Testimony of Dr. Burke Hales
Professor of Ocean Ecology and Biogeochemistry
College of Earth, Ocean, and Atmospheric Sciences
Oregon State University

Before the
Committee on Science, Space, and Technology
Subcommittee on Environment
U.S. House of Representatives

Hearing on
"Leading the Way: Examining Advances in Environmental Technologies"

June 21, 2017

Thank you Chairman Biggs, Vice Chair Banks, and Ranking Member Bonamici for the opportunity to speak to you today to discuss the importance of federal investment in environmental monitoring systems and technology innovation. It is an honor to be with you all to have this important conversation.

I am Burke Hales, Professor in Ocean Ecology and Biogeochemistry in the College of Earth, Ocean and Atmospheric Sciences at Oregon State University. I have degrees in Chemical Engineering and Chemical Oceanography at The University of Washington, and served as a Department of Energy Distinguished Postdoctoral Fellow in Climate Change at Columbia University before joining the faculty at Oregon State University. I have a long record of publication and technical innovation in ocean science research, particularly with regard to ocean chemistry and carbon cycling.

I am a biogeochemical oceanographer, studying the ocean's carbon cycles at its boundaries: The seafloor, the air-sea interface, and the land-ocean margins. My background is strongly technological. I came to the field of chemical oceanography as a chemical engineer, and applied myself to devising ways to observe the previously unobservable. For example, I devised autonomous robotic systems that made sub-millimeter scale measurements of pH, oxygen and CO_2 in sediments miles below the sea-surface, and developed mathematical physical models to interpret these unique observations (1-6). I also devised solutions to automate upper-ocean towed profiling and sampling devices and developed the analytical systems to capture the high-frequency signals generated by these sampling systems (7-19). Finally, I have combined ocean chemistry measurements with satellite observations to build mechanistic predictive models of carbon cycling in ocean margin waters based on remote sensing (20), and devised ways to assess the decreased occurrence frequency of favorable conditions for early larval shellfish under elevated atmospheric CO_2 (21-22).

Importance of Strategic Federal Investment in Ocean-based Monitoring Systems

My work advances and is supported by a number of federally-funded ocean monitoring programs across several agencies. Data produced by analytical systems I developed is now being delivered to and served online in near real-time by the National Oceanic and Atmospheric Administration's (NOAA) Integrated Ocean Observing System in the Northwest (Northwest Association of Networked Ocean Observing Systems, or NANOOS). I also support ocean mooring systems that provide real-time data to NANOOS and NOAA's Pacific Marine Environmental Laboratory (PMEL) CO_2 program, and are now providing important new meteorological observations in low-data regions of the Oregon Coast to the National Weather Service. Additionally, I work with the National Science Foundation's Ocean Observatories Initiative (OOI) infrastructure off the Oregon Coast to provide validation analyses and time-series sensor measurements for carbonate-system chemistry. In addition to work to support these initiatives, I also make extensive use of the regional observations provided by OOI and NANOOS for my own research. Beyond ocean-based monitoring systems, my work intersects with NOAA and NASA earth-observing satellites which provide critical information in the development of predictive models of ocean carbon cycling with relevance to ocean plankton productivity, carbon sequestration, and acidification. Each of these federal programs and systems are unique, but complimentary.

