C-CAN OA-SHELLFISH WORKSHOP II
Costa Mesa CA
July 6-7, 2011

OA PROJECT SUMMARIES

The Bodega Ocean Acidification Research (BOAR) group (Professors Hill, Gaylord, Sanford & Russell) at the University of California Davis Bodega Marine Laboratory is a major research collaboration addressing the impacts of acidification on coastal upwelling and estuarine ecosystems. Using an interdisciplinary approach that draws on the expertise of oceanographers, marine chemists, and ecologists, we combine moored, shipboard and coastal measurements of seawater chemistry with controlled laboratory and field studies of ecological responses in key species. BML is situated on Bodega Head, a rocky headland within a major upwelling center where the effects of acidification may be exacerbated.
To address changes in regional oceanography and seawater properties, we are using highly instrumented oceanographic moorings combined with broad scale coastal and intertidal measurements along the West Coast of the U.S. Our "coast wide" sampling transect includes 47 sites along the West Coast that are sampled 2x per year for a full suite of water chemistry parameters. At several individual sites along this transect, we are collecting higher resolution pH and water quality data. For example, an oceanographic mooring located offshore of BML has been continuously monitoring pH and pCO_2 since November 2010. This mooring is coupled with intertidal pH and water chemistry measurements at the shore on Bodega Head.
Nearby Tomales Bay is a 20 km long estuary that supports productive oyster aquaculture. Like many estuaries in California, Tomales Bay receives fresh water inflow seasonally, with dramatic effects on pH. A second mooring to be deployed in Tomales Bay in 2011 will be combined with ongoing monthly oceanographic surveys (since 2009) to extend an existing historical record of water chemistry and understand the relative roles of climate and hydrology in influencing estuarine pH.
Utilizing these key oceanographic data collected along the California coast, we are addressing ongoing and future ecological impacts of ocean acidification on calcifying marine invertebrates that play critical roles in local ecosystems. Efforts to date have targeted the California mussel (*Mytilus californianus)*, the Olympia oyster (*Ostrea conchaphila*), and the Purple urchin (*Strongylocentrotus purpuratus*). We are using a novel culturing facility at BML that allows us to raise larvae under elevated-CO_2 conditions through the full pelagic period and into juvenile life. We are especially interested in "carry-over" effects that originate from exposure during the larval stage, but influence subsequent growth and survival of benthic juveniles, themselves critical as population bottlenecks for adult demographics.
The BOAR group is dedicated to the training and education of future scientists in ocean acidification research. Through support of the National Science Foundation and the UC Multicampus Research Programs & Initiatives, BOAR is involved in the training of 7 graduate students and 2 postdoctoral fellows.

Todd Martz, UC San Diego, Scripps Institution of Oceanography
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Research Interests:
- Sensor Development
- Marine Biogeochemistry
- Aqueous CO2 chemistry

My group develops autonomous sensors used to measure pH, and build integrated systems with additional sensors for dissolved oxygen and salinity. These packages are designed to operate unattended in the ocean for up to one year at a sampling frequency of 30-60 min. We are also in the early stages of evaluating sensor concepts for total alkalinity and total dissolved inorganic carbon. To enhance sensor development, calibration, and inter-comparison work we are planning a large test tank at Scripps.

pH sensors using the Honeywell DuraFETR were designed by Ken Johnson and myself around 2008 and the resulting "SeaFET" and "SeapHOx" sensors now built at SIO have gained some attention in the community following a paper published last year (Martz, Connery, Johnson 2010. Testing the Honeywell DurafetR for seawater pH applications, Limnology and Oceanography: Methods, 8, 172-184). In the past two years we have constructed 52 sensors for 13 collaborators. Satlantic Inc. has commercialized the SeaFET design through a partnership with MBARI and SIO and it will become commercially available this fall.

Richard Feely, Senior Scientist
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Research Interests:
My research interests focus on carbon cycling and ocean acidification, specifically mechanisms controlling sources and sinks of anthropogenic CO2 in the oceans, and impacts of CO2 on marine ecosystems.

Synopsis of current ocean acidification-relevant research or work:
I have been using the CLIVAR/CO2 Repeat Hydrography and North American Carbon Program cruise data sets in collaboration with modelers to determine the rates of acidification of open-ocean and coastal waters in the Pacific and to determine the relative contributions of anthropogenic CO2 inputs, circulation, mixing, biological productivity, and remineralization on the acidification process. This year we'll be studying the combined impacts of ocean acidification and hypoxia along the Cascadia Margin between Canada and Mexico. This will allow us to make detailed observations throughout the Cascadia region focusing on areas of known recurring hypoxic conditions consistently observed through the past decade.

