NANOOS Partnerships for Assessing Ocean Acidification in the Pacific Northwest

J. Newton[1,2,3], D. Martin[1,2], E. Mayorga[1,2], A. Devol[1,3], R. Feely[4], S. Alin[4], B. Dewey[5], B. Eudeline[5], A. Barton[6], and A. Suhrbier[7]
[1]NANOOS: Northwest Association of Networked Ocean Observing Systems
[2]Applied Physics Laboratory-University of Washington
[3]University of Washington School of Oceanography
[4]NOAA Pacific Marine Environmental Laboratory
[5]Taylor Shellfish, Inc.
[6]Whiskey Creek Shellfish Hatchery
[7]Pacific Shellfish Institute

Abstract—**Ocean acidification has serious implications for the economy and ecology of the Pacific Northwest United States. A combination of factors renders the Pacific coast and coastal estuaries particularly vulnerable to acidified water. The Northwest Association of Networked Ocean Observing Systems, NANOOS, the Regional Association of the United States Integrated Ocean Observing System, IOOS, is set up to deliver coastal data to serve the needs and decisions of its region. NANOOS has worked through IOOS with the NOAA Ocean Acidification Program, NOAA PMEL, academic, local, and commercial and tribal shellfish growing partners to provide existing observing assets to accommodate pCO_2 and pH sensors, to deliver data streams from these and other providers, including that from sensors in shellfish hatcheries, and to network this capacity regionally and nationally. This increase in data access regarding OA is of value to scientists, managers, educators, and shellfish growers who are especially appreciative of the near real-time readouts of the data, upon which to make hatchery and remote setting decisions. This is a regional example of NANOOS and IOOS contributions to societal impacts from ocean acidification.**

Index Terms— **ocean observing, IOOS, shellfish growing, pCO_2 and pH sensors, data access**

I. INTRODUCTION

Ocean acidification is a serious problem with implications for the local economy and ecology of the Pacific Northwest United States. The chemistry of the ocean is changing due to atmospheric carbon dioxide (CO_2) levels that are now higher than at any time in at least the past 800,000 years [1]. Global measurements show that about 30% of the CO_2 released to the atmosphere over the past 250 years from human activities is now dissolved in the ocean [2, 3]. Once dissolved in the ocean, the additional CO_2 interacts chemically with other components in seawater in a complex way to change the characteristics of the water itself, lowering the pH and increasing the solubility of calcium carbonate. On a global basis, these changes, commonly referred to as ocean acidification (OA), are larger and are occurring faster than the planet has previously experienced [4]. If the acidification effect is strong enough, the shells and skeletons of calcareous marine organisms, many of which are economically important, cannot be formed or maintained [5, 6]. Larval stages of organisms like oysters are particularly vulnerable and of regional interest due to the thriving shellfish aquaculture industry in the Pacific Northwest (PNW) [7].

The Northwest Association of Networked Ocean Observing Systems, NANOOS, the Regional Association of the United States Integrated Ocean Observing System, IOOS, is set up to deliver coastal data to serve the needs and decisions of its region. Shellfish growers along the Pacific coast have been acutely aware of changes in the settling success of their larval shellfish. Since 2004, particularly natural sets and hatchery success have declined [7]. Several Pacific coast shellfish growers have conducted research to evaluate if OA could be a driving factor in this downturn.

We know that the distribution of effects from OA will be different around the globe. A combination of factors renders the Pacific coast of North America vulnerable to acidified or “corrosive” water events. First, subsurface Pacific waters (150–300 m) naturally have higher CO_2 concentrations than surface waters due to the lack of photosynthesis (which takes up CO_2) at depth and the contribution of CO_2 through organic decomposition and respiration processes. On top of this natural signal, our society’s addition of CO_2 further increases the acidity of Pacific coast waters. Additionally, seasonal upwelling along the PNW coast transports the more corrosive water onto the continental shelf, where in some areas these conditions can reach the surface and may affect organisms [8]. Finally, in coastal estuaries, inputs of nutrients and organic matter from land can increase the water’s acidity even further [9]. Consequently, natural processes, additions of CO_2 from human activities, and additions of nutrients and organic matter to estuaries all combine to intensify ocean acidification in the PNW and especially in our coastal estuaries.