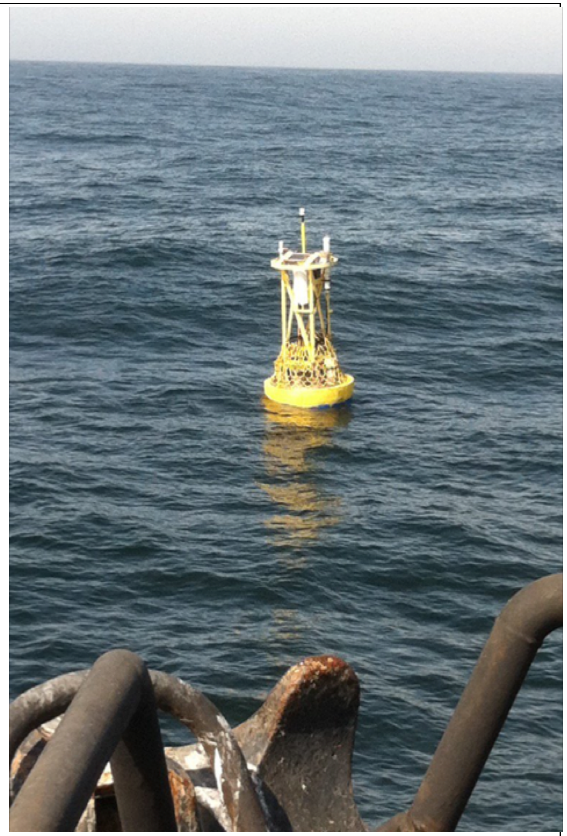

Figure 1. OSU's small-boat serviceable oceanographic mooring, carrying physical, chemical and biological oceanographic sensors and a meteorological sensor array now deployed in a low data-coverage region off Cape Arago on the Southern Oregon coast.

Example of Ocean Monitoring Technology Innovation

I will focus my testimony here to highlight an example of the important role federal investment in ocean monitoring systems and technology innovation had for my work on the Oregon Coast to address a unique industry's concerns for ocean acidification.

It all started when the Pacific Northwest Seedstock Crisis began in 2007. The shellfish hatcheries that support the commercial shellfish aquaculture industry began experience crippling mortality in the larval shellfish, or seed, that is sold to commercial growers (23-25). Commercially available monitoring technology failed to provide a robust environmental link between the failures and environmental conditions, and commercially-available remediation approaches failed to resolve the issue. It was not until personnel at the Whiskey Creek Shellfish Hatchery (WCSH) in Netarts Bay, Oregon, contacted me to pursue linkages to bay-water carbonate chemistry that the environmental trigger was identified: Low favorability for larval shell development in the first few hours to days of life (23,26), and appropriate remedies for conditioning hatchery intake water were undertaken (25).

Ultimately, I devised a system for the robust constraint of carbonate chemistry of natural waters, popularized by shellfish aquaculturist (aka oysterman) Mark Wiegardt as the ‘Burke-o-Lator’.

Figure 2. Burke-o-Lator systems at selected locations.

Clockwise from upper left: System deployed in Molluscan Broodstock Program laboratory at Hatfield Marine Science Center in Newport Oregon; Whiskey Creek Shellfish Hatchery, Netarts, OR; Aluutiq Pride Hatchery, Seward, AK; gas-water separator system at Sitka Tribes of Alaaska Environmental Research Laboratory, Sitka, AK.

This system allowed commercial users to assess real-time carbonate chemistry conditions in the context of production of shellfish seed-stock that supports the commercial shellfish industry on the US west coast (24-25). This system has been commercialized via a license awarded by OSU to my LLC, and will soon be sublicensed to Sunburst Sensors, LLC, of Missoula, MT, a leader in the autonomous measure of natural water pH and CO_2.

Carbonate chemistry in natural waters responds in a variety of ways to natural and anthropogenic forcing, including changes in dissolved CO_2 gas, pH, and the favorability of waters for precipitation of calcium carbonate, the bio-mineral from which many shellfish build their shells and skeletons. This favorability for mineral formation, also known as Ω, cannot be directly measured, but must rather be determined by multiple parallel measurements of carbonate chemistry and subsequently calculated. In dynamic coastal waters, simple connections between this critically important term and the more easily observable pH are poorly constrained, and the seemingly simple measurement of pH has analytical challenges that are not understood outside of a community of highly-specialized researchers. Without the full constraint of the carbonate system provided by the Buke-o-Lator's parallel measurements of dissolved CO_2 gas and total dissolved carbonates, the system chemistry could only be determined by infrequent and costly discrete samples that could sometimes wait months for analysis. Shellfish hatchery operators were without any tools for timely observation of the parameter that impacted their operation the most.