We plan to conduct a full suite of high-quality measurements of inorganic carbon (total CO2, alkalinity, pCO2), oxygen, nutrients, salinity, and temperature. These measurements will form the core of the data set needed to extend the predictive relationships for Ωarag and pH to water masses with hypoxic conditions.

I am a member of the OCB Scientific Steering Committee and Ocean Acidification Subcommittee, and the Interagency Working Group on Ocean Acidification (IWGOA) established by the Joint Subcommittee on Ocean Science and Technology (JSOST). I am also a member of the international SOLAS-IMBER Ocean Acidification Working Group (SIOA WG).

For more information visit our website at: http://www.pmel.noaa.gov/co2/

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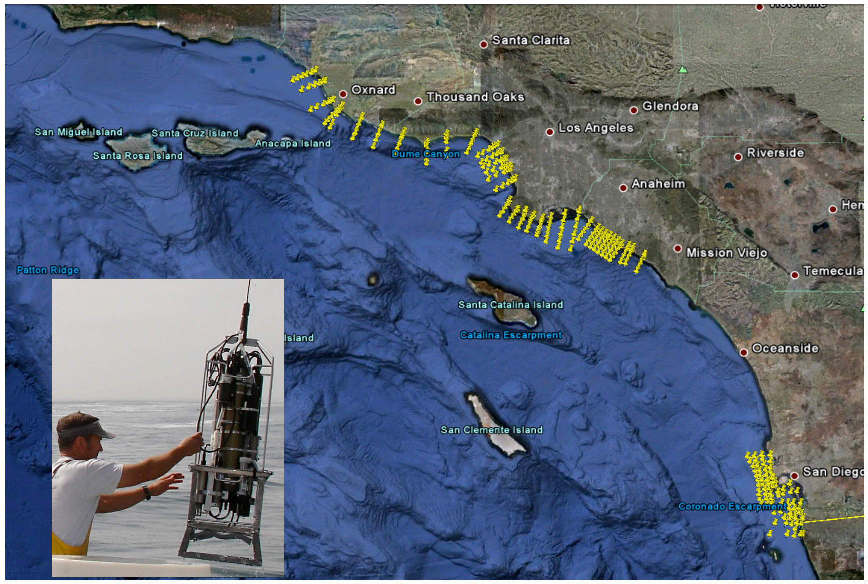
Recent ocean acidification activities include monitoring efforts in Totten inlet, Lummi shellfish hatchery, Bay Center and Nahcotta ports in WIllapa bay, and the Whiskey Creek shellfish hatchery. Totten inlet sampling is not currently funded so efforts are being targeted to further understand daily fluctuations of CO_2 in this South Puget Sound inlet. This continues efforts in 2009 and 2010 which were funded by the Puget Sound Partnership with a partnership with NOAA, the Puget Sound Restoration Fund, Washington State department of Ecology and the University of Washington. Monitoring efforts include whole water sampling for CO_2, DO, nutrients, Olympia oyster (*Ostreola conchaphila)* larvae and phytoplankton.

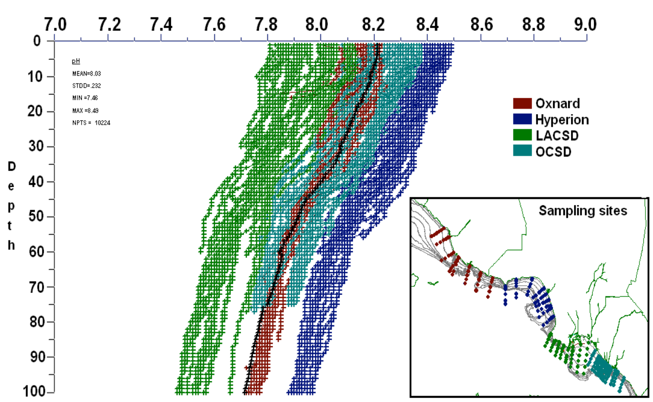
All other sites are supported by Cantwell funding until the fall of 2011 where limited funding is available to continue efforts until the end of 2012. Monitoring efforts include whole water sampling for CO_2, DO, nutrients, and *Vibrio tubiashii* . Mr. Suhrbier acts as the field manager for sample collection at ports of Nahcotta, Bay Center, and Tokeland along WIllapa Bay and at the Lummi shellfish hatchery. He also maintains water quality meters measuring DO, pH, salinity and temperature inside the Lummi and Whiskey Creek shellfish hatcheries and near remote setting intakes at Bay Center and Nahcotta. In addition he maintains water quality meters measuring DO, pH, salinity, temperature, ORP and chlorophyll at the intakes of the Lummi and Whiskey Creek shellfish hatcheries.

