Executive Summary

In 2012, Washington state's leading scientists, industry and conservation representatives, and state, local, federal, and tribal policymakers came together under the Washington State Blue Ribbon Panel (the Panel) on Ocean Acidification in response to poorly understood but drastic changes in marine chemistry that had caused dramatic shellfish hatchery production failures in Puget Sound. The Panel reviewed the current state of knowledge on ocean acidification and developed a comprehensive, science-based strategy for action set forth in its seminal 2012 report *Ocean Acidification: From Knowledge to Action*. In establishing its groundbreaking strategy, Washington state became a global leader in tackling this enormous marine resource challenge.

The Panel recognized the significant threat of ocean acidification to Washington – potentially leading to disaster for marine industries, rural economies and jobs, tribal communities, and the broader marine environment – and the need for strategic coordination on a proactive response. Alongside a summary of the latest scientific knowledge, the comprehensive 2012 strategy identified 42 recommended actions for Washington state to better understand, address, adapt, and raise awareness around ocean acidification. The recommended actions centered around six focus areas:

1. Reducing carbon emissions
2. Reducing local land-based contributions to ocean acidifcation
3. Increasing our ability to adapt to and remediate the impacts of ocean acidification
4. Investing in monitoring and scientific investigations
5. Informing, educating, and engaging stakeholders, the public, and decision makers
6. Maintaining a sustainable and coordinated focus on ocean acidification

Photo credit: Dan Ayres, Washington Department of Fish and Wildlife

The purpose of the 2017 Addendum

To capture the significant progress made towards the Panel's 2012 recommendations, advances in scientific understanding, the changing needs of managers, and the strengthening network of ocean acidification partners, the Marine Resources Advisory Council (MRAC) identified a need to reevaluate and revise, as necessary, the 2012 strategy. Beginning in 2016, it led its partners in a review process to:

- Document all that has been accomplished since 2012;
- Determine updates or additions to the Blue Ribbon Panel's comprehensive strategy to account for emerging issues and new management needs;
- Identify efforts Washington will focus on in the next several years to continue progress; and
- Renew Washington's commitment to maintaining strategic momentum in addressing the ongoing threat from our changing ocean chemistry.

This 2017 Addendum to the Blue Ribbon Panel's 2012 report is the outcome of that effort. As an addendum, this document is intended to be a companion to the original report, expanding on – not replacing – the work of the Panel. While several new actions were identified as part of this evaluation, it is important to note that no work in pursuit of the original 42 actions is complete, and all original recommendations continue to be important.

Washington has made great progress to implement this comprehensive strategy

In 2013, the Washington State Legislature established and funded the MRAC to help oversee the implementation of the Blue Ribbon Panel recommendations. The Legislature also established and funded the Washington Ocean Acidification Center (WOAC) at the University of Washington to advance and coordinate scientific research and monitoring. These two entities, along with strong support from the shellfish industry, state agencies, tribes, non-profit partners, and the Washington State Governor's Office, have been critical to guiding local efforts since 2012.

Over the last five years, Washington state has made significant progress towards the 42 recommended actions, increasing local knowledge and taking action in the fight to combat ocean acidification and its impacts. The many examples of progress across the Panel's six identified focal areas include:

- Establishing a clean air rule to reduce carbon emission from large in-state emitters (Chapter 4)
- Developing a local source attribution model to help determine the relative influence and impact of land- and air-based inputs in local ocean acidification conditions (Chapter 5)
- Launching an ocean acidification conservation hatchery that serves as a hub for shellfish research and restoration (Chapter 6)
- Initiating enhanced and widescale monitoring–with real-time sharing through the Northwest Association of Networked Ocean Observing Systems (NANOOS)–to collect data and support shellfish hatchery adaptation practices (Chapter 7)
- Increasing ocean acidification awareness and literacy through a multitude of outreach events, targeted advocacy with legislators, and the creation of an ocean acidification K-12 curricula compendium (Chapter 8)
- Coordinating with key science and policy partners at the state, regional, and international level, such as with the Global Ocean Acidification Observing Network and the International Alliance to Combat Ocean Acidification to inspire other jurisdictions at all levels to create customized plans for local ocean acidification action (Chapter 9)