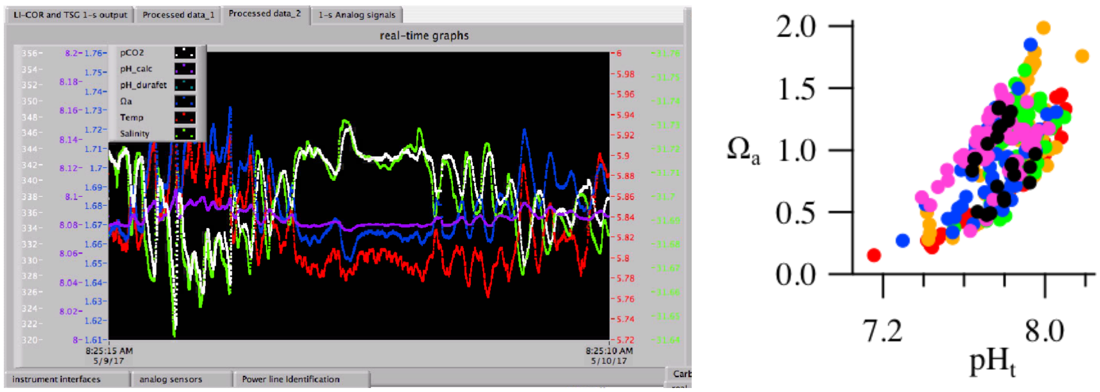

Figure 3. Left, data output screen for 24-hour period of observations at Aluutiq Pride Shellfish Hatchery, showing real-time determinations of seawater CO_2 content (white), pH (purple), and shell-formation favorability (Ω_a; blue) along with water temperature (red) and salinity (green). Right, illustration of independence of Ω_a from pH, for samples collected in collaboration with the Pacific Coast Shellfish Growers Association in Willapa Bay, WA.

Federal-University Supported Technology Innovation Results in Real-World Impacts

With technological developments motivated by my own ocean carbon cycle research and supported by grants from the National Science Foundation and the National Oceanic and Atmospheric Administration, I was able to develop systems for these measurements that were significantly lower-cost, faster-analysis, and more-robust for dynamic coastal waters than much of the research community, and were unparalleled by any existing technology in the commercial sector.

Given the extensive federal support of the technological development of these systems, it was then only a matter of integrating these measurements into a single system and devising sampling protocols with low cost- and skill-barriers to develop the beta Burke-o-Lator technology systems for routine service sample analyses in my laboratory at OSU and the real-time monitoring of bay-water intake at Whiskey Creek Hatchery. Since that time, systems have been deployed in shellfish production facilities and marine laboratories from San Diego, California to Seward, Alaska. There are currently 20 systems deployed or in the late stages of production, constructed either at OSU or by myself in my garage.

At near total collapse in 2007, the installation of the prototype Burke-o-Lator in 2009 and development of proper approaches to buffering intake seawater began to bring operations at Whiskey Creek back from the brink. In fact, when I asked to take my loaned prototype out on a research cruise that year, WCSH owner Sue Cudd refused, saying, "I'll go out of business if you take that instrument out of my hatchery," and I had to assemble a field instrument from spare parts in my lab to support my core oceanographic research. Now, WCSH is back to near total production recovery to pre-crash levels. While the price per instrument is still high, at $50,000 per copy, the recurring maintenance cost is significantly lower, and further commercialization will continue to reduce unit cost. In addition, the continued generation of research-quality monitoring data serves the working-waterfront stakeholder and oceanographic research communities alike.

Closing

In summary, while there was urgency among the shellfish industry for a BoL technology solution, there was no motivation to independently develop a market-driven prototype from a purely commercial perspective prior to the research-driven environmental monitoring technology development. The federal and university supported innovation pathway that this Burke-o-Lator technology developed represents the ideal model for technological development for unique market needs, and, ultimately, technology transfer to the commercial sector.