Collection of coastal ocean data by the Central Bight Cooperative Water Quality Survey (CBCWQS).

A consortium of Southern California POTWs coordinate coastal ocean monitoring efforts required by their individual NPDES permits for ocean discharge of treated wastewater. Coordinated monitoring is done quarterly on the 1st week of February, May, August and November at over 300 sites using multiple vessels and Sea-Bird CTDs equipped with pH, chlorophyll-a and CDOM fluorescence, light transmissometer and DO sensors.

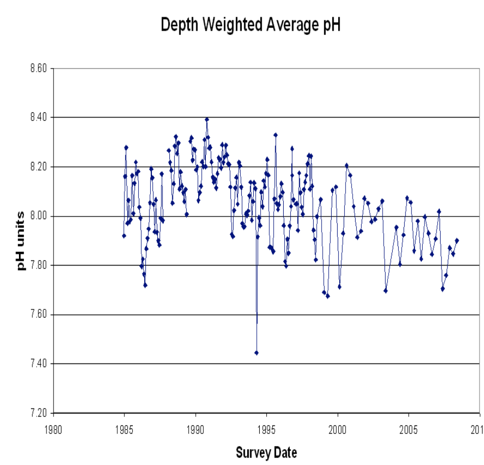


The POTWs are required to meet all conditions in the California Ocean Plan (COP) immediately outside an initial dilution zone around their outfalls. For pH, the COP specifies *"The pH shall not be changed at any time more than 0.2 units from that which occurs naturally"*. Permits require continuous pH monitoring of effluent. Recent JWPCP effluent had an average pH of 7.15, alkalinity of 330-430 mg/l, and a predicted CO_2 for typical effluent properties of 20 mg/l. Dilution tank tests in seawater observed pH change from 8.17 down to 8.15 as effluent was added to lower dilution from 2000:1 to 100:1. The resolution of the Sea-Bird, Inc pH sensor is 0.1 pH unit under optimal conditions.

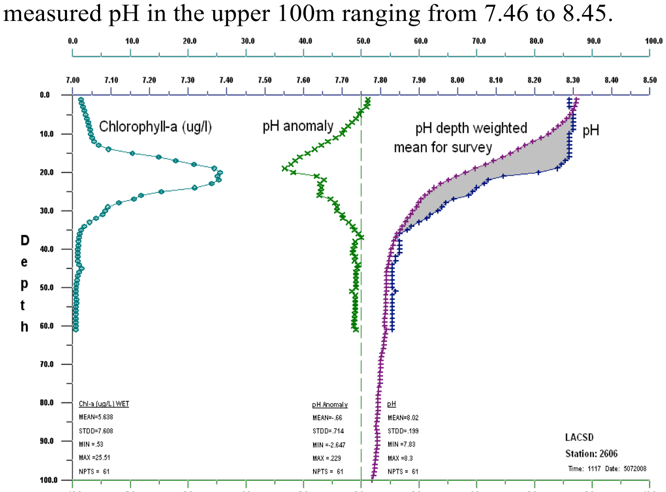


The POTWs use a sequence of pH buffer solutions and a linear best-fit algorithm to calibrate the sensor voltage to pH prior to each survey. Despite this, pH from simultaneous sampling is frequently found to be inconsistent between agencies/sensors.

Limited efforts have been made to look for trends in two decades of offshore pH measurements. Results have varied between agencies.



The pH data show significant stratification through most of the year, pH is reduced at depth, and elevated where high concentrations of phytoplankton are detected. Between 2008-09 Los Angeles County Sanitation Districts surveys measured pH in the upper 100m ranging from 7.46 to 8.45.



Recently simultaneous casts using CTDs of two agencies have been completed offshore when research vessels meet at an agreed site. Unfortunately pH is still not consistent.

This summary of the CBCWQS coastal ocean monitoring program and discussion of pH sampling and results was prepared for the California Current Acidification Network Workshop, July 2011, SCCWRP.

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My "Ocean Time Series Group" group at SIO specializes on research and technology that involves the collection and analysis of sustained and rapidly sampling autonomous observations, mostly using mooring techniques. Our own expertise is mainly physical oceanography, but strong collaborations with colleagues within and outside SIO enable us to collect moored data with biogeochemical and ecosystem sensors as well. We have spent a lot of effort to enable real-time telemetry from any instruments anywhere in our moorings, using inductive and acoustic technology, and using gliders as "data shuttles" with acoustic modems. Both the mechanical design and the electronics for data collection and telemetry of our moorings are designed to be modular and flexible, allowing easy accommodation and integration of sensors from other collaborators. Our projects and real-time data can be viewed at the website given above.

