2017 Addendum to

Ocean Acidification: From Knowledge to Action

Washington State's Strategic Response

December 2017

Marine Resources Advisory Council

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**As of Fall 2017*

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Contents

This addendum expands upon the original 2012 report *Ocean Acidification: From Knowledge to Action* developed by the Washington State Blue Ribbon Panel on Ocean Acidification. The 2012 report established a comprehensive strategy for how to address ocean acidification in Washington. This addendum identifies updates to the comprehensive strategy based on emerging science and management practices and is intended to be a companion to the 2012 report. The Marine Resources Advisory Council led the review and update of this comprehensive strategy.

"Ocean acidification threatens Washington shellfish, fisheries industries, and the coastal communities that depend on them. Our state is on the front lines of responding to these threats through the leadership of the Blue Ribbon Panel on Ocean Acidification and the Marine Resource Advisory Council. We must keep up the momentum and leadership and continue to take bold action to protect these resources for future generations."

– Governor Jay Inslee

The First to Act – Washington is acting locally and exchanging knowledge globally to restore the health of our oceans

Our oceans are the cradle of life. They are the planet's workhorse. Their sheer size drives the planet's climate, produces more than half of the oxygen we breathe, and absorbs tens of millions of tons of CO_2 a day as it has since the advent of the Industrial Revolution, making the rest of the planet a more pleasant place to live. Our daily lives, no matter our proximity, are tied directly to oceans – the air we breathe, the food we eat, the rain that falls, the products we use, all come from or are transported by oceans. Here the Pacific Coast waters and Puget Sound are our economic engines, central to our cultural heritage and are places of beauty and respite for the millions who live here. Even at the farthest inland reaches of the watersheds, we are deeply connected with the vast salt water of the state.

But our marine waters are in trouble. The western coastal waters and the southern Salish Sea consistently experience low pH, making the nearshore environment, home to some of our most critical habitats, less hospitable to life. The latest research shows that acidification has gotten worse in our coastal waters over the last five years due to the combined effects of both the global and the local sources of the carbon dioxide that drive the acidification process. The sobering reality of being at the epicenter of one of the most highly affected regions in the world means that marine organisms in Washington state experience some of the highest stress from increasing ocean acidification. Upsetting but true. This imposes on us the responsibility—and the opportunity—to take action.

From small pteropods to shellfish, we see already the foundational threats ocean acidification poses. Alarmingly, these are only a precursor of what lies ahead if we do not change course. No species, not even our iconic salmon or whales, is beyond the reach of ocean acidification. We can no longer underestimate how this, a fundamental change in ocean conditions, ocean acidification, is changing our way of life. At risk are the very livelihoods of people in our rural, coastal communities, and the iconic natural system which defines so much of who we are as a state, a region, and as Washingtonians.

Plainly put, our way of life in the Pacific Northwest is at risk from ocean acidification. Too many indigenous people, families, businesses and communities, our seafood heritage and culture for so long reliant on the rich diversity of resources found in our marine waters are existentially threatened by this shift in the condition of the marine waters of our state.

In 2017, there is no question about what drives this change. Global and local carbon dioxide (CO_2) emissions, as well as local nutrient sources beyond natural levels, are significantly altering seawater chemistry. We are the cause for the rapid accumulation of 30 to 50 percent of the enriched CO_2 in surface waters in Puget Sound and 20 percent of enriched CO_2 in deep waters off our shores. The world's leading experts – at NOAA, our universities, our tribal agencies, and in our state resource agencies – live and work in our waters. These authorities shoulder to shoulder with the affected industries have made us understand that this is our new reality. We are facing this immediate threat together by taking measures to rein in local land- and air-based nutrient sources and better predicting low pH events in the shorter term. But we also understand fundamentally that decarbonizing our economy, locally, regionally, nationally and globally, is the key to restoring resilience and a recognizable future into the system.

What we've learned underlies a single call – we need to use the progress we've made, take courageous steps forward, and take further action now.

Washington state didn't hesitate as we became the first to lead the world in looking at the threat of ocean acidification to our shellfish industry in 2008. In 2012, through the Blue Ribbon Panel, we created a science-based action plan to better understand the facts in the water and to aid an industry on the verge of collapse. Out of that work, we created the Marine Resources Advisory Council (MRAC) to be a local leader, with global consequences. Over the last five years, MRAC has supported various partners locally, regionally, nationally, and internationally to act.

As changing ocean conditions continue to be the new normal, this broad stakeholder group is focused on deploying science-based management actions to make more resilient the waters that marine life and businesses depend on. While we are focused locally, we're also networked globally to share knowledge and information, encouraging other regions to go from science to action, to follow our lead. With five years under our belts, we are now sharing with you the update to Washington's original ocean acidification action plan, grounded in the latest science and designed to leverage work across the multiple partners that have emerged since 2012.

Washingtonians understand what is so dramatically at stake. We are not standing by waiting for someone else to inform or rescue us. With this update of the Blue Ribbon Panel comprehensive strategy and the ongoing work of MRAC and its partners, we have taken the lead regionally and globally in finding a way forward with science, policy, and most importantly on the ground, in the water, with action. Join us, won't you?

Sincerely,

Martha Kongsgaard
Marine Resources Advisory Council Chair

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.

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[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.

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1 Leading the Fight Against Ocean Acidification

1 Leading the Fight Against Ocean Acidification

Ocean acidification poses a serious threat to Washington's marine economy, communities, and environment. The Pacific Northwest shellfish industry has been among the first to feel significant, recognizable effects of ocean acidification. Disastrous production failures between 2005 and 2009 at major commercial Pacific Northwest oyster hatcheries saw billions of oyster larvae mysteriously die. Similar concerns were raised when wild Pacific oyster reproduction diminished. Increasing evidence suggests ocean acidification also has the potential to impair marine ecosystems including species that are direct drivers of economic activity (such as salmon or rockfish) as well as those that support the food web (such as pteropods and algae).

The ocean acidification threat has real implications for our economy and livelihoods. Washington is the country's leading producer of farmed bivalves, with recent annual revenue of nearly $150 million[1]. In 2013, Pacific oysters alone contributed nearly $35 million to the state's farmed shellfish harvest production value, while geoduck and other clam sales contributed an additional $42 million[2]. In addition to farmed bivalves, the wild Dungeness crab fishery is also a significant economic driver, providing more than $82 million in annual revenue in 2016[3].

Workers at Herrold's Fish and Oyster Co. transplant oysters in Willapa Bay.
Photo credit: Benjamin Drummond / benjandsara.com

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[1] U.S. Department of Agriculture, 2013.

[2] Washington Sea Grant, 2015.

[3] Crab landing summary information from shellfish receiving tickets provided by Washington Department of Fish and Wildlife Information Services.

The shellfish and seafood industries are important employers in Washington state, especially in some rural, coastal communities. In recent years, the shellfish aquaculture industry alone employed nearly 3,000 Washingtonians in direct and indirect jobs[4]. Washington's total seafood industry generates even more impressive employment and revenue at neighborhood seafood restaurants, distributors, processors, importers, and retailers, contributing over 50,000 jobs in Washington and over $2.5 billion to the state's economic output[5].

Not included in these statistics are the economic and cultural value of marine resource to Washington's tribal communities. Some tribal people refer to native seafood as feeding their spirit as well as their physical needs. While we still need to learn more about how ocean acidification affects the full range of species driving our economic and cultural systems, it is clear that the effects of ocean acidification could significantly impact the state's economy and people.

1.1 The Strategy to Act on Ocean Acidification

In 2012, recognizing the threat to Washington's shellfish industry, its tribal communities, and its broader marine environment, Governor Christine Gregoire created the Washington State Blue Ribbon Panel on Ocean Acidification (referred to as "the Panel"). The Panel consisted of scientists; public opinion leaders; industry representatives; state, local, federal, and tribal policymakers; and conservation community representatives. The Panel:

- Reviewed and summarized the current state of scientific knowledge about ocean acidification
- Identified the research and monitoring needed to increase scientific understanding and improve resource management
- Developed recommendations to respond to ocean acidification and reduce its harmful causes and effects
- Identified opportunities to improve coordination and partnerships to enhance public awareness on how to address ocean acidification

[4] Northern Economics, 2013.

[5] National Marine Fisheries Service, 2017 (for calendar year 2015).

The Panel released their findings and recommendations in the 2012 *Ocean Acidification: From Knowledge to Action* report, available at: www.ecy.wa.gov/water/marine/oa/2012panel.html

The report established a comprehensive strategy of 42 actions to address ocean acidification in Washington, organized across six areas:

1. Reduce emissions of carbon dioxide
2. Reduce local land-based contributions to ocean acidification
3. Increase our ability to adapt to and remediate the impacts of ocean acidification
4. Invest in Washington's ability to monitor and investigate the causes and effects of ocean acidification
5. Inform, educate, and engage stakeholders, the public, and decision makers in responding to ocean acidification
6. Maintain a sustainable and coordinated focus on ocean acidification at all levels of government

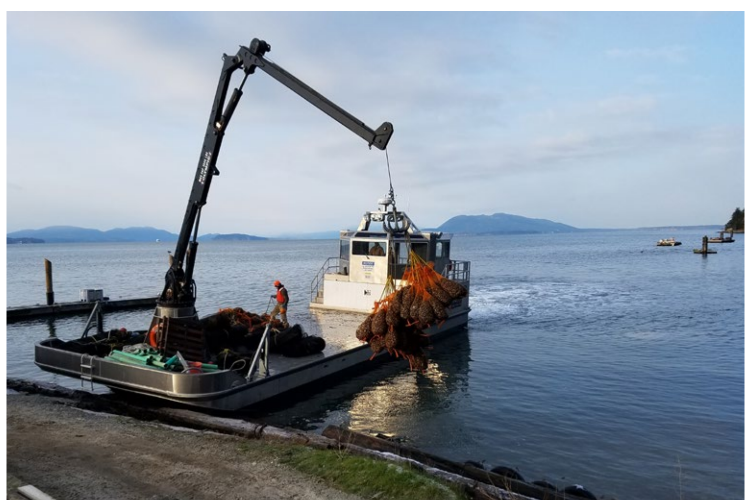
Deckhands sort through a Dungeness crab catch.
Photo credit: Benjamin Drummond / benjandsara.com

