trouble-shoot the problem was difficult. In total we had nine collection trips for euphausiids which eventually revealed that the NOAA OA system water was contaminated, but when the contamination had occurred and what the specific contaminant was have not been resolved. After we had problems with initial copepod experiments and other researcher saw stunted development in their experiments, NOAA conducted a complete clean of the system. The euphausiid spawning season had passed and we had moved on to copepod experiments (which were also experiencing poor growth. Following the system clean, we successfully conducted several copepod experiments. We had very high hatching with them which seems to indicate that the problem has been resolved. Euphausiid experiments will resume in early March 2013 and our priority for the year is to successfully complete those experiments.

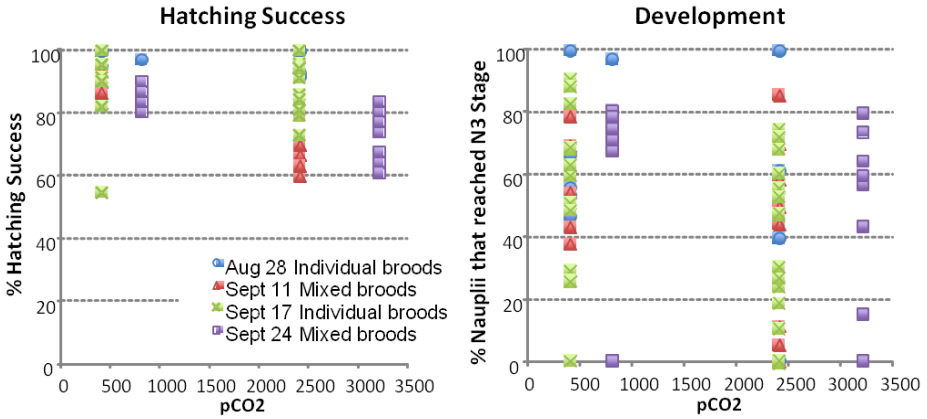

Figure 3. Results of laboratory experiments testing the hatching success and subsequent development of *Calanus pacificus* to pCO_2. Development was measured as the percent of hatched nauplii that developed to the N3 stage by the end of the experiments.

Plans for Year 2

In 2013, we will complete analysis of all of the field samples (~25% remain to be analyzed) and will focus on successfully completing lab experiments on *E. pacifica*. Their spawning season begins in approximately mid-March in Puget Sound and lasts 3-4 months. Our priority will be to conduct experiments at constant pCO_2 levels (400, 800, 2400, and 3200 µatm), then conduct 'time-varying' experiments 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.

Once the euphausiid experiments are complete, we will continue with copepod experiments. In light of our field results, which don't show that early life stages of copepods experience high pCO_2 variability, we are considering changing our effort on *Calanus* from time-varying experiments to constant, intermediate pCO_2 levels (e.g., 1200 and 1600) to determine the functional response of hatching success to pCO_2 and increase our number of replicate experiments. We will also complete the outreach component of the project (to develop an education 'kit' focused on OA) and will work with our NOAA partners to disseminate our results for inclusion in trophic models and management plans.

Participants

Participants in this project have been numerous. Dr. Paul McElhany's OA staff at NOAA NWFSC have been heavily involved, particularly Michael Maher who has assisted with sampling and experiment set-up and who has primary responsibility for maintaining the OA lab facilities. Dr. Shallin Busch performed the chemistry sampling at sea; Sarah Norberg assisted with building and maintaining the facilities and experimental vessels. Graduate and undergraduate involvement has been high: the project provides full support for an Oceanography Ph.D. student, Anna McLaskey at the University of Washington. Ph.D. student, Lisa Raatikainen, participated in cruises and lab experiments. Nine undergraduate students assisted with field collections and experiments, and this project formed a portion of a NOAA Hollings Scholar's summer intern research project.