For ocean acidification, our lab operates three moorings that contribute observations in the California Current regime. The longest timeseries exists at Del Mar, just north of San Diego, on the continental shelf on the 100m isobath. We now have 5 years of continuous data throughout the water column of T, S, currents, and oxygen/chlorophyll at 2-3 depths. Near-bottom oxygen observations were started in November 2009, and in June 2011 near-bottom pH was added in collaboration with T.Martz. All data are received in real-time, and now reveal near-bottom hypoxia events in each year. In the California Current (off the continental shelf) we have two NOAA-funded highly multidisciplinary moorings (co-PI M.Ohman, collaborators T.Martz, C.Sabine, R.Feely, D.Demer, A.Dickson, L.Washburn, J.Hildebrand) off Pt. Conception (CalCOFI line 80) on the 800m isobath (upwelling regime) and in the southward low-salinity core of the California Current (open-ocean regime). These moorings observe, also in real-time, surface pCO_2 and pH, and oxygen, pH, nutrients, chlorophyll fluorescence at several depths, acoustic backscatter for zooplankton/fish abundance over 0-300m, in addition to T, S, and currents.

Uwe Send is also a co-chair for the international OceanSITES program, which is implementing a global open-ocean timeseries observing system, part of the official Global Ocean Observing System (and JCOMM, etc). OceanSITES has a strong biogeochemical component, and members such A.Dickson, D.Wallace, F.Chavez represent this community. Both a Scientific Steering Team and a Data Management Team exist, and the data management effort (lead by NOAA NDBC) now appears to be the most advanced among such oceanographic programs. The global ocean acidification observing network advocated and planned by R.Feely (see the OceanObs09 papers about this), maps onto and is coordinated with OceanSITES for the open-ocean sites. Discussions are underway to explore whether OceanSITES can also assist with the coastal component of this.

Paul G. Matson Current Research

Research in the Hofmann lab at UC Santa Barbara is currently focused towards assessing the effects of ocean acidification on coastal marine species. While much work has focused on predicting future levels of pCO_2 within the ocean surface, we know relatively little about natural pH dynamics within modern oceans, particularly in coastal regions. This information may be very important in understanding whether modern species possess the physiological plasticity to cope with future decreased pH due to ocean acidification. Through a collaborative effort with Dr. Todd Martz, we are utilizing SeaFET sensors to observe natural pH dynamics within our study areas to inform manipulative laboratory experiments testing the physiological tolerances of marine larvae to elevated pCO_2. Our work has been conducted in multiple ecosystems, including temperate (Santa Barbara Channel), tropical (Moorea, French Polynesia) and polar (McMurdo Sound, Antarctica).

Within the Santa Barbara Channel, we are collaborating jointly with Dr. Martz, Dr. Libe Washburn, and other investigators from the Santa Barbara Coastal Long Term Ecological Research project (SBC LTER) to deploy SeaFET sensors at multiple coastal moorings within the SBC LTER observation network. At these locations, pH will be integrated with ongoing oceanographic current and hydrography measurements conducted by the SBC LTER (including but not limited to temperature, salinity, current velocity, pressure, etc.) and made accessible to the public. We will use this information to parameterize ongoing laboratory experiments investigating the physiological sensitivity of early life stages of the purple sea urchin, *Strongylocentrotus purpuratus*, an ecologically important member of kelp forest systems in the northeastern Pacific. In addition, this data will be analyzed to identify oceanographic processes driving pH variation within our area.

As a senior postdoc in the Hofmann lab, I have been actively involved in two major data collection efforts related to ocean acidification. While my current appointment is under the auspices of the Office of Polar Programs, I continue to be involved with data collection related to local experiments.

I have been a collaborator with graduate student Paul Matson and Prof. Todd Martz in managing the collection of ocean pH data using SeaFET sensors developed by Prof. Martz, and also in conducting informal pH monitoring of the seawater system on the UCSB campus. The first Santa Barbara pH dataset capturing summer upwelling activity was published recently as Yu et al., 2011 in JEMBE. I have assisted with additional SeaFET deployment activities in Antarctica, and am participating in the dissemination of those results. In the meantime, I am also supervising a visiting foreign student in the regular collection of pH data on the on campus seawater system at UCSB (Fig. 1). As the campus has a flow-through seawater system with an intake just off of Campus Point in Goleta, continuous monitoring of seawater in the pipes (both filtered and unfiltered at different points in the system) shows that despite a small but consistent increase in pCO2 related to internal biofouling, sampling of the pipe seawater fairly closely reflects the nearshore seawater chemistry (2500ft off the beach at 51ft depth) over a temporal scale of days to months. As shown by Juranek et al, 2010, there is a close association between temperature and pH over time during upwelling season.