1.2 From Knowledge to Action

While the Panel outlined a comprehensive strategy to address ocean acidification, it purposefully did not specify how to implement the strategy. In 2013, the Washington State Legislature established the Marine Resources Advisory Council (MRAC) to act as a state body to maintain a sustainable and coordinated focus on ocean acidification by:

- Advising and working with the Washington Ocean Acidification Center (WOAC) on the effects and sources of ocean acidification
- Delivering recommendations to the governor and Legislature on ocean acidification
- Seeking public and private funding resources to support the MRAC's recommendations
- Assisting in conducting public education activities regarding ocean acidification

Since 2013, the MRAC has reviewed, evaluated, and prioritized the 42 actions from the Panel's recommendations. MRAC works across organizational boundaries to ensure ocean acidification work is efficient, leveraged, and focused so that it becomes integrated into key programs across the state. Learn more about the MRAC and its work: www.ecy.wa.gov/water/marine/oceanacidification.html



Washington's oyster aquaculture industry is vulnerable to the impacts of acidifying waters. Photo credit: Taylor Shellfish Farms

Setting an example, across the nation and across the globe

Following the 2012 Panel, Washington state emerged as a global leader in the fight against ocean acidification. The Panel's recommendations created a framework for transferring knowledge to action – a model that other states and entities across international borders have emulated. Examples of others following Washington's lead include the state of Maine's Ocean Acidification Commission, a task force to study the effects of ocean acidification and impacts on commercially valuable species. Additionally, following Washington's Panel, the California Ocean Science Trust convened the West Coast Ocean Acidification and Hypoxia Science Panel (OAH) from 2013 to 2016, which functioned as a catalyst for management actions in collaboration with California, Oregon, Washington, and British Columbia.

Taking this work internationally, the Pacific Coast Collaborative and leaders in Washington state launched the International Alliance to Combat Ocean Acidification (OA Alliance) in 2016. The OA Alliance is building an international network of governments, organizations, and other affiliates working with the common goal of addressing changing ocean conditions. Members of the OA Alliance commit to taking meaningful actions, as crafted in their own jurisdictional Ocean Alliance Action Plan.

1.3 Updating Our Strategy to Continue Moving Forward

In 2017, MRAC recognized the need to convene the state's leading ocean acidification thinkers to evaluate progress, next steps, and potential revisions to the recommended actions identified by the Panel. In the five years since the Panel released their strategy:

- **Significant progress has been made on the Panel's 2012 recommendations.** MRAC has prioritized the actions from the Panel's recommendations, tracked implementation, and secured funding for several partners.
- **Scientists have a better understanding of ocean acidification and how it affects the marine environment.** Scientific monitoring and investigation has advanced our understanding of ocean acidification conditions and impacts. To keep the linkage between science, policy, and management strong, new knowledge should be incorporated into strategic priority-setting for future actions.
- **The needs of managers have changed.** Marine resource managers continue to identify and implement on-the-ground strategies to address ocean acidification. These efforts lead to new and emerging management and policy questions, which should shape future research efforts to maximize feedback from scientists to managers.
- **The network of ocean acidification partners is now stronger than ever.** The landscape of ocean acidification partners at regional, national, and international scales has grown since 2012. These efforts should be strategically coordinated to leverage resources and avoid duplicative efforts in a constrained budget environment.

Photo credit: Washington State Department of Natural Resources

Gov. Jay Inslee, left, listens to Bill Dewey, right, of Taylor Shellfish Farms talk about the shellfish industry in Samish Bay. Photo credit: The Office of Gov. Jay Inslee

Martha Kongsgaard, MRAC Chair, presenting at the Blue Ribbon Panel "Refresh" Meeting on March 17, 2017. Photo credit: EnviroIssues

"It is impressive to see how Washington's leadership on ocean acidification continues to get national and international recognition. Implementation of the Blue Ribbon Panel's recommendations has enabled the shellfish industry to recover our oyster seed production as well as prepare for the more acidic ocean conditions that are predicted for our future."

– Bill Dewey, Taylor Shellfish Farms

The process for revising the 2012 recommended actions

Beginning in fall 2016, MRAC's ad hoc committees, organized around the Panel's six focus areas, documented progress to date based on the 2012 recommendations, evaluated the existing recommendations, and proposed revisions and new recommendations. These proposals were vetted with the broader ocean acidification community at the Blue Ribbon Panel "Refresh" meeting on March 17, 2017. In addition to discussing revisions and additions to the recommendations, participants discussed key efforts to focus on over the next five years.

The purpose of this addendum

This addendum details the results of discussions to update and revise the 2012 strategy, where needed. As an addendum, this document does not replace the work of the Panel in 2012, but instead highlights new or emerging developments that need to be added into the original strategy to address ocean acidification. As such, this document focuses on clarifying changes to the 42 actions in the 2012 report and any new actions deemed important to continue addressing the threat of ocean acidification.

As a companion piece to the 2012 *Ocean Acidification: From Knowledge to Action* report, this addendum follows the same chapter organization. Chapter 2 provides a synthesis of our advancements in scientific understanding over the last five years. Chapter 3 includes a complete list of strategies and actions Washington needs to pursue to address ocean acidification, and calls out updated and new actions. Chapters 4 through 9 each focus on the six focus areas identified by the Panel, and include highlights in ocean acidification accomplishments over the last five years, updated and new actions, and the rationale behind them. These chapters also highlight which efforts Washington's ocean acidification community recommends for focus in the next five years.

2 | Ocean Acidification in Washington State Marine Waters

2 Ocean Acidification in Washington State Marine Waters

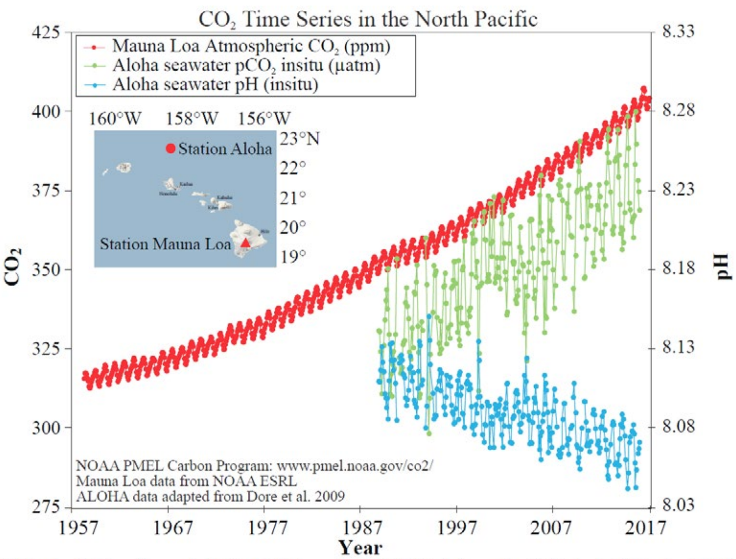
New research seeks to describe specific responses of a wider suite of local species to ocean acidification. Photo credit: Washington State Department of Natural Resources

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[1], by reading the *Scientific Summary of Ocean Acidification in Washington State Marine Waters*[2], or science documents developed by the West Coast Ocean Acidification and Hypoxia Panel[3]. 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[4]. 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[5]. In short, research shows that acidification has increased in Washington coastal waters over the last five years because of the combined 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.

Atmospheric CO_2 in the Puget Sound area is increasing faster than on Washington's coast and faster than the global average.[1]

[1] 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.[2] Such rapid change can outpace the ocean's natural ability to buffer ocean pH and carbonate chemistry.[3] The rapid pace of change gives marine organisms and humans less time to adapt, evolve, or otherwise adjust to changing circumstances.[4]

[2] Zachos et al., 2005.
[3] Orr et al., 2005.
[4] Turley et al., 2010.

Understanding these patterns over both space and time is essential to effective action, and thus it is critical that we sustain both physio-chemical 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 ($CaCO_3$) 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

[1] www.environment.uw.edu/research/major-initiatives/ocean-acidification/washington-ocean-acidification-center
[2] Feely et al., 2012.
[3] www.westcoastoah.org
[4] Reum et al., 2014. Reum et al., 2016. Alin et al., 2016. Fassbender et al., 2017.
[5] Alin et al., 2016.

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[6]. 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.

[6] 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 Ω (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*[7]. 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[8]. 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 real-time 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.

7 Feely et al., 2012.

8 Chan et al., 2016.

3 Recommended Strategies and Actions to Address Ocean Acidification

3 Recommended Strategies and Actions to Address Ocean Acidification

Oysters from Washington. Photo credit: Marc Dewey

The strategies and actions recommended by the Panel in 2012 reflected the need for action across a range of areas. In the 2017 review, no new focus areas were identified. Instead, recommendations were made to update actions and add new actions to address emerging questions, changes in knowledge, or clarify action intent. These changes are discussed in detail in the following chapters.

The table below includes a complete list of strategies and actions Washington needs to pursue to address ocean acidification. New and updated actions identified from the 2017 efforts are called out; for reference, the revisions to updated actions are underlined. Key Early Actions (KEAs) are actions designated as essential next steps for reducing the risks associated with ocean acidification as identified by the Panel. Progress toward all recommendations is strongly urged, however.