The same PNW coastal estuaries that are threatened by ocean acidification are the source of highly valued shellfish and shellfish fisheries. Shellfish aquaculture provides an important source of jobs in Washington and Oregon, and revenues directly benefit state and local economies. Loss of shellfish aquaculture from the PNW would impose substantial social and economic costs. Therefore, this issue is of importance to the NANOOS region. Over the last several years, NANOOS has evaluated whether its observing efforts can help in assessing this condition.

II. OA Partnerships in the Pacific Northwest

A. NANOOS–IOOS contributions to an OA observing system

An effective partnership with respect to OA has emerged in the PNW involving NANOOS, NOAA, universities, and shellfish growers. NOAA is the nation's lead agency for ocean acidification and as such has established an Ocean Acidification Program office at its headquarters in Washington, D.C. The NOAA Pacific Marine Environmental Laboratory (PMEL) in Seattle, Washington has world-renowned expertise in the measurement and evaluation of OA. NANOOS has partnered with NOAA PMEL to put their pCO_2 and pH sensors on some of the NANOOS network of buoys in Washington (in partnership with the University of Washington) and Oregon (in partnership with Oregon State University). On the outer coast, there are now pCO_2 and pH data available from Newport, OR, and La Push, WA, for view on both the NANOOS and NOAA PMEL Carbon Program websites. In the inland waters, UW has buoys within Puget Sound outfitted with NOAA PMEL pCO_2 sensors (Fig. 1) and another NANOOS partner, the NSF-funded Coastal Margin Observation and Prediction program run out of Oregon Health and Sciences University, has pH and pCO_2 sensors in the Columbia River estuary maintained with partial NANOOS support.

Additionally, funding from Senator Cantwell to shellfish growers through the Pacific Coast Shellfish Growers Association (PCSGA) was used to purchase pCO_2 and pH monitoring equipment for participants, including Whiskey Creek Shellfish Hatchery in Oregon and Taylor Shellfish, Pacific Shellfish Institute, and the Lummi Indian Nation in Washington, who all have implemented monitoring in their hatcheries and growing areas. These data streams are unique in that these are in shallower, near-shore areas and where biology is also monitored. NANOOS serves these data streams in addition to the NANOOS-supported data streams (Fig. 2).

While this is a useful start, OA observations in the PNW and elsewhere are currently quite limited in scope. Observations serving OA assessment are expensive and constrained by technology to measure pH and carbon parameters (DIC, TA, pCO_2). A promising direction being further tested is use of mathematical relationships developed by scientists at NOAA PMEL, Scripps Institution of Oceanography, Universidad Autonoma de Baja California, and UW to utilize common variables, e.g., temperature, salinity, and oxygen, to estimate pH and the aragonite saturation state (aragonite being a major calcium carbonate biomineral used by shelled organisms). This will allow assessment of OA from many more observing platforms, including autonomous gliders, such as those operated by the regional ocean observing systems including NANOOS.

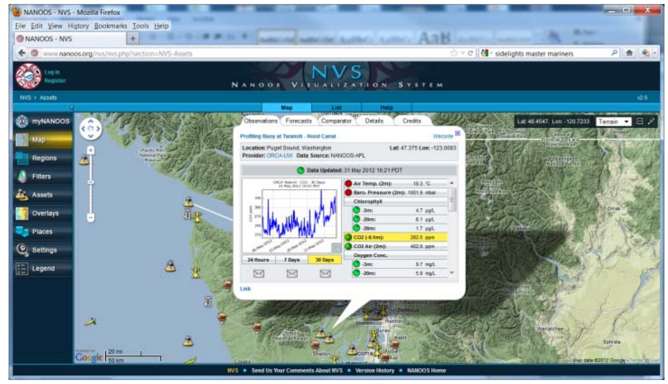

Fig. 1. Screen shot from NANOOS Visualization System showing 30 days pCO_2 data from a University of Washington buoy supported by NANOOS with NOAA PMEL sensors at Twanoh, Hood Canal, WA. The variation is being studied by scientists to understand underlying mechanisms driving OA in these local waters.

