# 2 Ocean Acidification in Washington State Marine Waters

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New research seeks to describe specific responses of a wider suite of local species to ocean acidification. Photo credit: Washington State Department of Natural Resources

Global ocean acidification is well-documented from observations and its impacts are being felt in the Pacific Northwest. The transfer of carbon dioxide from the atmosphere to the ocean is rapidly and measurably lowering seawater pH. Local land-based sources of nutrients and organic carbon can exacerbate ocean acidification by adding carbon dioxide to the water as a product of microbial decomposition. This is especially likely in areas where human activities increase the flow of nutrients and organic carbon from land to marine waters.

In addition to increasing seawater carbon dioxide and decreasing its pH, ocean acidification reduces the carbonate ion concentration in seawater, thereby reducing the stability of calcium carbonate an important biogenic mineral used by calcifying organisms to build and maintain shells and other hard body parts. Ocean acidification's effects on shelled organisms are well-documented. Many other life processes, such as growth, respiration, recruitment, reproduction, and behavior, can also be sensitive to increases in carbon dioxide and reductions in pH. As a result, acidification has the potential to affect a wide range of organisms both directly and indirectly. These impacts are expected to have significant biological, economic, and social consequences. The 2012 Panel report summarized scientific understanding of the causes and consequences of ocean acidification in Washington's marine waters. The ability of managers and decision-makers to address ocean acidification requires strong scientific understanding of the problem. Recognizing the importance of strong science to support action, the Washington State Legislature established the Washington Ocean Acidification Center (WOAC) at the University of Washington in 2013. WOAC is charged with connecting researchers, policymakers, industry, and others across Washington to advance the science of ocean acidification and provide a foundation for proactive strategies and policies to protect marine ecosystems.

Chapter 7 of this report summarizes many of the key findings on ocean acidification that have emerged since the original Panel report was published. Here we provide a brief overview of the major areas of focus for this new research. Further details about the status of ocean acidification in Washington can be found through the WOAC website<sup>1</sup>, by reading the *Scientific Summary of Ocean Acidification in Washington State Marine Waters*<sup>2</sup>, or science documents developed by the West Coast Ocean Acidification and Hypoxia Panel<sup>3</sup>. Many entities have contributed to these new research findings, working together via existing or new partnerships to establish a better understanding of ocean acidification.



The rise in atmospheric  $CO_2$  at Mauna Loa and seawater data from a nearby ocean monitoring station showing a rise in seawater  $CO_2$  and decrease in seawater pH. Source: Updated from Feely et al., 2008

### 2.1 Ocean Acidification: Causes and Trends

The 2012 Panel report defines ocean acidification, its causes, and its status in Washington state coastal waters. Much effort since then has gone towards measuring how ocean acidification in Washington waters varies depending on depth, season, and location. Southern Hood Canal has the highest surface seawater values of  $pCO_2$  in Washington coastal waters<sup>4</sup>. At the same time, atmospheric  $CO_2$  in the Puget Sound area is increasing faster than on Washington's coast and faster than the global average<sup>5</sup>. In short, research shows that acidification has increased in Washington coastal waters over the last five years because of the combined Atmospheric CO<sub>2</sub> in the Puget Sound area is increasing faster than on Washington's coast and faster than the global average.<sup>1</sup>

<sup>1</sup> Alin et al., 2016.

# Ocean acidification is progressing rapidly

The current rate of acidification is several times faster than what has been observed over the past 50 million years.<sup>2</sup> Such rapid change can outpace the ocean's natural ability to buffer ocean pH and carbonate chemistry.<sup>3</sup> The rapid pace of change gives marine organisms and humans less time to adapt, evolve, or otherwise adjust to changing circumstances.<sup>4</sup>

<sup>2</sup> Zachos et al., 2005.

<sup>3</sup> Orr et al., 2005.

effects of global and local sources of the 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. As described in Chapter 7 of this report, variation in corrosive conditions tells us that local processes can either enhance or offset the global condition.

Understanding these patterns over both space and time is essential to effective action, and thus it is critical that we sustain both physiochemical and biological monitoring efforts over the entirety of Washington's marine, estuarine, and nearshore waters. Use of indicator species such as pteropods, whose calcium carbonate (CaCO<sub>3</sub>) shells can show evidence of recent dissolution, is a promising technique under development. Additionally, understanding patterns in both water chemistry and organismal response will help

<sup>&</sup>lt;sup>1</sup> www.environment.uw.edu/research/major-initiatives/ocean-acidification/ washington-ocean-acidification-center

<sup>&</sup>lt;sup>2</sup> Feely et al., 2012.

<sup>&</sup>lt;sup>3</sup> www.westcoastoah.org

 <sup>&</sup>lt;sup>4</sup> Reum et al., 2014. Reum et al., 2016. Alin et al., 2016. Fassbender et al., 2017.
<sup>5</sup> Alin et al., 2016.