Reduce Emissions of Carbon Dioxide (Chapter 4)	
Take action to reduce global, national, and local emissions of carbon dioxide (Strategy 4.1)	Work with international, national, and regional partners to advocate for a comprehensive strategy to reduce carbon dioxide emissions (Action 4.1.1) [KEA]
	Updated Action: Implement additional actions to reduce carbon emissions where such actions would reduce acidification of Washington's marine waters (Action 4.1.2)
	Updated Action: Explore relationships between local air emissions and elevated regional atmospheric carbon dioxide through observations and modeling. Use numerical models to evaluate scenarios of elevated regional atmospheric carbon dioxide. Take actions to reduce local air emissions that are shown to contribute significantly to acidification. (Action 4.1.3)
	Enlist key leaders and policymakers to act as ambassadors advocating for carbon dioxide emissions reductions and protection of Washington's marine resources from acidification (Action 4.1.4)

Share significant findings and progress on reducing carbon emissions (Strategy 4.2)	**New Action:** Identify and share key findings from reducing emissions of carbon dioxide with ocean acidification communicators to support outreach and communication efforts designed to raise public awareness of ocean acidification. (Action 4.2.1) [Related to Action 8.1.6]
Reduce Local Land-Based Contributions to Ocean Acidification (Chapter 5)	
Strengthen and augment existing pollutant reduction actions to reduce nutrients and organic carbon (Strategy 5.1)	**Updated Action:** Implement, support, and enforce existing and effective nutrient, sediment, and organic carbon reduction programs in locations where these pollutants are causing or contributing to multiple water quality problems (Action 5.1.1) [KEA]
	Updated Action: Support and reinforce current planning efforts and programs that address the impacts of nutrients, sediment loading, and organic carbon (Action 5.1.2) [KEA]
	Updated Action: Support research efforts for developing water quality criteria relevant to ocean acidification in collaboration with new and existing monitoring efforts (Action 5.1.3)
	Adopt legislation that will allow sewer connections in rural areas to limit nutrients entering marine waters where it is determined to be necessary based on water quality impacts (Action 5.1.4)
Impose stringent controls to reduce and limit nutrients and organic carbon from sources that are contributing significantly to acidification of Washington's marine waters (Strategy 5.2)	**Updated Action:** If it is scientifically determined that nutrients from sewage systems are contributing to local acidification, identify opportunities to reduce stress on or improve treatment of sewage systems (Action 5.2.1)
	If determined necessary based on scientific data, reduce nutrient loading and organic carbon from point source discharges (5.2.2)
	New Action: If determined necessary based on scientific data, establish new programs to reduce nutrient, sediment, and organic carbon loading from nonpoint sources (Action 5.2.3)
New Strategy: Share significant findings and progress on local land-based contributions actions (Strategy 5.3)	**New Action:** Identify and share key findings from local land-based contributions actions with ocean acidification communicators to support outreach and communication efforts designed to raise public awareness of ocean acidification (Action 5.3.1) [Related to Action 8.1.6]
Increase Our Ability to Adapt and Remediate the Impacts of Ocean Acidification (Chapter 6)	
Remediate seawater chemistry (Strategy 6.1)	**Updated Action:** Develop land and aquatic vegetation-based systems of remediation for use in upland habitats and in shellfish areas (Action 6.1.1) [KEA]
	Maintain and expand shellfish production to support healthy marine waters (Action 6.1.2)
	Study the use of shells in targeted marine areas to remediate impacts of local acidification on shellfish (Action 6.1.3)
	New Action: Identify and support research and implementation of activities to increase the marine ecosystem's ability to preserve carbon stored in sediments and capture and store additional carbon from atmospheric sources (Action 6.1.4)

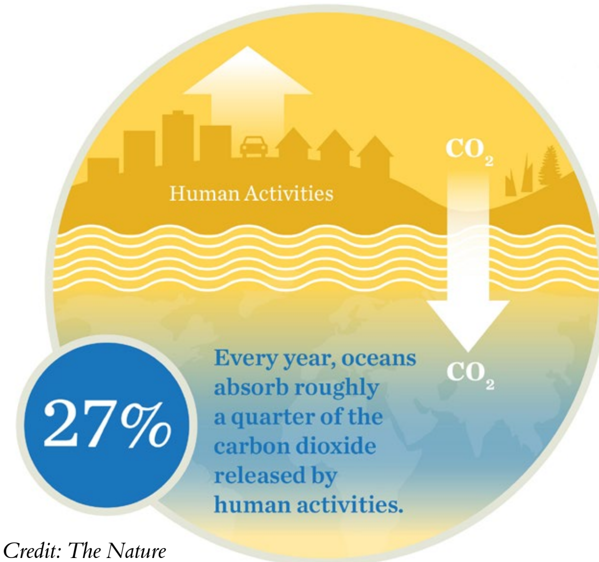
	New Action: In watersheds where models show land-based pollution contributes to local acidification, implement macroalgae recycling programs between local shellfish farms and terrestrial farms (Action 6.1.5)
Increase the capacity of resource managers and the shellfish industry to adapt to ocean acidification (Strategy 6.2)	Ensure continued water quality monitoring at the six existing shellfish hatcheries and rearing areas to enable real-time management of hatcheries under changing pH conditions (Action 6.2.1) [KEA]
	Expand the deployment of instruments and chemical monitoring to post-hatchery shellfish facilities and farms (Action 6.2.2)
	Investigate and develop commercial-scale water treatment methods or hatchery designs to protect larvae from corrosive seawater (Action 6.2.3) [KEA]
	Develop and incorporate acidification indicators and thresholds to guide adaptive action for species and places (Action 6.2.4)
	New Action: Investigate the relationship between ocean acidification resistance in shellfish and feed quantity and quality, to assess potential to strengthen shellfish through adjusted feeding regimes (Action 6.2.5)
Enhance resilience of native and cultivated shellfish populations and ecosystems on which they depend (Strategy 6.3)	Preserve Washington's existing native sea grass and kelp populations and, where possible, restore these populations (Action 6.3.1)
	Identify, protect, and manage refuges for organisms vulnerable to OA and other stressors (Action 6.3.2) [KEA]
	Support restoration and conservation of native oysters (Action 6.3.3)
	Use conservation hatchery techniques to maintain the genetic diversity of native shellfish species (Action 6.3.4)
	Investigate genetic mechanisms and selective breeding approaches for acidification tolerance in shellfish and other vulnerable marine species (Action 6.3.5)
	New Action: Identify and protect intertidal and nearshore habitats that currently support, or will support in the future due to sea level rise, organisms vulnerable to ocean acidification, and those that mitigate ocean acidification impacts (Action 6.3.6)
	New Action: Review and evaluate current regulations governing the culture and harvest of aquatic vegetation and develop recommendations for regulatory changes, if needed (Action 6.3.7)
New Strategy: Share significant findings and progress on adaptation and remediation actions (Strategy 6.4)	**New Action:** Identify and share a summary of key findings from adaptation and remediation actions with ocean acidification communicators to support outreach and communications efforts designed to raise public awareness of ocean acidification (Action 6.4.1) [Related to Action 8.1.6]

Invest in Washington's Ability to Monitor and Investigate the Effects of Ocean Acidification (Chapter 7)	
Understand the status and trends of ocean acidification in Washington's marine waters (Strategy 7.1)	Establish an expanded and sustained ocean acidification monitoring network to measure trends in local acidification conditions and related biological responses (Action 7.1.1) [KEA]
	Develop predictive relationships for indicators of ocean acidification (pH and aragonite saturation state) [Action 7.1.2]
	Support development of new technologies for monitoring ocean acidification (Action 7.1.3)
Identify factors that contribute to ocean acidification in Washington's marine waters and estimate the relative contribution of each (Strategy 7.2)	**Updated Action:** Quantify key natural and human-influenced processes that contribute to acidification based on estimates of sources, sinks, and transfer rates of carbon and nitrogen (Action 7.2.1) [KEA]
	Develop new models or refine existing models to include biogeochemical processes of importance to ocean acidification (Action 7.2.2)
Characterize biological responses of local species to ocean acidification and associated stressors (Strategy 7.3)	Determine the association between water and sediment chemistry and shellfish production in hatcheries and in the natural environment (Action 7.3.1) [KEA]
	Conduct laboratory studies to assess the direct effects of ocean acidification, alone and in combination with other stressors, on local species and ecosystems (Action 7.3.2) [KEA]
	Conduct field studies to characterize the effects of ocean acidification, alone and in combination with other stressors, on local species (Action 7.3.3)
Build capabilities for short-term forecasting and long-term prediction of ocean acidification (Strategy 7.4)	Establish the ability to make short-term forecasts of corrosive conditions for application to shellfish hatcheries, growing areas, and other areas of concern (Action 7.4.1) [KEA]
	Enhance the ability to predict the long-term future status of carbon chemistry and pH in Washington's waters and create models to project ecological response to predicted ocean acidification conditions (Action 7.4.2)
	Enhance the ability to model the response of organisms and populations to ocean acidification to improve our understanding of biological responses (Action 7.4.3)
New Strategy: Coordinate and leverage resources among monitoring and investigation efforts (Strategy 7.5)	**New Action:** Support coordination at the state level to capitalize on existing data and efforts for monitoring ocean acidification (Action 7.5.1)
	New Action: Support co-location of observational resources and coordinate lab and field efforts for mutual benefit (Action 7.5.2)
New Strategy: Share significant findings and progress on monitoring and investigations actions (Strategy 7.6)	**New Action:** Identify and share key findings from monitoring and investigations actions with ocean acidification communicators to support outreach and communications efforts designed to raise public awareness of ocean acidification (Action 7.5.1) *[Related to Action 8.1.6]*

Inform, Educate, and Engage Stakeholders, the Public, and Decision Makers in Addressing Ocean Acidification (Chapter 8)	
Share information showing that ocean acidification is a real and recognized problem in Washington state (Strategy 8.1)	Identify key findings for use by the governor, Panel members and others who will act as ambassadors on ocean acidification (Action 8.1.1) [KEA]
	Increase understanding of ocean acidification among key stakeholders, targeted audiences, and local communities to help implement the Panel's recommendations (Action 8.1.2) [KEA]
	Build a network of engaged shellfish growers, tribes, and fishermen to share information on ocean acidification with key groups (Action 8.1.3)
	Updated Action: Provide a forum for agricultural, forestry, business, and other stakeholders to engage with coastal resource users and managers in developing and implementing solutions (Action 8.1.4) [KEA]
	New Action: Raise awareness of available ocean acidification tools and resources (Action 8.1.5)
	New Action: Develop and periodically update an ocean acidification outreach and communications strategy and an annual list of key messages and key findings (Action 8.1.6)
Increase ocean acidification literacy (Strategy 8.2)	Develop, adapt, and use curricula on ocean acidification in K-12 schools and higher education (Action 8.2.1)
	Leverage existing education and outreach networks to disseminate key information and build support for priority actions (Action 8.2.2)
	Share knowledge on ocean acidification causes, consequences, and responses at state and regional symposiums, conferences, workshops, and other events (Action 8.2.3)
Maintain a Sustainable and Coordinated Focus on Ocean Acidification (Chapter 9)	
Ensure effective and efficient multi-agency coordination and collaboration (Strategy 9.1)	**Updated Action:** Continue to coordinate, through the Marine Resources Advisory Council, implementation of the Panel's recommendations with other ocean and coastal actions (Action 9.1.1) [KEA]
	Updated Action: Continue operation of the Washington Ocean Acidification Center as the state's ocean acidification science coordination team to promote scientific collaboration across agencies and organizations, and connect ocean acidification science to adaption and policy needs (Action 9.1.2) [KEA]
	New Action: Coordinate Washington's efforts to address ocean acidification with those of other regional, domestic, and international groups (Action 9.1.3)