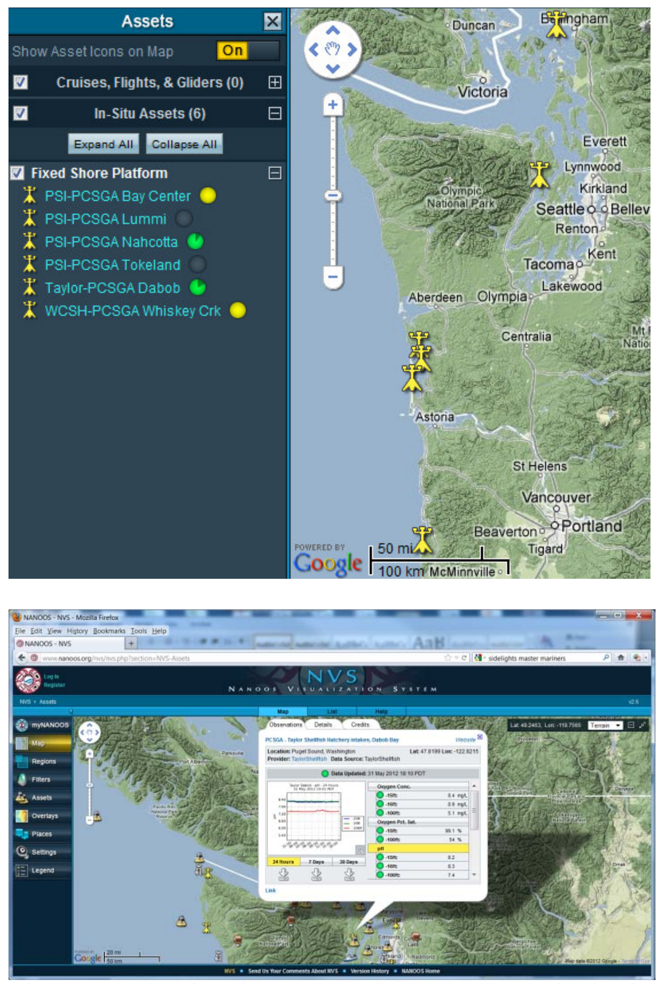

Fig. 2. Screen shots from the NANOOS Visualization System showing the monitoring sites from the shellfish growing community (PCSGA) in OR and WA (upper), and 24-hours pH data from the Taylor Shellfish hatchery in Dabob Bay, WA (lower), for two intakes, one shallow and one deep. The deeper intake has an appreciably lower pH and is not used to fill tanks.

B. *Real-time OA data via the NANOOS–IOOS data delivery system*

NANOOS has endeavored to pull in regional, OA-relevant near real-time data streams regardless of institutional affiliation or whether the provider receives direct IOOS funding. The close partnership between NANOOS and the PCSGA-organized community of shellfish growers engaged in water monitoring is of particular interest. NANOOS has an ongoing collaboration with technical staff from this community to facilitate the transmission of their near real-time data streams and ingestion into the NANOOS data integration system. In addition to making the shellfish growers' data streams widely accessible (Fig. 2), this collaboration has resulted in common, practical data handling solutions that have lowered participation barriers for local partners.

NANOOS now serves OA-relevant data from Northern California to British Columbia. All regional and federal data streams integrated by NANOOS are served in a consistent and user-friendly fashion via the NANOOS web portal (Figs. 1 and 2) as well as on NANOOS smart phone apps. The latter are particularly useful for the shellfish growers in the field, helping them to both assess water conditions and monitor the health of their own observation sensors. Shellfish growers are especially appreciative of the near real-time readouts of the data, upon which to make hatchery and remote setting decisions.

In addition to serving these data via the NANOOS Visualization System that currently addresses a broad audience, NANOOS also distributes targeted data streams via an application developed specifically to meet the needs of shellfish growers. With input from shellfish growers, this focused application is now being restructured and expanded to include OA-relevant data and provide a more effective and responsive service that will fully leverage the capabilities of the NANOOS data infrastructure.

C. *OA outreach and education*

There is much confusion and misunderstanding regarding ocean acidification. Outreach and education are fundamental parts of the IOOS and Regional Association efforts. NANOOS is working to collate information on OA so users and the public can readily find it. On its web portal, NANOOS has a "theme page" on OA, where viewers can find tutorial information on the science of OA, who is doing what regionally, and links to a variety of useful websites on the subject. NANOOS places high value on providing data and information to increase public understanding of coastal waters and their variation.

NANOOS has also worked with partners in OA outreach and education, including being featured on the NOAA PMEL Carbon Program website, collaborations with the Pacific Science Center, giving tutorial presentations at the Northwest Association of Marine Educators conference, and planning a workshop for educators with the Olympic Coast National Marine Sanctuary. Additionally, NANOOS has attended and presented at numerous PCSGA meetings over the years, and now is engaging with the grower community on their data and information needs regarding OA.