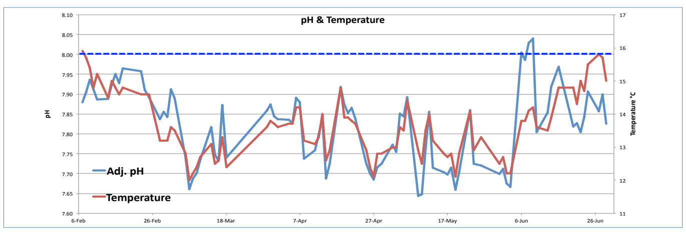
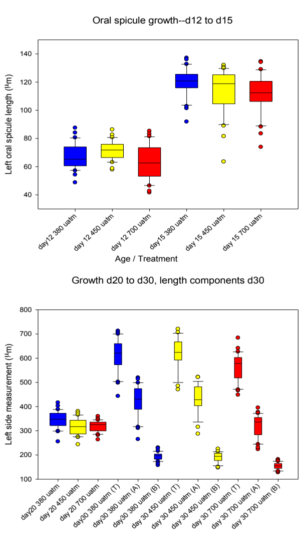
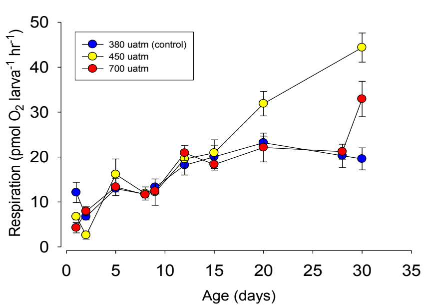
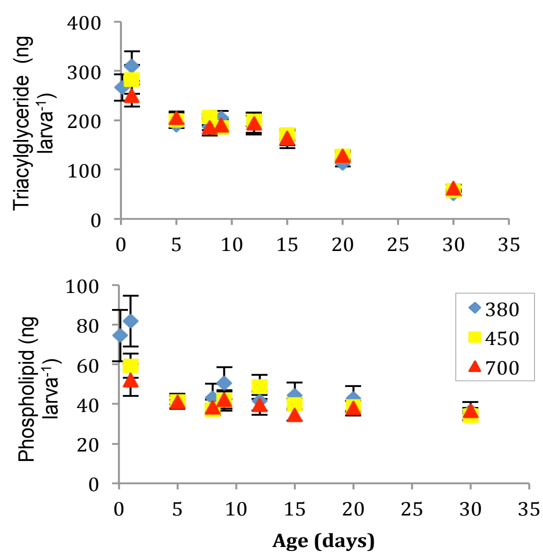


Figure 1. pH and temperature of the seawater system at UCSB from early February-late June 2011. Dashed dark blue line marks pH 8.0, blue line shows pH (as measured by discrete spectrophotometric pH samples) and red line shows temperature.

My main research efforts have been in studying physiological changes in sea urchin larvae under high CO_2. Experiments in collaboration with Paul Matson have revealed small but significant differences in size in purple urchin *Strongylocentrotus purpuratus* that are also affected by maternal biochemical contribution. Some of these data have already been published as Yu et al., 2011, a second manuscript is in preparation, and additional data are being collected from these experiments on *S. purpuratus*. Last summer, I supervised an undergraduate experiment on fertilization success under high CO_2 and high temperature in *Lytechinus pictus*. We observed some abnormal fertilization under high CO_2 conditions, which are being followed up by another postdoc, Dr. Jessica Dutton. This summer I will be supervising an experiment on larvae of *L. pictus* performed by undergraduate interns. While in Antarctica, I have been studying the polar species *Sterechinus neumayeri*, which similarly appears to have diminished size in response to high CO_2 (Fig. 2). However, metabolic rate data shows that there appear to be no negative effects on respiration in *S. neumayeri* embryos, but some later differentiation (Fig. 3). Lipid biochemistry (Fig. 4) also seems fairly similar under normal and high CO_2 conditions, but those analyses are ongoing. We are planning additional analyses of enzyme activity, gene expression and proteomic data.