4 Reduce Emissions of Carbon Dioxide

4 Reduce Emissions of Carbon Dioxide



Credit: The Nature Conservancy

In Chapter 4 of the original 2012 Blue Ribbon Panel report, the Panel noted emissions of carbon dioxide must be significantly reduced to mitigate harm to marine organisms and coastal ecosystems. It described the urgent global and local issue that carbon dioxide emissions present to our oceans. It also noted the leadership role that Washington state and its communities have assumed for the better part of a decade in enacting carbon reduction policies. Given that the absorption of atmospheric carbon dioxide into the oceans is the largest source of acidifying pollution, the Panel recommended Washington continue working to reduce emissions of carbon dioxide under Strategy 4.1.

This chapter describes accomplishments since 2012 in reducing carbon emissions, revised and new actions, and key next steps to continue progress in this area. Refer to Chapter 4 in the original 2012 Panel report for a full summary of why reducing carbon emissions is critical, and for descriptions of each original action.

4.1 Accomplishments since 2012

Carbon Emissions Reductions Taskforce: In 2014, Governor Jay Inslee established the Carbon Emissions Reductions Taskforce composed of 21 leaders from business, labor, health, and public interest organizations. The taskforce provided recommendations on design and implementation of a market-based carbon pollution prevention program. The work of this taskforce informed the proposed carbon emission limit legislation in 2014 and 2016, including the Governor's Carbon Pollution Accountability Act, which sought to set a cap on carbon emissions and have major emitters purchase pollution allowances. While it did not come to fruition, this proposed legislation sets the stage for ongoing efforts to implement innovative carbon policy.

Tax incentives for electric vehicles: A wide range of fully electric and hybrid cars now benefit from a sales tax break in Washington state.

Elimination of coal fired electricity: Washington's electric utilities have created a plan for reducing and ultimately eliminating the use of electrical power produced by coal.

Clean Energy Fund: Created by executive order in 2014, this fund provides $80 million to enable a mix of projects supporting development, demonstration, and deployment of clean energy technologies.

Clean Air Rule: After revising the state's greenhouse gas emission reduction limits to be more aggressive, Washington Department of Ecology's Clean Air Rule began requiring large in-state emitters to gradually reduce emissions over time, beginning in 2017. This rule is the first of its kind in the United States.

Reductions from local jurisdictions: Local jurisdictions across Washington state have also shown leadership in recent years by committing to reducing greenhouse gas emissions and sequestering carbon. As an example, King County's 2015 Strategic Climate Action Plan describes a variety of emission reduction and sequestration activities taken on by the county, including the purchase of clean electricity and the commitment to planting one million trees by 2020.

West Coast clean energy economy: Washington, Oregon, California, and British Columbia have worked together under the Pacific Coast Collaborative to promote clean energy along the West Coast. Their collective work has grown the West Coast's clean energy economy more than twice as fast as the rest of the United States.

4.2 Updated Actions

Specific revisions to the Panel's 2012 action language are underlined for easy reference.

Action	Original Language	Updated Language	Rationale
4.1.2	Implement additional actions recommended by the Climate Action Team where such actions would reduce acidification of Washington's marine waters	Implement additional actions to reduce carbon emissions where such actions would reduce acidification of Washington's marine waters	• Broadens actions beyond those recommended by the Climate Action Team (no longer in existence)
4.1.3	Review data model results to validate whether there is a causal relationship between local air emissions and local marine water acidity. If the data confirms such a relationship, take actions to reduce local air emissions that contribute to acidification	Explore relationships between local air emissions and elevated regional atmospheric carbon dioxide through observations and modeling. Use numerical models to evaluate scenarios of elevated regional atmospheric carbon dioxide. Take actions to reduce local air emissions that are shown to contribute significantly to acidification.	• Acknowledges the Washington Department of Ecology and the Pacific Northwest National Laboratory's model to characterize the relationship between regional atmospheric carbon dioxide and marine acidity • Use the model to explore various scenarios that are supported by additional data and/or atmospheric models of relationships between local air emissions and regional atmospheric carbon dioxide

4.3 New Actions

Action	Language	Rationale
4.2.1	Identify and share key findings from reducing emissions of carbon dioxide with ocean acidification communicators to support outreach and communication efforts designed to raise public awareness of ocean acidification *(Related to New Action 8.1.6)*	• As part of developing a strong ocean acidification outreach and communications strategy, each topic area is charged with sharing key findings, success stories, and relevant information to ensure communicators can successfully develop accurate key messages

Predicting the significance of carbon pollution from the top of the Space Needle

Data collected from the top of Seattle's most iconic landmark show elevated local atmospheric carbon dioxide. Washington State Department of Ecology and Pacific Northwest National Laboratory have developed a model that characterizes the effects of local atmospheric carbon dioxide on marine conditions across the Salish Sea. The model found that local sources of atmospheric carbon can be a significant driver of pH in certain areas of Puget Sound, though spatial variability exists. This means that actions to address local carbon emissions are likely to have a meaningful effect in addressing acidifying conditions at the local level. While additional research and model calibration is needed, this key finding can serve to inform state-based pollution control efforts in Washington state moving forward.

4.4 Continuing Progress

In reviewing accomplishments and updated and new actions, the following were identified as key steps to reducing carbon emissions over the next five years:

- In the near term, coordinate a meeting for modelers and other Washington-based researchers with observational data to discuss the current state of the science on the relationships between regional emissions and regional atmospheric CO_2, the marine effects of locally-elevated atmospheric CO_2, and to determine future priority research questions. Use this discussion to guide next steps for carbon-related efforts, policy design, and budget prioritization
- Consider and define MRAC's role in carbon emissions efforts and legislative advocacy
- Update and/or develop ocean acidification materials to highlight new research and current state of the science related to the effects of local emissions on marine acidifying conditions
- Continue enforcement and support for Washington Department of Ecology's Clean Air Rule
- Continue conversations among Washington Department of Ecology, Environmental Protection Agency, and Puget Sound Clean Air Agency to discuss an action plan for regulatory and legislative change related to Washington's carbon commitments
- Continue Washington's leadership in carbon reduction efforts, including but not limited to efforts relating to the state's participation in the Pacific Coast Collaborative

5 Reduce Local Land-Based Contributions to Ocean Acidification

5 Reduce Local Land-Based Contributions to Ocean Acidification

Jefferson Marine Resources Committee has installed several raingardens in Port Townsend to address pollution concerns in marine waters. Photo credit: Northwest Straits Commission

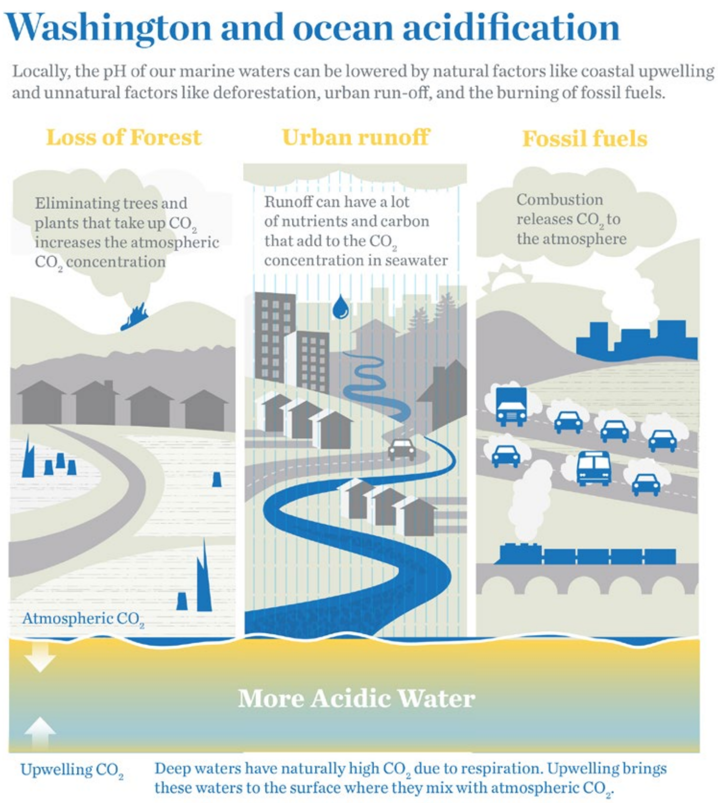
Chapter 5 of the original 2012 Blue Ribbon Panel report outlined the importance of reducing inputs of nutrients and organic carbon from local sources. Given the impacts of ocean acidification and the multiple benefits of nutrient and carbon source reduction, the Panel recommended enhanced actions to control and reduce local sources. To achieve this, the Panel set forth a two-tier approach for moving forward on nutrient and carbon reductions.

- The first tier (Strategy 5.1) constitutes a set of actions that build on existing programs to reduce nutrient and organic carbon inputs in ways that provide near-term economic and environmental benefits.
- The second tier (Strategy 5.2) recognizes that more stringent controls of nutrients and organic carbon pollutants will be required if additional data confirm that these inputs are contributing significantly to ocean acidification.