<sup>&</sup>lt;sup>4</sup> Turley et al., 2010.

#### Do the impacts of ocean acidification vary in Puget Sound and along Washington's coast?

This is one of the questions the Washington State Department of Natural Resources' Acidification Nearshore Monitoring Network (ANeMoNe) aims to answer. ANeMoNe is a network of sensors located in the nearshore around Puget Sound and along the Pacific coast to measure local variations of marine chemistry. These data can be used to evaluate site-specific variability in pH, assess impacts on marine organisms, and identify potential sites that may be more exposed to or buffered against changes in marine chemistry. Data from nearshore areas will be compared to the measurements being taken by WOAC and multiple agencies in marine waters beyond the nearshore environment.



Testing marine chemistry. Photo credit: Washington State Department of Natural Resources

us understand the mechanistic basis for change. Chapter 7 relays new progress defining the attribution of human-generated  $CO_2$  in Washington waters, which has been shown to be measurable and sufficient to cause biological response.

## 2.2 Local Ocean Acidification

The Panel report described processes that contribute to ocean acidification and, particularly, regional distinctions within Washington related to local conditions. Since 2012, the Washington Department of Ecology has worked in collaboration with Pacific Northwest National Laboratory to develop a numerical model of hydrodynamics and biogeochemical processes in the Salish Sea, including prediction of carbonate system variables. The Department of Ecology published a report in June 2017 documenting the addition of the ocean acidification module to the Salish Sea Model<sup>6</sup>. The 2017 report also describes the results of using the model to evaluate the changes in carbonate system variables that are due to regional anthropogenic nutrient sources and regional atmospheric  $CO_2$ .

The model results show that the aragonite saturation state has decreased due to global and regional anthropogenic  $CO_2$  and regional anthropogenic nutrient sources. The impact of regional anthropogenic nitrogen and organic carbon sources varies widely in time and space. Regional anthropogenic nutrient loadings decreased pH and the aragonite saturation state in some areas, particularly in several South Puget Sound shallow inlets and bays. The impact of regional anthropogenic nutrient sources is predicted to be greatest at the bottom of the water column.

## 2.3 Species Responses to Ocean Acidification

In 2012, scientists had a general understanding that many calcifying species would be vulnerable to ocean acidification. The Panel report was limited by a paucity of studies, especially on local species. New research has been conducted to describe specific responses of a wider suite of local species to ocean acidification, which includes salmon, crab, oysters, and krill. Chapter 7 describes what has been learned to date, with other studies still in progress. Several negative impacts have been observed, suggesting a critical area for further study.

<sup>6</sup> Pelletier et al., 2017. Available at https://fortress.wa.gov/ecy/publications/SummaryPages/1703009.html

## 2.4 Using Science for Adaptation and Management

The Panel clearly articulated the need to conduct research and monitoring in order to support action. A major accomplishment of research to date has been support for shellfish hatcheries in monitoring ocean acidification conditions and learning how to use monitoring data to adapt their practices to local seawater conditions. Monitoring equipment was installed at six hatchery sites and technical assistance was provided to hatchery managers on how to read data outputs. Data are shared in near real-time through the Northwest Association of Networked Ocean Observing Systems (NANOOS) portal. Since this monitoring began, shellfish hatcheries and shellfish growing operations are benefiting from the real-time monitoring data available online. Hatcheries are using seawater modification methods to adapt to ocean acidification conditions based on the information provided by monitoring equipment.



Benoit Eudeline, chief hatchery scientist for Taylor Shellfish Farms, carefully monitors a hatchery's water-quality levels to keep plumes of acidic water from threatening young oysters. Photo credit: Taylor Shellfish Farms

A forecast model developed by the University of Washington provides a second important tool to support action. The model's output is available online at NANOOS, showing 3-day forecasts of temperature, salinity, pH, aragonite saturation, oxygen and nutrients for the outer coastal waters of Washington. The model will be extended to the Salish Sea over the next year. This tool allows shellfish growers to anticipate corrosive conditions and allows natural resource managers to detect areas of high or persistent corrosivity that could be of concern to natural populations.

# Working together for water quality evaluation

The National Oceanic and Atmospheric Administration (NOAA) Pacific Marine Environmental Laboratory and the Washington Ocean Acidification Center worked together in a federal-state partnership on multiple cruises in Washington waters, both offshore and within the Salish Sea. On these cruises, researchers collected water chemistry and plankton data. These data were submitted to the Washington Department of Ecology and the Environmental Protection Agency (EPA) for their assessments under Section 303(d) of the Clean Water Act. The data were then analyzed to determine if they meet water quality standards that protect beneficial uses - such as for drinking, recreation, aquatic habitat, and industrial use. Waters with results that do not meet standards, as reviewed by EPA, are added to the 303(d) list of impaired waters. Jurisdictions found with impaired waters are eligible for additional funding to address the pollutant concerns, and would need to pursue public awareness measures as well as comply with a Total Maximum Daily Load (TMDL) limit, restoration plan, or mitigation plan.