Photo credit: Bill Dewey

Alongside progress made at home, Washington state has also emerged as a recognized leader on the regional, national, and global stages in the fight to address ocean acidification. The Blue Ribbon Panel's comprehensive strategy has inspired other coastal states such as Maine, Maryland, Massachusetts, New York, and Oregon to develop similar action plans to address and adapt to ocean acidification off their shores. With key partners such as the Washington State Governor's Office, the Pacific Coast Collaborative, the International Alliance to Combat Ocean Acidification, and the West Coast Ocean Acidification and Hypoxia Science Panel, Washington has also played a central role in elevating the problem to national and international arenas, connecting broader dialogues around ocean issues and climate change that will ultimately benefit our mitigation and adaptation efforts at home.

Advancements in science: What we now know

In 2012, the scientific community was aware ocean acidification posed a major threat to marine environments, industries, and societies. It was clear ocean acidification was caused by the absorption of atmospheric carbon dioxide (CO_2) and the discharge of nutrients from air and water into our oceans. Researchers also understood the modern rate of acidification was ten times faster than any time in the past 50 million years, outpacing the ocean's natural ability to buffer pH and lessening the chance for marine organisms and the ecosystems they support to adapt, evolve, and survive.

The understanding of ocean acidification has progressed since 2012. New research offers greater insight into the sources, scale, and impacts posed by acidifying conditions in Washington's marine waters, and these insights justify more concerted efforts at the local scale. Over the last five years, research shows that acidification has increased in Washington coastal waters because of the combined effects of both global and local sources of carbon dioxide that drive the acidification process. From both laboratory and field studies, we are now seeing the effects of acidification in some marine organisms. For example:

- Atmospheric CO_2 in the Puget Sound area is increasing faster than on Washington's coast and faster than the global average[1]. Additionally, Southern Hood Canal shows the highest surface seawater values of pCO_2 in Washington coastal waters[2]. The impacts of ocean acidification are being felt today and Washington will likely see some of the biggest impacts sooner than other coastal jurisdictions. Monitoring efforts show drastic need for action today.

- Human-generated atmospheric CO_2 is substantially increasing ocean acidification in surface waters[3] and local human-derived nutrient sources contribute significantly to ocean acidification conditions in certain areas of Puget Sound, though spatial variability exists[4]. To effectively reduce the risks presented by ocean acidification, hard decisions on decarbonizing the economy and finding local strategies to reduce nutrient inputs will be needed.

- Local species, including Dungeness crab[5], foraminifera[6], pteropods[7], and krill[8], are showing sensitivity to ocean acidification. This early research highlights how ocean acidification poses a broad threat and could impact species across the marine food web, including salmon and whales who consume these smaller species.

- Impacts may be more severe in nearshore coastal waters than in offshore open ocean waters, because corrosive conditions are closer to the surface in nearshore coastal waters and in Puget Sound[9]. The effects already witnessed among shellfish are not likely to be in isolation. Shellfish and other nearshore species, many of which are cultivated or provide significant ecological benefits, may continue to bear the brunt of ocean acidification's impacts.

What recent science says about ocean acidification supports and expands on what was known in 2012. While further research is needed to answer outstanding questions, there is no scientific debate that ocean acidification is a threat, and a significant driver of these changes is local carbon emissions and nutrient sources. Without additional action soon, even more severe economic, social, and environmental consequences are on the horizon.

Continuing to move from knowledge into action

The first five years of Washington's efforts towards implementing this comprehensive ocean acidification strategy were focused on building knowledge, connecting with partners, leveraging resources, and starting discussions about on-the-ground implementation. Looking forward, it is time to draw on the foundation we have built to carry us towards more effective and strategic action. As part of this ongoing commitment to transform knowledge into action, Washington will continue to advance the conversation at the global level while acting locally, and ground policy and programs in sound science and strong collaboration.

---

[1] Alin et al., 2016.

[2] Reum et al., 2014.

3 Feely et al., 2016.

[4] Pelletier et al., 2017.

[5] Miller et al., 2016.

[6] Miller et al., 2016.

[7] Bednaršek et al., 2016. Busch et al., 2014.

[8] McLaskey et al., 2016.