This chapter describes accomplishments related to reducing local-land based contributions since 2012, revised and new actions, and key next steps to continue progress in this area. Refer to Chapter 5 in the original 2012 Panel report for a full summary of why reducing local contributions is critical and for descriptions of each original action in this area.

Land use and changing local conditions

Locally, the pH of our marine waters can be lowered by natural factors like coastal upwelling, as well as human factors such as loss of forest cover, wastewater, and runoff from cities and farms.



Credit: The Nature Conservancy

5.1 Accomplishments since 2012

Nutrient and carbon reduction programs: Many nutrient and organic carbon reduction programs are being implemented across Washington state. These programs focus on multiple water quality concerns, and implementing these programs will reduce the severity of acidifying conditions. Examples include the Environmental Protection Agency's Best Management Practices (BMP) for stormwater and nutrient reduction strategies within the National Pollution Discharge Elimination System (NPDES).

Ocean acidification in planning: Ocean acidification is starting to be more broadly incorporated into various planning efforts focused on addressing impacts of nutrients and organic carbon, including: the Puget Sound Action Agenda, the Washington Department of Health's Marine Recovery Planning Areas, and Washington Department of Ecology's Nonpoint Source Control Plan and Voluntary Stewardship Program. This complements the work of several local jurisdictions working to protect and expand natural shorelines and fish habitat.

Ocean acidification indicators: Research is underway on the West Coast to develop better ocean acidification indicators to answer questions regarding natural versus anthropogenic sources of ocean acidification.

How are we reducing nutrient inputs in our waterways?

A central driver of nutrient reduction in our waterways is Washington state's Water Quality Program, in which the U.S. Environmental Protection Agency (EPA) delegates the Washington Department of Ecology to control point source pollution (from cities and industrial users, for example) through permitting. EPA and Ecology work together to encourage the use of best management practices (BMPs) for nonpoint pollution sources, offering guiding principles for individuals and businesses that engage in activities such as boating, yard care, human and animal waste disposal, and agricultural practices, among others.

In addition to the statewide efforts, King County and other jurisdictions are working locally to improve septic systems and stormwater infrastructure with the goal of reducing nutrient inputs.

Research now suggests that local land-based contributions are a likely significant driver of marine conditions in some locations of Puget Sound

The 2017 Salish Sea Model demostrates that while variability exists, overall, local nutrient sources significantly contribute to local ocean acidfication conditions in certain areas of Puget Sound. This is an advancement in our undestanding of what drives acidfying conditions at the local level. The 2012 Blue Ribbon Panel knew that the land-based nutrient and carbon reduction programs would be important in addressing ocean acidification, but it didn't know how significant local actions would be. The model provides new rationale for focusing on state and local nutrient and organic carbon control programs in the fight against ocean acidicification.

Ocean acidification and agriculture: The agricultural community now has access to funds from the Washington State Conservation Commission to incorporate ocean acidification actions and best management practices, and groups like the Northwest Straits Commission have been working to engage farmers on ocean acidification issues.

Local source attribution model: Where adjacent land cover is highly urbanized or agriculturally developed, ocean acidification is likely to be a result of combined effects of various processes: nutrient inputs, respiration, nitrogen oxide and sulfur oxide inputs, local atmospheric sources of carbon dioxide, and dissolved and particulate carbon loadings. The Panel called for the development of a quantitative estimate on how much local individual processes contribute to ocean acidification in Washington waters to help determine if more stringent programs to address local sources are needed. This was codified as Action 7.2.1.

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 (fortress.wa.gov/ecy/publications/SummaryPages/1703009.html). This 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.

5.2 Updated Actions

Specific revisions to the Panel's 2012 action language are underlined for easy reference.

Action	Original Language	Updated Language	Rationale
5.1.1	Implement effective nutrient and organic carbon reduction programs in locations where these pollutants are causing or contributing to multiple water quality problems	Implement, support, and enforce existing and effective nutrient, sediment, and organic carbon reduction programs in locations where these pollutants are causing or contributing to multiple water quality problems	• Includes sediment loading as a local contributor to ocean acidification • Highlights implementation alone is not enough; programs need support and enforcement to achieve results • Clarifies action focusing on existing programs
5.1.2	Support and reinforce current planning efforts and programs that address the impacts of nutrients and organic carbon	Support and reinforce current planning efforts and programs that address the impacts of nutrients, sediment loading, and organic carbon	• Includes sediment loading as a local contributor to ocean acidification
5.1.3	Assess the need for water quality criteria relevant to ocean acidification	Support research efforts for developing water quality criteria relevant to ocean acidification in collaboration with new and existing monitoring efforts	• It has been determined that state water quality criteria and standards should be developed for ocean acidification; new language focuses on next steps required to start developing criteria • The criteria should consider the biological responses of multiple species
5.2.1	If it is scientifically determined that nutrients from small and large on-site sewage systems are contributing to local acidification, require the installation of advanced treatment technologies	If it is scientifically determined that nutrients from sewage systems are contributing to local acidification, identify opportunities to reduce stress on or improve treatment of sewage systems	• Clarifies intent of action to minimize nutrient loading due to sewage systems and provide leeway to look at various methods to achieve effective results rather than prescribe a set solution

5.3 New Actions

Action	Language	Rationale
5.2.3	If determined necessary based on scientific data, establish new programs to reduce nutrient, sediment, and organic carbon loading from nonpoint sources	• Action 5.1.1 focuses on existing programs; new action focuses on new programs which could be implemented if determined necessary • Recognizes that local contributions to ocean acidification will likely differ by geography; certain areas may require more concentrated or targeted efforts to reduce pollutants
5.3.1	Identify and share key findings from local land-based contributions actions with ocean acidification communicators to support outreach and communication efforts designed to raise public awareness of ocean acidification *(Related to New Action 8.1.6)*	• As part of developing a strong ocean acidification outreach and communications strategy, each topic area is charged with sharing key findings, success stories, and relevant information to ensure communicators can successfully develop accurate key messages

5.4 Continuing Progress

In reviewing accomplishments and updated and new actions, the following were identified as key steps to reduce local land-based contributions over the next five years:

- Continue research efforts to better understand the natural versus anthropogenic biological impacts from ocean acidification, and use results to determine whether new programs or geographically targeting existing programs will achieve the greatest benefit
- Continue support for existing nutrient, sediment, and organic carbon reduction programs, including:
  - Working with the agricultural and forestry communities and others to respond to ocean acidification information needs
  - Implementing effectiveness monitoring to determine best management practices
  - Targeting projects together to maximize limited resources and enhance results in key locations where pollutants are causing or contributing to multiple water quality problems
  - Considering how to address seasonal variation of local-source contributions when implementing existing programs
  - Supporting nutrient reduction plans and strategies
- Continue to support current planning efforts and work to clarify how nutrient loading can contribute to ocean acidification. Specifically consider opportunities to better incorporate ocean acidification into planning efforts, such as:
  - The Puget Sound Action Agenda
  - Update to the Puget Sound Partnership's Vital Signs
  - Washington Department of Commerce's update on rules and guidance to local governance for critical areas ordinances
  - Puget Sound Nutrient Source Reduction Project
- Where appropriate, use Washington's existing water quality standards rule to reduce and control local-based nutrient sources
- Collaborate and build on California's efforts related to developing water quality criteria relevant to ocean acidification
- Consider the benefits and disadvantages of requiring sewer connections in rural areas and which locations in the state would be appropriate for such legislation
- Increase coordination with the Washington Department of Health on their efforts to address septic tanks in rural areas

6 Increase Our Ability to Adapt to and Remediate the Impacts of Ocean Acidification

6 Increase Our Ability to Adapt to and Remediate the Impacts of Ocean Acidification

Kelp demonstration site at Hood Head. Kelp may act as a buffer to acidifying conditions, and could be an important adaptation tool. Photo credit: John Mickett

Chapter 6 of the original 2012 Blue Ribbon Panel report outlined the importance of learning how to adapt and remediate the impacts of ocean acidification. Washington state needs to use a wide range of approaches to limit future losses of shellfish and other key marine resources. The Panel recommended preserving and enhancing the resilience of native shellfish and the ecosystems upon which they depend, and implementing a mix of innovative approaches and technologies to maintain and enhance cultivated shellfish production. These recommendations require collaboration across the private sector, nongovernmental organizations, academia, and federal, state and tribal governments.

This chapter describes accomplishments related to adaptation and remediation since 2012, revised and new actions, and key next steps to continue progress in this area. Refer to Chapter 6 in the original 2012 Panel report for a full summary of why adaptation and remediation measures are critical and for descriptions of each original action in this area.

A public-private partnership for shellfish conservation

The Kenneth K. Chew Center for Shellfish Research and Restoration was established through a cooperative agreement between NOAA and Puget Sound Restoration Fund to collaborate and conduct research and restoration activities. Using federal and state funds as well as a $1.5 million grant from the Paul G. Allen Family Foundation, this research facility is an example of successfully leveraging public and private partnerships to jointly work towards tackling ocean acidification.

6.1 Accomplishments since 2012

Ocean acidification conservation hatchery: The conservation hatchery at the Kenneth K. Chew Center for Shellfish Research and Restoration, located in Manchester, Washington on the Puget Sound, is a hub for native species propagation and restoration and ocean acidification research. Its size and location provide a unique opportunity for researchers and managers to learn more about ocean acidification and test strategies that local industry and managers could eventually use to mitigate impacts of ocean acidification on species of economic significance. No other facility in Washington exists that can serve researchers and managers in the manner necessary to make progress against increasingly acidifying conditions in Puget Sound and Washington's coast. Since it opened, the conservation hatchery has:

- Operated a kelp propagation lab to provide a steady and reliable source of native kelp to use in research and remediation efforts to determine if native kelp can improve pH conditions for calcifying species, which play important roles in food webs and healthy ecosystems
- Completed several adaptation and remediation actions recommended by the Panel that require hatchery propagation and research, including producing native kelp species (bull kelp and sugar kelp) and Olympia oysters suitable for different basins
- Produced Olympia oyster seed to help rebuild breeding populations in the state's 19 priority locations
- Cultured native species such as Olympia oysters, Pinto abalone, rock scallops, sea cucumbers, and geoducks to improve ecosystem resiliency and test resistance to ocean acidification
- Maintained the genetic diversity of native shellfish species
- Conducted research to identify and produce ocean acidification-resistant strains of several commercially-important shellfish species, such as Pacific oysters and Manila clams

Shellfish hatchery treatment methods: Water quality monitoring is ongoing at six existing shellfish hatcheries and rearing areas. Updated equipment and new pH sensors have been installed and funding received to expand to new sites. Managers have developed new hatchery methods to mitigate corrosive conditions and tests are ongoing for new monitoring and treatment methods.