Larvae of *S. neumayeri* raised under three pCO2 levels (blue-normal 380 µatm, yellow-"medium" 450 µatm, red-"high" 700 µatm). Morphological measures (left panels, Fig. 2), respiration (above, Fig. 3) and lipid class measures (right panels, Fig. 4).

The Global Oceans Health Program of the Sustainable Fisheries Partnership (SFP) helps leaders in the seafood industry protect seafood supplies from ocean acidification (OA) and related changes in seawater composition.

One major initiative of our program works with growers, fishermen and scientists to:

(i) Document changing seawater chemistry and its effects on seafood production, using low-cost, proven methods;

(ii) Help growers and fishermen develop monitoring skills and scientific guidance to build their capacity to acquire reliable data on changing seawater chemistry and its effects on seafood production (e.g. in shellfish hatcheries).

(iii) Strengthen the seafood industry's capacity to protect seafood supplies from changing seawater chemistry, via both adaptation and prevention. For example, we document and share adaptive monitoring and production practices to help producers avoid impacts from changing seawater chemistry that cannot be prevented. We also help seafood producers and buyers understand and pursue policy options: a) for strengthening controls on the causes of OA (e.g. through bringing acidifying emissions under management); and b) for supporting scientific research to inform more effective responses.

Four recent accomplishments of SFP's Global Oceans Health Program include:

1) Spring 2011: We raised foundation funds to ensure that the Pacific Coast Shellfish Growers Association can continue its monitoring and sampling program for another year in hatcheries and bays in the Pacific Northwest, working with Alan Parks who runs the PCSGA program. This program represents an important model of harvester-scientist cooperative monitoring that we are working to sustain and expand (see below).
2) Winter 2010-2011: We organized an initiative in Maine that enabled shellfish hatchery operators to develop their own monitoring and sampling program based on the PCSGA model, working in cooperation with OA researchers at the University of New Hampshire and St. Joseph's College.
3) 2007-2010: We organized a series of briefings and workshops (including testimony at three House & Senate hearings), where seafood industry representatives and scientists briefed federal lawmakers and other leaders on acidification, its potential consequences, and options for response.
4) 2008-2011: We run an ongoing series of industry-facing workshops, a website, and a study groups to help fishermen, growers and seafood companies learn about changing ocean chemistry, its implications, and opportunities to address its causes and consequences.

In cooperation with leading oceanographers and industry groups, we are currently working to refine and expand the model of harvester-scientist cooperative monitoring of acidification, especially in regions where seafood production and marine ecosystems are believed to most at risk. This approach is a cost-effective strategy for advancing several aims simultaneously:

a) Strengthening the industry's capacity to protect seafood supplies from changing ocean chemistry;
b) Generating data that clarify effects of acidification on seafood supplies, coastal economies, and people who rely on them;
c) Expanding capacity for cooperation between scientists, industry, and policymakers in order to respond effectively to the causes and consequences of OA and related changes in ocean chemistry.

Burke Hales – COAS, Oregon State University

Burke Hales is currently involved in a number of projects studying the carbon cycle of the ocean margin, and the effects of carbonate chemistry on calcifying organisms. Most are based in the PNW, but one is ongoing in the Neuse River/Pamlico Sound system in NC.

Pacific Coast
SHELLFISH GROWERS ASSOCIATION
Partners with Mother Nature

Understanding seed mortality and its effects on the Pacific Coast Shellfish Industry

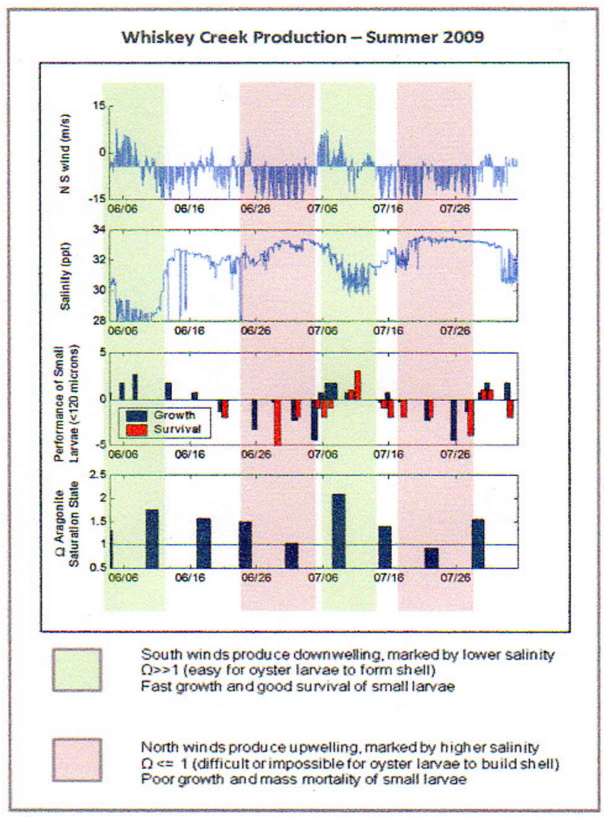
The West Coast shellfish industry is an integral part of many coastal communities throughout the Pacific Northwest, and currently supports over 3000 family wage jobs across the region. The farm gate value of shellfish sold each year exceeds $110 million, and contributes a total of $278 million per year in economic activity to rural communities along the coast.