Further, impactful environmental monitoring technology innovation is made possible by the critical investments we make as a society for basic science and the pursuit of new knowledge. Environmental research allows us to constantly push the limits of our current understanding of our oceans, atmosphere, and the earth. This constant expansion of our knowledge allows us to develop high quality data parameters to deploy useful monitoring and observation systems that are beneficial across public and private sector interests.

Federal and state governments, universities, and private sector stakeholders all have a role to play in driving environmental technology innovation for impactful monitoring systems. In the case of the Burke-o-Lator, federal investment supported exploratory technological development when markets for such technology were not yet viable for commercial R&D investment. Then, as knowledge and technology capacity hardens, private-sector commercialization opportunities arise. This innovation pathway can yield commercial environmental technology products that, when applicable, can provide excellent resources for cost-effective monitoring systems.

Thank you for the opportunity to testify today on the importance of our federal investment in environmental research, monitoring and observation systems, and research-led technology innovation. I look forward to further discussion and welcome opportunity to expand on my comments in response to any questions you may have.

Citations

1. Hales, B., S. R. Emerson, and D. E. Archer, 1994. Respiration and dissolution in sediments of the western North Atlantic: Estimates from models of *in situ* microelectrode measurements of porewater oxygen and *p*H. *Deep-Sea Research* **41**, 695-719.
2. Hales, B. and S. R. Emerson, 1996. Calcite dissolution in sediments of the Ontong-Java Plateau: *In situ* measurements of porewater O_2 and *p*H. *Global Biogeochemical Cycles*, **10**, 527-541.
3. Hales, B. and S. R. Emerson, 1997. Calcite dissolution in sediments of the Ceara Rise: *In situ* measurements of porewater O_2, *p*H, and $CO_{2(aq)}$. *Geochimica et Cosmochimica Acta*, **61**, 501-514.
4. Hales, B., L. Burgess, and S. R. Emerson, 1997. An absorbance-based fiber-optic sensor for $CO_{2(aq)}$ measurement in porewaters of sea floor sediments. *Marine Chemistry*, **59**, 51-62
5. Hales, B. and S. R. Emerson, 1997. Evidence in support of first-order dissolution kinetics for calcite in seawater. *Earth and Planetary Science Letters*, **48**, 317-327
6. Hales, B., 2003. Respiration, dissolution, and the lysocline. *Paleoceanography*, **18**, 1099-1113
7. Hales, B. and T. Takahashi, 2002. The Pumping Seasoar: A high resolution seawater sampling platform. *J. Tech.* **19**, 1096-1104
8. Hales, B., T. Takahashi, and A. van Geen. 2004. High-frequency measurement of seawater chemistry: Flow-injection analysis of macronutrients. *Limnology and Oceanography: Methods* **2,** 91–101
9. Hales, B., D. Chipman and T. Takahashi, 2004. High-frequency measurement of partial pressure and total concentration of carbon dioxide in seawater using microporous hydrophobic membrane contactors. *Limnology and Oceanography: Methods* **2**, 356-364.
10. Hales, B., and T. Takahashi, 2004. High-resolution biogeochemical investigation of the Ross Sea, Antarctica, during the AESOPS (U. S. JGOFS) program. *Global Biogeochemical Cycles* **18**, GB3006, doi:10.1029/2003GB002165.
11. Karp, L., P. Wheeler, B. Hales, and P. Covert, 2004. Distributions and variability of POM in a coastal upwelling system. *Journal of Geophysical Research—Oceans* **109**, C09010, doi:10.1029/2003JC002184.
12. Hales, B., and T. Takahashi, 2004. High-resolution biogeochemical investigation of the Ross Sea, Antarctica, during the AESOPS (U. S. JGOFS) program. *Global Biogeochemical Cycles* **18**, GB3006, doi:10.1029/2003GB002165.
13. Hales, B., T. Takahashi and L. Bandstra, 2005. Atmospheric CO_2 uptake by a coastal upwelling system *Global Biogeochem. Cycles* 19, doi:10.1029/2004GB002295
14. Hales, B., L. Karp-Boss, A. Perlin, and P. Wheeler, 2006. Oxygen production and carbon sequestration in an upwelling coastal margin. *Global Biogeochemical Cycles*, 20, GB3001, doi:10.1029/2005GB002517.