Bioindicators: Researchers funded through WOAC developed oyster bioassays and are working to use pteropods as a biological indicator for ocean acidification. Additional research looks at developing a species sensitivity index to assess the impacts of ocean acidification across several local species.

Species restoration: Several Panel recommendations focus on supporting species restoration. Efforts to achieve this are underway, including:

- Updating the Puget Sound Action Agenda and Washington Shellfish Initiative, among other efforts, to include maintaining and expanding shellfish production
- Evaluating the feasibility of a local commercial shell recycling pilot program
- Developing a strategy to increase eelgrass by 20% in Puget Sound by 2020; work is underway on restoration practices, techniques, and necessary information to restore populations
- Developing a kelp recovery plan and investigation to optimize kelp restoration techniques
- Monitoring potential sites to act as oyster refuges and forming a workgroup to identify criteria and select locations to apply remediation strategies
- Restoring 60 acres of native oyster habitat in Puget Sound

Vegetation strategies: Multi-year experiments and modeling are being conducted to test use of vegetation-based systems for remediation.

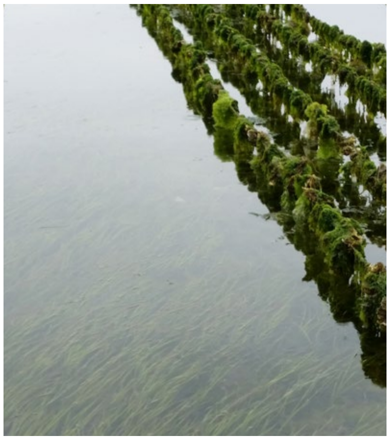


Photo credit: Bill Dewey

Researching how eelgrass could be used to combat ocean acidification

The Washington State Department of Natural Resources (WDNR) has developed a robust research program to test practical management options to combat ocean acidification. Eelgrass – a marine plant – covers 22,000 hectares in greater Puget Sound, and provides numerous ecosystem services. Following Key Early Action 6.1.1, WDNR set out to determine whether eelgrass can absorb enough CO_2 to mitigate ocean acidification and provide refuge to species sensitive to ocean acidification.

Can eelgrass photosynthesis counteract ocean acidification?

In 2014, WDNR partnered with the University of Washington to test whether eelgrass affects local pH. Through a field experiment spanning five sites, WDNR scientists showed that eelgrass can significantly increase pH in nearshore environments, where crucial natural resources are concentrated.

Are shellfish larvae more abundant in eelgrass?

In 2015, WDNR designed an experiment to test whether shellfish larvae move towards eelgrass to take advantage of improved pH. By measuring shellfish DNA, WDNR and University of Washington scientists found that shellfish larvae do not appear to congregate in eelgrass when it is photosynthesizing.

Can eelgrass enhance shellfish growth and reduce environmental stress?

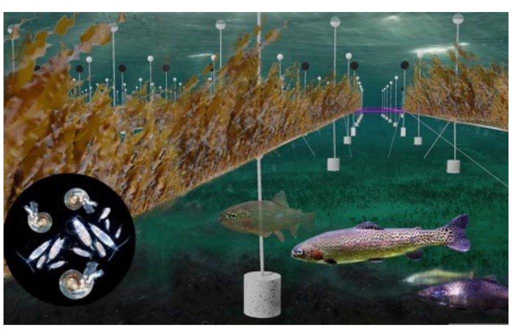
In 2016, WDNR worked with commercial shellfish growers and the University of Washington to test whether eelgrass can protect juvenile shellfish from ocean acidification. WDNR scientists transplanted juvenile Pacific oysters, Olympia oysters, and geoducks from a hatchery setting into the wild. At five sites, these juveniles were left for a one-month exposure period, inside and outside of eelgrass. Results show that eelgrass can enhance shellfish growth: Pacific and Olympia oysters grew 20 to 25% faster in eelgrass than outside of it.

Can eelgrass improve shellfish growth and pH in a halo around the meadow?

In 2017, WDNR led a field experiment to explore whether eelgrass can provide benefits to nearby juvenile shellfish. At five sites, WDNR scientists transplanted hatchery Pacific oysters and geoducks at set distances from eelgrass meadows. Pacific oysters once again grew most quickly in eelgrass, and oysters near the meadow grew faster than oysters farther away.

Benoit Eudeline of Taylor Shellfish Farms tests water quality. Photo credit: Taylor Shellfish Farms

Brian Allen with Puget Sound Restoration Fund pictured with sugar kelp on a grow-line at Hood Head, March 20, 2017. Photo credit: Stephen Schreck



A graphic showing how kelp lines provide underwater habitat during the growing period. Photo credit: Hannah Davis

Cultivating seaweeds to mitigate ocean acidification and generate habitat, fertilizer, food, and fuel

A collaborative team led by Puget Sound Restoration Fund is investigating the power of kelp to improve seawater conditions locally as a strategy for protecting species and resources amid increasingly corrosive conditions. The five year project, launched in 2015, implements one of the Key Early Actions recommended by the Panel with funding from The Paul G. Allen Family Foundation.

Sugar kelp is being cultivated at a 2.5-acre site north of the Hood Canal Bridge leased by Hood Canal Mariculture. During the growing season, kelp soaks up CO2 and nitrogen from the surrounding seawater, potentially creating a refuge for sensitive species. At harvest, carbon and nitrogen within the kelp are removed from the marine environment, improving conditions locally and providing an organic biomass that can be transformed into food, fertilizer, feed, and other products. Scientists at University of Washington (Applied Physics Laboratory), NOAA (Pacific Marine Environmental Laboratory, National Marine Fisheries Service, and Manchester Research Station), and Washington Department of Natural Resources are assessing the effects of kelp cultivation on pH, carbonate chemistry, biology, and fish utilization.

Modelers at System Science Applications are creating a computer model that analyzes carbon and nitrogen sequestration, kelp biomass, and net production in order to illustrate the potential for kelp cultivation to remediate ocean acidification conditions. Washington Sea Grant is conducting outreach and communication. An Advisory Team of kelp experts is providing guidance on propagation, phytoremediation strategies, and ocean acidification.

2017 is the first year of full-scale cultivation and assessment, with kelp harvested in July and transported to SkyRoot Farm on Whidbey Island for direct soil enrichment and compost trials. A second year of full-scale cultivation and assessment will occur in 2018.

6.2 Updated Actions

Specific revisions to the Panel's 2012 action language are underlined for easy reference.

Action	Original Language	Updated Language	Rationale
6.1.1	Develop vegetation-based systems of remediation for use in upland habitats and in shellfish areas	Develop land and aquatic vegetation-based systems of remediation for use in upland habitats and in shellfish areas	• Clarify language so action applies to both land and aquatic vegetation-based systems

6.3 New Actions

Action	Language	Rationale
6.1.4	Identify and support research and implementation of activities to increase the marine ecosystem's ability to preserve carbon stored in sediments and capture and store additional carbon from atmospheric sources	• Emerging opportunity to act on research and implementation related to capturing and storing atmospheric carbon in the marine ecosystem
6.1.5	In watersheds where models show land-based pollution contributes to local acidification, implement macroalgae recycling programs between local shellfish farms and terrestrial farms	• Local seaweed recycling could be used to buffer corrosive conditions in ocean acidification hotspots created by local land-based pollution sources • Developing a macroalgae recycling program could create financial incentives for local shellfish and terrestrial farms
6.2.5	Investigate the relationship between ocean acidification resistance in shellfish and feed quantity and quality to assess potential to strengthen shellfish through adjusted feeding regimes	• Research suggests feed quantity and quality may influence capacity of shellfish larvae and calcifying zooplankton to survive and grow under stress from ocean acidification and other adverse environmental conditions (e.g., at low or high temperatures and low oxygen levels) • Careful study of the effects of feed regimes on growth, survival, and physiological responses to these stresses may lead to adaptation strategies that are practical and useful in shellfish culture
6.3.6	Identify and protect intertidal and nearshore habitats that currently support, or will support in the future due to sea level rise, organisms vulnerable to ocean acidification and those that mitigate ocean acidification impacts	• As climate change impacts our region through sea-level rise, protecting key habitat through restoration and/or preservation of what could become key habitat is an important adaptation strategy • Initial focus should be on priority species, including kelp, eelgrass, and native oysters

6.3. New Actions, continued

Action	Language	Rationale
6.3.7	Review and evaluate current regulations governing the culture and harvest of aquatic vegetation and develop recommendations for regulatory changes, if needed	• Research has shown photosynthesizing marine vegetation may locally remediate acidified waters, potentially conferring some protection from ocean acidification to both wild and cultured shellfish and other calcifiers • Existing regulations governing harvest and interaction with aquatic vegetation may impede development of adaptation practices that take advantage of this function to reduce ocean acidification impacts • Conversely, existing regulations and enforcement practices allow recreational harvest that, in some instances, could impair efforts to conserve and restore eelgrass and kelp • A thorough, multi-agency, multi-disciplinary review could generate proposed regulatory changes that better serve conservation and restoration goals as well as ocean acidification remediation goals
6.4.1	Identify and share key findings from adaptation and remediation actions with ocean acidification communicators to support outreach and communication efforts designed to raise public awareness of ocean acidification *(Related to New Action 8.1.6)*	• As part of developing a strong ocean acidification outreach and communications strategy, each topic area is charged with sharing key findings, success stories, and relevant information to ensure communicators can successfully develop accurate key messages

Jefferson Marine Resource Committee's voluntary no anchor zones protect eelgrass that is a natural buffer to rising acidity. Photo credit: Northwest Straits Commission