Several consecutive years of dramatic seed shortages pose a serious threat to our industry, and to a way of life held by shellfish growers for over 130 years. Many growers in the Northwest rely heavily on natural recruitment of oyster larvae, and after six years of failed natural sets in Willapa Bay, many growers are scrambling for solutions.

Production in some commercial hatcheries has also declined dramatically in recent years, leaving many established farmers short of product, and deeply concerned about the future of their industry. Whiskey Creek Shellfish Hatchery in Netarts, Oregon has been a consistent producer of oyster larvae for over thirty years, and typically supplies 75-80% of all growers in the Pacific Northwest. Beginning in 2007, however, high larval mortality throughout the summer growing season reduced annual production to 25% of normal levels, and forced the hatchery to step back and identify the source of these unprecedented mortality events.

Research at the hatchery in recent years has identified the upwelling of acidified seawater as a major contributor to these larval mortality events. The intrusion of corrosive seawater onto the Oregon continental shelf has been commonly observed in recent years (Feely et al 2008), and heavily influences the shallow waters of Netarts Bay. Comparison of larval performance in the hatchery with environmental data in 2009 showed a strong relationship between the presence of upwelled, corrosive seawater and high mortality in young oyster larvae, which form their shells from aragonite.

The following graph summarizes production data collected June and July 2009, and correlates the survival and growth of oyster larvae with changes in seawater conditions. During this period, winds reversed direction several times, producing alternating periods of upwelling and downwelling. This pattern shows the dramatic effects of upwelled, acidified water on groups of young oyster larvae.



The strong correlation between high pCO2 and larval mortality has become an important diagnostic tool for the hatchery, and monitoring of seawater quality has allowed Whiskey Creek to 'pick their moments' and significantly increase hatchery production in both 2009 and 2010. The success of these efforts underlines the importance of reliable, real-time data as a management tool for the Pacific Coast shellfish industry, and has fostered a number of collaborative efforts between the oceanographic community and shellfish growers throughout Oregon and Washington. The outcome of these collaborations is a new network of monitoring stations established by PCSGA in areas of commercial importance, where real time data can be linked to larval performance, both in commercial hatcheries and in the natural environment. NOAA funds help support this program, through the assistance of Senator Maria Cantwell.

The PCSGA monitoring program provides a stable platform for data acquisition at the exact locations of interest to our industry, including seawater intakes at commercial hatcheries and sites that traditionally support high natural recruitment of oyster larvae. Larvae are present in commercial hatcheries from February-November each year, and these facilities provide the unique opportunity to examine trends in larval performance as ocean conditions evolve throughout the growing season. These data will be used in concert with ongoing research projects throughout the Pacific Northwest, and together should provide valuable insights into the effects of seawater chemistry on shellfish larvae in the real ocean. A number of exciting collaborations have already been established between PCSGA and the research community at large, which are outlined below.

2011 PCSGA Monitoring Stations

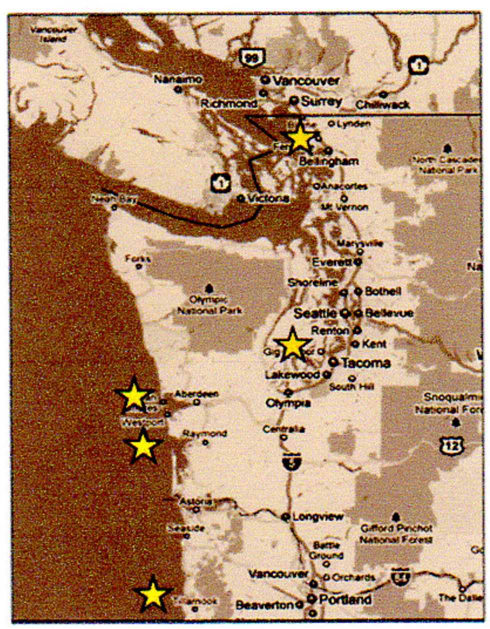
☆ **Bellingham, WA-** Lummi Indian Nation Hatchery
new site in 2011
nearby NOAA buoy scheduled to add pCO2 measurements in 2011