[9] Feely et al., 2010. Feely et al., 2016. Bednaršek et al., 2014. Bednaršek et al., 2017a.

Works cited

Alin, S., C. Sabine, R. Feely, A. Sutton, S. Musielewicz, A. Devol, W. Ruef, J. Newton, and J. Mickett, 2016. In: PSEMP Marine Waters Workgroup. 2016. Puget Sound marine waters: 2015 overview. S.K. Moore, R. Wold, K. Stark, J. Bos, P. Williams, K. Dzinbal, C. Krembs, and J. Newton (Eds). www.psp.wa.gov/PSEMP/PSmarinewatersoverview.php.

Bednaršek, N., R.A. Feely, J.C.P. Reum, W. Peterson, J. Menkel, S.R. Alin, and B. Hales. 2014. Limacina helicina shell dissolution as an indicator of declining habitat suitability due to ocean acidification in the California Current Ecosystem. Proc. Roy. Soc. B, 281, 20140123, doi: 10.1098/rspb.2014.0123.; 10.1016/j. pocean.2016.04.002.10.1016/j. pocean.2016.04.002.. Deep-Sea Res. II, 127, 53–56, doi: 10.1016/j. dsr2.2016.03.006.

Bednaršek, N., J. Johnson, and R.A. Feely. 2016. Vulnerability of pteropod (Limacina helicina) to ocean acidification: Shell dissolution occurs despite an intact organic layer. Deep-Sea Res. II, 127, 53–56, doi: 10.1016/j.dsr2.2016.03.006.

Bednaršek, N., R.A. Feely, N. Tolimieri, A.J. Hermann, S.A. Siedlecki, G.G. Waldbusser, P. McElhany, S.R. Alin, T. Klinger, B. Moore-Maley, and H.O. Pörtner. 2017. Exposure history determines pteropod vulnerability to ocean acidification along the US West Coast. Sci. Rep., 7, 4526, doi: 10.1038/s41598-017-03934-z.

Busch, D.S., M. Maher, P. Thibodeau, and P. McElhany. 2014. Shell condition and survival of Puget Sound pteropods are impaired by ocean acidification conditions. PLoS ONE, 9(8), doi: 10.1371/journal.pone.0105884.

Feely R.A., S.R. Alin, J.A. Newton, C.L. Sabine, M. Warner, A. Devol, C. Krembs, C. Maloy. 2010. The combined effects of ocean acidification, mixing, and respiration on pH and carbonate saturation in an urbanized estuary. Est., Coast. Shelf Science 88: 442-449.

Feely, R.A., S. Alin, B. Carter, N. Bednaršek, B. Hales, F. Chan, T.M. Hill, B. Gaylord, E. Sanford, R.H. Byrne, C.L. Sabine, D. Greeley, and L. Juranek. 2016. Chemical and biological impacts of ocean acidification along the west coast of North America. Estuar. Coast. Shelf Sci., 183(A), 260–270, doi: 10.1016/j.ecss.2016.08.043.

McLaskey, A. K., J. E. Keister, P. McElhany, M. B. Olson, D. S. Busch, M. Maher, A. K. Winans. 2016. Impaired development of krill larvae (Euphausia pacifica) reared at pCO2 levels currently observed in the Northeast Pacific. Marine Ecology Progress Series.

Miller, J.J., Maher, M., Bohaboy, E., Friedman, C.S., and P. McElhany. 2016. Exposure to low pH reduces survival and delays development in early life stages of Dungeness crab (Cancer magister). Marine Biology. 163(5):1–11.

Pelletier, G., Bianucci, L., Long, W., Khangaonkar, T., Mohamedali, T., Ahmed, A., and C. Figueroa-Kaminsky. 2017. Salish Sea Model: Ocean Acidification Module and the Response to Regional Anthropogenic Nutrient Sources. Washington Department of Ecology. Publication No. 17-03-009.

Reum J.C.P., Alin S.R, Feely R.A., Newton J., Warner M., et al. 2014. Seasonal carbonate chemistry covariation with temperature, oxygen, and salinity in a fjord estuary: Implications for the design of ocean acidification experiments. PLoS ONE 9(2): e89619 doi: 10.1371/ journal.pone.0089619.