6.4 Continuing Progress

In reviewing accomplishments and updated and new actions, the following were identified as key steps to continue adaptation and remediation efforts over the next five years:

- Continue to maintain and expand shellfish production
- Continue expanding deployment of instruments and operations of current instruments
- Continue developing new monitoring and treatment methods to increase implementation of effective methods for mitigating corrosive conditions at hatcheries
- Continue developing other ocean acidification indicators such as pteropods and working to incorporate thresholds (i.e., species tolerance limits) to guide action

- Continue improving and refining restoration practices and monitoring protocols for marine vegetation, and transplant eelgrass and kelp to meet stated restoration goals and improve monitoring protocols to better identify vulnerable populations of eelgrass and kelp
- Continue progress of selecting refuge sites and ensure their protection and management
- Continue restoration efforts to achieve the goal of restoring 100 acres of Olympia oyster habitat in Puget Sound, and pursue restoration on the Washington coast
- Continue operations of the Kenneth K. Chew conservation hatchery and its work to promote genetic diversity
- Use findings from research to develop implementable projects that use vegetation-based systems for remediation
- Assess benefits and risks of seaweed harvest at shellfish farms, quantify value of organic material to farmers in the watershed, and develop potential cost structure for marketing biomass to farmers
- Identify local opportunities to retain and use shell in key marine areas rather than relying on commercial sources
- Identify activities that could increase the ability to capture and store atmospheric carbon
- Research the effects of feed regimes on growth, survival, and physiological responses to ocean acidification stresses that may lead to practical and useful adaptation strategies for shellfish and other cultured species. Initially focus on larval effects with future work to study later life stages
- Conduct a thorough, multi-agency, multi-disciplinary review of current regulations on the culture and harvest of aquatic vegetation, and propose changes, as needed, that better protect native vegetation, serve conservation and restoration goals, and contribute to ocean acidification remediation goals

Cultchless oyster seed in hand. As a result of actions taken by the Panel, Washington's oyster seed crisis has been alleviated. Photo credit: Taylor Shellfish Farms

7

Invest in Washington's Ability to Monitor and Investigate the Causes and Effects of Ocean Acidification

7 Invest in Washington´s Ability to Monitor and Investigate the Causes and Effects of Ocean Acidification

The NOAA research ship Ronald H. Brown taking calibration samples at the NANOOS Cha'ba monitoring mooring. Photo credit: R. Feely, Pacific Marine Environmental Laboratory/NOAA.

Chapter 7 of the original 2012 Panel report outlined the importance of understanding the causes and effects of ocean acidification. Scientifically based actions are required to reduce the risk of ocean acidification to Washington's shellfish, other organisms, and marine ecosystems, and to sustain the ecological, economic, and cultural benefits they provide. Investing in the capacity to monitor and investigate the effects of ocean acidification is central to providing – and building on – that necessary scientific foundation.

Our knowledge about the causes and consequences of ocean acidification is rapidly advancing, but important gaps remain as we continue to move from knowledge to action. Critical information needs that are addressed by the Panel's research and monitoring recommendations include:

- Understanding the status of and trends in ocean acidification in Washington's marine waters
- Quantifying the relative contribution of different acidifying factors to ocean acidification in Washington's marine waters
- Understanding the biological responses of local species to ocean acidification and associated stressors
- Developing capabilities to identify real-time corrosive seawater conditions, as well as short-term forecasts and long-term projections of global and local acidification effects

This chapter describes accomplishments related to monitoring and investigations since 2012, revised and new actions, and key next steps to continue progress in this area. Refer to Chapter 7 in the original 2012 Panel report for a full summary of why monitoring and scientific investigations are critical and for descriptions of each original action in this area.

7.1. Accomplishments since 2012

A first step in revisiting the Panel's recommendations for monitoring and investigations was to review accomplishments and implementation of actions since 2012. Below is a list of high-level accomplishments.

Gained a better understanding of the status and trends of ocean acidification through a distributed monitoring network: Since its creation, the Washington Ocean Acidification Center (WOAC) has expanded an ocean acidification monitoring network for chemical and biological variables through various partnerships, including the National Oceanic and Atmospheric Administration (NOAA), King County, and state agencies, among others. This network established new monitoring of plankton species, including pteropods. WOAC funds seasonal cruises in the Salish Sea and offshore coastal waters, occupying stations, many of which were historical University of Washington stations since the 1930s. Ocean acidification variables were added in 2008 through other programs, and WOAC incorporated plankton monitoring in 2013. Several other advances include:

1. Research on existing mooring and cruise datasets yielded predictive relationships to estimate pH and aragonite saturation from pCO_2 and other hydrographic measurements[1].
2. New technologies are being developed and applied to chemical and biological monitoring, including new sensors and automation.
3. Data are being shared in near real-time through the Northwest Association of Networked Ocean Observing Systems (NANOOS) portal (www.nanoos.org).

Based on new monitoring data, we now know that ocean acidification in Washington's waters varies greatly depending on depth, season, and location[2]. At the same time, we also know that atmospheric CO_2 in the Puget Sound area is increasing faster than

Leveraging state resources to address ocean acidification

Over the past five years, state agencies have dedicated resources to help understand the threats that ocean acidification may pose to our shared natural resources and marine economies. To continue to advance our capacity to prepare for and understand the science of ocean acidification, three state agencies – the Washington State Department of Ecology, the Washington Department of Fish and Wildlife, and the Washington State Department of Natural Resources – are committed to establishing one to two monitoring locations within Washington. These locations, along with the WOAC monitoring effort, will help focus, align, and build on statewide monitoring and research efforts. By aligning and coordinating work, these agencies will be able to more completely assess and describe how ocean acidification is impacting the nearshore environment and important ecological and economic resources.

[1] Fassbender et al., 2016.

[2] Feely et al., 2012.

Collecting marine water quality data by plane

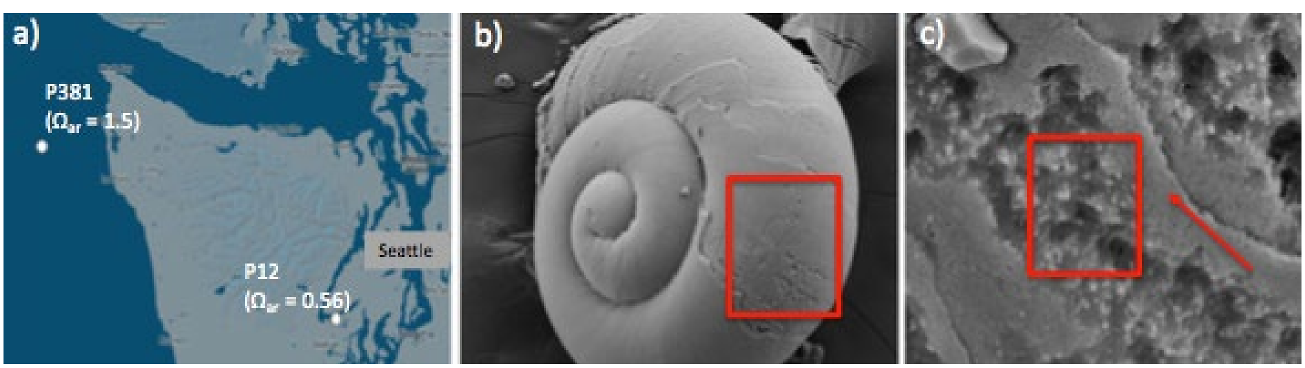
As part of state agency efforts, every month the Washington Department of Ecology collects marine water quality data from stations in Puget Sound, Grays Harbor, and Willapa Bay through their long-term marine water quality monitoring program. These monitoring activities are unique in that instead of collecting samples by boat, they are collected by floatplane, which allows a large geographic area to be sampled in a short amount of time. Water samples from approximately 40 stations are measured for many parameters, such as pH, temperature, salinity, dissolved oxygen, turbidity, and nitrates. Some of these stations have been surveyed by scientists since the 1950s, valuable for long-term trend analyses.

along the Washington coast and faster than the global average[3]. Additionally, Southern Hood Canal has the highest surface seawater values of pCO_2 in Washington coastal waters[4]. Direct, high-resolution observations of seawater pCO_2 and pH reveal that marine life is currently exposed to surface ocean pH and aragonite saturation values outside the envelope of preindustrial variability that they have evolved under, as measured at the La Push buoy, operated by University of Washington (UW), NOAA, and NANOOS[5].

While many advances have been made, sustained and enhanced monitoring is still necessary to identify patterns in time and space that can inform management actions and lead to effective adaptation.

Additionally, research has shown that human-generated atmospheric CO_2 is substantially increasing ocean acidification in surface waters[6]. This is also true even for subsurface waters off the Washington coast, which replace surface water pushed away during strong northwesterly winds, a process known as upwelling. Scientists have found that upwelled water now is more corrosive to calcifying (i.e., shell-making) organisms than it was in the past, with 30-50 percent of the enriched CO_2 concentration in surface waters attributable to human activities, and 20 percent at 100 meters depth[7]. Corrosive waters have been observed very close to the surface in many locations off the coast, and some organisms have already been impacted by acidified waters[8].

Research in Willapa Bay has shown how this unique embayment is being affected by ocean acidification. Due to input to Willapa



Dissolution of pteropods in Washington. Figure b is from station p381 and Figure c is from station P12. Image credit: Bednaršek et al., 2016

[3] Alin et al., 2016.

[4] Reum et al., 2015. Reum et al., 2016. Fassbender et al., 2016.

[5] Sutton et al., 2016.

[6] Feely et al., 2016.

[7] Feely et al., 2016.

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

Bay from both upwelled CO_2-rich ocean waters (primarily during summer) and the Columbia River's low alkalinity plume waters (primarily during winter), this bay receives corrosive waters from two different sources. Research on carbonate chemistry within the bay revealed that aragonite saturation state levels often fall below thresholds that in laboratory experiments are associated with poor oyster production[9]. Notably, temperature and carbonate conditions favorable for early oyster larval development co-occurred for only a few weeks to a month each year during 2012 through 2014 and not at all in 2011. In contrast, without the effect of ocean acidification, calculations reveal that in the pre-industrial period, aragonite saturation states would have been higher and the duration of periods favorable for larval development (when both temperature and carbonate conditions are conducive to survival and development) were significantly longer, lasting several months. Another study[10] conducted in Willapa Bay found temperature to have a dominant influence on oyster larval settlement patterns. However, larval survival was found to be equal on both sides of the bay despite differences in water chemistry.