An adult krill specimen under the microscope. Krill larval development and survival are sensitive to low pH levels that are currently observed in Washington's marine waters. Photo credit: Russ Hopcroft, University of Alaska-Fairbanks

#### What is aragonite saturation?

Aragonite saturation state is often used to describe ocean acidification conditions for organisms like pteropods, oysters, mussels that produce a calcium carbonate shell. Aragonite is one of the more soluble forms of calcium carbonate and is widely used by marine calcifiers. When aragonite saturation state falls below 2, these organisms can become stressed, and when saturation state is less than 1, shells and other aragonite structures can begin to dissolve. The saturation state is denoted with the Greek term  $\Omega$  (omega).

#### The significance of local actions

What does the 2017 Salish Sea Model tell us? While there is variability due to space, time, and weather patterns, the model suggests that local sources are a significant driver of acidification in certain Puget Sound waters. For these areas, actions to address local air pollution and local nutrient loading into our water systems from point and nonpoint sources are likely to have a meaningful effect in addressing acidifying conditions. This key finding can serve to inform state-based pollution and nutrient control efforts in Washington state moving forward.

In 2014, a conservation hatchery was established at the Kenneth K. Chew Center for Shellfish Research and Restoration. The hatchery, located at Manchester Lab in Central Puget Sound, is a hub for native species propagation and ocean acidification research. Its size and location provide an opportunity for researchers and managers to test strategies that local industry and managers could use to mitigate impacts of ocean acidification on key species of economic importance. The hatchery also operates a kelp propagation lab that provides a source of native kelp to use in research and remediation efforts.

### 2.5 Summary

While our basic understanding of ocean acidification hasn't changed since 2012, what we know about causes and consequences of ocean acidification is rapidly advancing. We now have a greater understanding of the scale, types of impacts, and consequences posed by ocean acidification in Washington waters. Further study will continue building knowledge for action. As researchers continue to work on ocean acidification, they are focusing on several remaining questions, including:

- How do changes in seawater buffering affect the regional ocean acidification signal now and in the future?
- How important are local sources and processes to the ocean acidification signal?
- How does ocean acidification interact with other marine stressors (e.g., temperature, hypoxia, salinity) to affect marine ecosystems?
- How does ocean acidification influence harmful algal blooms?

#### Dig into the science

For more information about ocean acidification in Washington's marine waters, see the *Scientific Summary of Ocean Acidification in Washington State Marine Waters*<sup>7</sup>. This technical summary, written for the Panel by Pacific Northwest scientists, describes in detail what is known about local conditions and how various species, communities, and ecosystems will likely respond to ocean acidification. The summary also discusses current scientific work in the region and identifies significant knowledge gaps. The summary is available at: fortress.wa.gov/ecy/publications/ documents/1201016.pdf

For more information about ocean acidification along the West Coast, see Major Findings products from the West Coast Ocean Acidification and Hypoxia Panel<sup>8</sup>. The West Coast Ocean Acidification and Hypoxia Panel was convened from 2013 to 2016 by the Ocean Science Trust. The Panel developed a body of products, including a synthesis on the state of knowledge related to ocean acidification. View the Panel's final products at: www.westcoastoah.org/executivesummary

Additionally, the Washington Ocean Acidification Center developed a useful fact sheet sharing six things we know about ocean acidification in the Pacific Northwest. The purpose of this short resource is to clearly and succinctly present the scientific understanding of ocean acidification in the Pacific Northwest (as of its publication in 2015) based on evidence from the peer-reviewed scientific literature. That resource is available at: environment.uw.edu/wp-content/uploads/2015/05/OA-in-the-Pacific-Northwest-v1.pdf

NOAA's Ocean Acidification Program hosts a wealth of information about ocean acidification nationally, as well as information about research the program funds in Washington state and across both east and west coasts of the U.S. View NOAA's ocean acidification program website at: OceanAcidification.NOAA.gov



Four Marine Resource Committees are working to restore native Olympia oysters, which are more resilient to ocean acidification. Photo credit: Northwest Straits Commission

# Partnership between shellfish growers and scientists

A partnership between shellfish growers and scientists has flourished in the Pacific Northwest. Initial support was provided via emergency federal funding for monitoring, and now is maintained via state funding to support monitoring activities. The data collected have aided growers in making operational decisions, and helped scientists understand nearshore variation and drivers of ocean acidification. New NOAA funds are being invested to develop less expensive and more versatile sensors, and this work has expanded to California and Alaska, as well as British Columbia, Canada. Growers report that checking the realtime data has become standard practice. The new forecast model co-developed by the University of Washington and NOAA will serve as another tool for planning and assessing variation.

<sup>&</sup>lt;sup>7</sup> Feely et al., 2012.

<sup>&</sup>lt;sup>8</sup> Chan et al., 2016.