15. *Bandstra, L., B. Hales, and T. Takahashi, 2006. High-frequency measurement of seawater total carbon dioxide. *Mar. Chem*. doi:10.1016/j.marchem.2005.10.009.

16. Hales, B., J. N. Moum, P. Covert, and A. Perlin, 2005. Irreversible nitrate fluxes due to turbulent mixing in a coastal upwelling system. *J. Geophys. Res.,* 110, C10S11, doi:10.1029/2004JC002685.

17. Hales, B., D. Hebert, and J. Marra, 2009. Turbulent supply of nutrients to phytoplankton at the New England Shelfbreak Front. *J. Geophys. Res.*, doi:10.1029/2008JC005011.

18. Hales, B., R. Vaillancourt, L. Prieto, J. Marra, R. Houghton, and D. Hebert, 2009. High-resolution surveys of the biogeochemistry of the New England shelfbreak front during Summer, 2002. *J. Mar. Syst.*, doi:10.1016/j.jmarsys.2008.11.024.

19. Hales, B., and T. Takahashi, 2012. Mesoscale physical and biogeochemical responses to iron fertilization in the upper layers of the southern ocean iron experiment (SOFeX) area. *J. Geophys. Res. C: Oceans*, doi:10.1029/2011JC006956.

20. Hales, B., P. Strutton, M. Saraceno, R. Letelier, T. Takahashi, R. Feely, C. Sabine, and F. Chavez, 2012. Satellite-based prediction of pCO_2 in coastal waters. *Progress in Oceanography*, 10.1016/j.pocean.2012.03.001.

21. Harris, K.E., M.D. DeGrandpre, and B. Hales, 2013. Aragonite saturation states in a coastal upwelling zone, *Geophy. Res. Lett.,* DOI: 10.1002/grl.50460.

22. Hales, B., A. Suhrbier, G. G. Waldbusser, R. A. Feely, and J. Newton, 2016. The carbonate Chemistry of the 'fattening line' Willapa Bay, 2011-2014. *Estuaries and Coasts*, DOI: 10.1007/s12237-016-0136-7

23. Barton, A., B. Hales, G. Waldbusser, C. Langdon, and R. Feely, 2012. The Pacific oyster, *Crassostrea gigas*, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification impacts. *Limnology and Oceanography* 57, 698-710, doi:10.4319/lo.2012.57.3.0698.

24. Washington State Blue Ribbon Panel on Ocean Acidification, 2012. Ocean Acidification: From Knowledge to Action, Washington State's Strategic Response. H. Adelsman and L. Whitely Binder (eds). Washington Department of Ecology, Olympia, Washington. Publication no. 12-01-015.

25. Barton, A., G. G. Waldbusser, R. A. Feely, S. B. Weisberg, J. A. Newton, B. Hales, S. Cudd, B. Eudeline, C. Langdon, I. Jefferds, T. King, and K. Mclaughlin, 2015. Impacts of coastal acidification on the Pacific Northwest shellfish industry and adaptation strategies implemented in response. *Oceanography* 28(2):146–159, http://dx.doi.org/10.5670/oceanog.2015.38

26. Waldbusser, G. G., B. Hales, C. J. Langdon, B. A. Haley, P. Schrader, E. L. Brunner, M. W. Gray, C. A. Miller, I. Gimenez, and G. Hutchinson, 2015. Ocean acidification has multiple modes of action on bivalve larvae. *PLOS ONE* 10(6): e0128376. doi:10.1371/journal.pone.0128376 .