☆ **Dabob Bay, WA-** Taylor Shellfish Hatchery
Active participant in 2010
Continuous pCO2 data on incoming SW in 2010
Ongoing collaborations with NOAA, PSRF, and UW (Feely, Sabine, Newton)
NOAA buoy moved into Dabob Bay in 2010 as part of collaboration with the shellfish industry

☆ **Gray's Harbor, WA-**
new site in 2011
privately funded by local growers

☆ **Willapa Bay, WA-**
Three new sites in 2011 at North and South ends of the bay, and near the bay mouth
Ongoing collaborations with PSI, WDFW, and UW (Trimble- pCO2 transects in 2010)

☆ **Netarts Bay, OR-** Whiskey Creek Shellfish Hatchery
Ongoing collaborations with OSU (Langdon, Hales), with graduate support in the hatchery in 2010-11
Continuous pCO2 data at SW intake in 2010
Routine sampling at hatchery since 2009



Selected sites listed above will collect continuous pCO2 data in 2011, and both tCO2 and pCO2 will be monitored on site at Whiskey Creek in 2011. In addition, all site participants will collect data in the following framework:

- *Continuous sampling of pH, temperature, salinity, and dissolved oxygen at all sites*
- *Weekly Discrete samples at all sites – morning and afternoon samples at each site, analyzed for total carbonate chemistry, nutrients concentrations, DO, and bacteria levels*
- *Detailed larval performance data from all sites to compare with environmental data*

Jan Newton and NANOOS

1. Data for pH and/or pCO_2 from the following observing assets are served via NANOOS:

UW: (Newton, Mickett, Devol) La Push, WA coast, and Twanoh and Dabob Bay in Puget Sound buoys (in collaboration with NOAA PMEL)
OSU: (Hales) NH-10 Oregon Coast buoy
OHSU: (Baptista) CMOP Columbia River shelf buoy
King County: Puget Sound buoys
Pacific Shellfish Institute: (Willapa Bay now, Whiskey Creek in process)
Intellicheck Mobilisa: Puget Sound buoys
Seattle Aquarium: Puget Sound station off Seattle

2. Newton and Klinger et al. submitted a proposal to Washington Sea Grant for development of capacity for forecasting risk of corrosive waters. Will know Oct 2010, potential start date Feb 2011.

3. NANOOS has an active outreach "theme page" on ocean acidification.

4. NANOOS, as do all the IOOS RA's, has capability to provide platforms, data services, and outreach re OA.

Francis Chan, Oregon State University

My research centers on understanding the causes and consequences of changes in ocean biogeochemistry. I am involved in four research programs that can inform our understanding of coastal ocean acidification in the California Current.

First, as part of the PISCO (Partnership for Interdiscipinary Studies of Coastal Oceans – www.piscoweb.org), a coastwide consortium for long-term study of nearshore physics, ecology and biogeochemistry along the California Current, my efforts include work on studying changes in oxygen and carbon chemistry through the deployment of inner-shelf moored sensors and cruises.

These observations are further tied into the OMEGAS (Ocean Margin Ecosystem Group for Acidification Studies) project, an NSF-funded consortium of researchers from OSU, UCSC, UHawaii, UCD, UCSB, Stanford, and MBARI. Research by the OMEGAS consortium includes making observations of nearshore variations in ocean acidification stress across 8 study sites between Oregon and Southern California. These observations include moored pH and pCO2 sensors as well as pH sensors that are mounted in tidepools. These observations are collected to

1) resolve the seascape of OA stress
2) understand the climate conditions that intensifies or modulates the expression of that stress in coastal waters and
3) inform physiological and genetic studies on the responses of mussels and urchins to changing ocean chemistry.

As part of the MILOCO (Microbial Initiative in Low Oxygen areas off Concepcion and Oregon, http://mi-loco.coas.oregonstate.edu/) program, I have also been active in deploying pH and pCO2 sensors at a mid-shelf physical/biogeochemical/microbial time-series station in the central Oregon shelf. This time-series station is located in a core area of seasonal hypoxia and provides an important opportunity to study coupled microbial-biogeochemical changes as oxygen and pH are at their minima.

Lastly, I am also involved in an NSF-funded collaborative project with Bruce Menge, Sally Hacker from OSU and Karina Nielsen from SSU to examine the role of spatially-varying carbon chemistry on the interactions between intertidal coralline algae, non-calcifying macrophytes and invertebrates.