D. *NANOOS contributions beyond the Pacific Northwest*

The three continental Pacific west coast RAs, NANOOS, CeNCOOS, and SCCOOS, who have a joint Memorandum of Understanding to work together, are working within the West Coast Governor's Alliance (WCGA) and the California Current Acidification Network (C-CAN) to optimize data delivery regarding OA to users, ranging from scientists, shellfish growers, resource agencies, tribes, and the public at large [10].

C-CAN is a collaborative effort between the West Coast shellfish industry and scientists to explore what is causing shellfish losses, the role of ocean acidification, and how to adapt to these changes in order to sustain shellfish resources. As part of this effort with C-CAN, NANOOS, CeNCOOS, and SCCOOS have created an initial inventory of ocean acidification monitoring stations along the West Coast [10], and are working toward gaining resources to collectively promote effective observing practices and enhance their capacity to integrate and distribute the resulting data.

As with all IOOS Regional Association data, NANOOS data are visible and accessible in near real-time from the IOOS data portal via the use of IOOS standards for interoperable data transmission. This facilitates national assessments as well as provides a platform for contributions to global networks, such as have been proposed. NANOOS is also collaborating with IOOS, NOAA OA Program, and the NOAA National Oceanographic Data Center (NODC) OA Scientific Data Stewardship project to identify and implement data systems strategies that will enhance the cataloguing, discovery, and acess of OA-relevant datasets for the nation.

III. Summary

Ocean acidification is a critical issue to the NANOOS region, with the capacity to affect the region's economy, ecology, and cultural resources. In working to address data and information needs relevant to this topic, we see the benefit of the IOOS concept with its Regional Association structure, that allows for NANOOS to connect with regional partners and the public, while contributing consistently to West Coast-wide and national systems. The efficiency of an entity like NANOOS that actively partners across institutional lines is valuable and pays off in more ways than cost-savings alone.

References

[1] IPCC Core Writing Team, R.K. Pachauri, and A. Reisinger, Eds. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC, 2007.

[2] K. Caldeira and M. E. Wickett. "Anthropogenic carbon and ocean pH," Nature, vol. 425, pp. 365-365, doi: 10.1038/425365a, 2003.

[3] R. A. Feely, C. L. Sabine, K. Lee, W. Berelson, J. Kleypas, V. J. Fabry, and F. J. Millero, "Impact of anthropogenic CO_2 on the $CaCO_3$ system in the oceans" Science, vol. 305, 362-366, doi:10.1126/science.1097329, 2004.

[4] D. Archer, H. Kheshgi, and E. Maier-Reimer, "Multiple timescales for neutralization of fossil fuel CO_2," Geophys. Res. Lett., vol. 24, pp. 405-408, doi:10.1029/97gl00168, 1997.

[5] V. J. Fabry, B. A. Seibel, R. A. Feely, and J. C. Orr, "Impacts of ocean acidification on marine fauna and ecosystem processes," ICES J. Mar. Sci., vol. 65, pp. 414-432, doi:10.1093/icesjms/fsn048, 2008.

[6] J. M. Guinotte, and V. J. Fabry, "Ocean acidification and its potential effects on marine ecosystems," Ann. New York Acad. Sci., vol. 1134, pp. 320-342, doi:10.1196/annals.1439.013, 2008.

[7] A. Barton, B. Hales, G. G. Waldbusser, C. Langdon, and R. Feely, "The Pacific oyster, *Crassostrea gigas*, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification effects," Limnol. Oceanogr., vol. 57, pp. 698-710, doi:10.4319/lo.2012.57.3.0698, 2012.

[8] R. A. Feely, C. L. Sabine, J. M. Hernandez-Ayon, D. Ianson, and B. Hales, "Evidence for upwelling of corrosive 'acidified' water onto the continental shelf," Science, vol. 320, pp. 1490-1492, doi:10.1126/science.1155676, 2008.

[9] R. A. Feely, S. R. Alin, J. Newton, C. L. Sabine, M. Warner, A. Devol, C. Krembs, and C. Maloy, "The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary," Estuar. Coast. Shelf Sci., vol. 88, pp. 442-449, doi:10.1016/j.ecss.2010.05.004, 2010.

[10] J. Patterson, J. Thomas, L. Rosenfeld, J. Newton, L. Hazard, J. Scianna, R. Kudela, E. Mayorga, C. Cohen, M. Cook, M. Otero, and J. Adelaars, "Addressing ocean and coastal issues at the West Coast scale through regional ocean observing system collaboration," Proc. MTS/IEEE Oceans 2012, Hampton Roads, VA, submitted, 2012.