Determined that local anthropogenic nutrient sources contribute to ocean acidification in the Puget Sound region, and that there is spatial variation in the degree to which these contributions influence local water bodies:

One key research question raised by the Panel was how much local land-based pollution contributes to ocean acidification. It is clear that local sources do affect local waters. Even more clear is that the degree to which these local sources contribute to ocean acidification shows quite a bit of spatial variation (see figure below). The complexity of processes and inputs driving local ocean acidification requires a robust understanding of various influencing factors, an understanding we now have that was not available in 2012. Based on the Salish Sea Model developed by the Washington Department of Ecology and the Pacific Northwest National Laboratory, we now know that local human-derived nutrient sources originating from within the state of Washington contribute to ocean acidification conditions in the Puget Sound region and that these effects vary by location[11].

The aragonite saturation state in certain regions appears to be very sensitive to anthropogenic nutrient loadings. Specifically, portions of the main basin, South Sound, Port Susan, Skagit Bay, and

[9] Hales et al., 2017.

[10] Miller et al., 2016.

[11] Pelletier et al., 2017.

Increasing acidification impacts on U.S. West Coast

A synthesis of data from four NOAA cruises between 2007 and 2013 along the west coast of North America provides new evidence for increasing acidification of coastal waters and corresponding impacts on calcium carbonate ($CaCO_3$) shell dissolution of planktonic pteropods[1]. This represents the first time that pteropod shell dissolution has been quantitatively related to anthropogenic carbon concentrations on the continental shelf. Findings suggest that ocean acidification may be seriously impacting marine life on our continental shelf right now. The cruise results show high anthropogenic carbon concentrations in surface waters along the coast, with the lowest anthropogenic carbon values in strong upwelling regions off southern Oregon and northern California, and higher anthropogenic carbon values to the north and south of this region. Data show that:

- The most severe biological impacts occur in the nearshore waters, where corrosive waters are closest to the surface[2].
- Pteropods were ~22 percent more likely to be affected by severe shell dissolution in nearshore waters compared with offshore waters.
- Since pre-industrial times, models estimate that pteropod shell dissolution has likely increased approximately 20-25 percent in both nearshore and offshore waters[3].

These results clearly indicate that humankind may already be having a significant impact on a species that may play a vital role in this important marine ecosystem. Since pteropods are an important prey species for salmon, cod and herring, there is a need to obtain a better understanding of pteropod interactions with their predators in coastal waters.

[1] Feely et al., 2016.

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

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

The combined impacts of acidification and hypoxia in Washington coastal waters

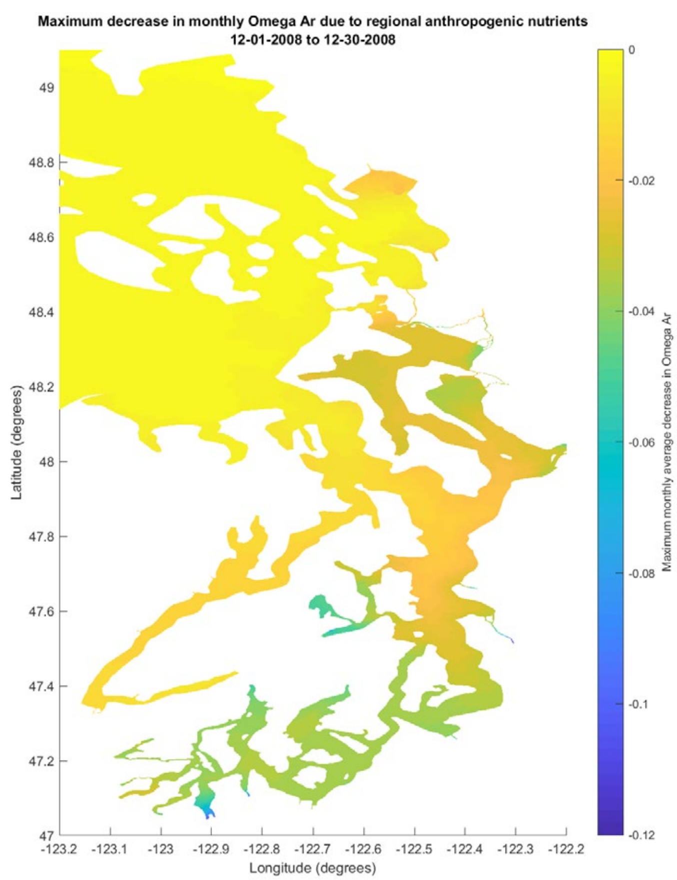
A newly published study by Feely et al. (2017) demonstrates that Washington coastal waters are particularly vulnerable to the synergistic effects of acidification and hypoxia.

The naturally high surface productivity in these waters results in high respiration at depth, which produces CO_2 and consumes oxygen, such that relatively low pH and aragonite saturation state and hypoxia are found at depth. These conditions are substantially enhanced by two other natural factors in our region: a lower buffering capacity of the seawater due to freshwater input from the Columbia, Fraser, Skagit, and other rivers, and the high amount of oxygen originally available for respiration because of relatively low surface water temperatures. A lower buffering capacity reduces the ability of the water to retain CO_2,

Whidbey Basin all show higher sensitivity of aragonite saturation levels in response to anthropogenic nutrient loadings. The impact of these sources is predicted to be greatest at the bottom of the water column, suggesting gradients in vertical habitats as well.

The changes in Ω_A due to regional anthropogenic nutrient sources in 2008 range from near zero in the Strait of Juan de Fuca, to around -0.01 in Hood Canal and the northern Main Basin, to about -0.02 to -0.05 in the Whidbey Basin, southern Main Basin, and most of South Puget Sound, and as much as -0.12 in inner Budd Inlet. For comparison, another study[12] reported basin-average changes in Ω_A in the bottom layer due to global anthropogenic sources of as much as -0.16. Consequently, the local nutrient-derived sources of acidification may be a significant fraction of the total in some locations.

Future model scenarios will examine local source attribution by location and perform more extensive analyses using this new tool to quantify the degree to which these nutrients impact ocean acidification over the recent past.



Predicted maximum monthly average decrease in Ω_A in the bottom layer in 2008 due to regional anthropogenic nutrient sources, originating within Washington. Credit: Pelletier et al., 2017.

[12] Feely et al, 2010.

Characterized biological responses of local species: Many life processes, including photosynthesis, growth, respiration, recruitment, reproduction, and behavior are sensitive to carbon dioxide and pH. The Panel recommended laboratory and field studies be implemented to understand the effects of ocean acidification, alone and in combination with other stressors, on local species.

New findings reveal responses of local species to ocean acidification:

- Early life stages of Dungeness crab show sensitivities to pH that could ultimately cause population declines[13].
- Krill larval development and survival are sensitive to low pH levels that are currently observed in Washington's marine waters[14].

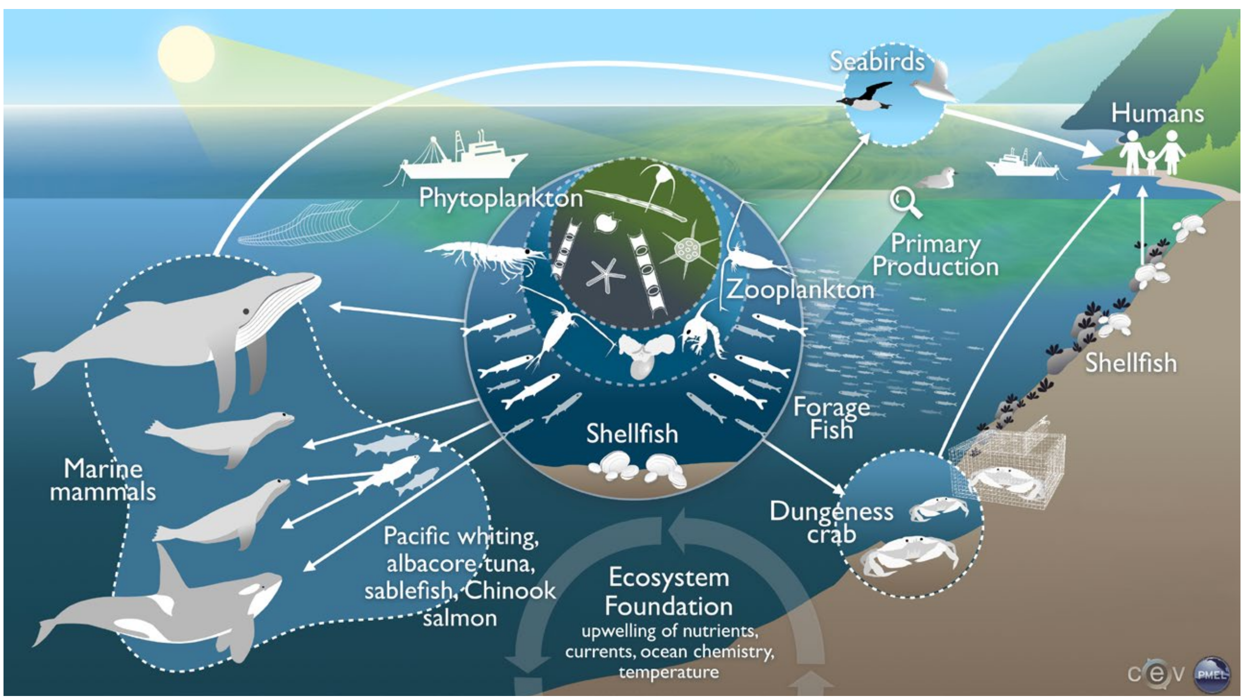
The food web and ocean acidification

The marine food web is highly interconnected. While some species, like shelled organisms, are directly affected by ocean acidification, other species are affected because they depend on those species for food or habitat. Thus, ocean acidification threatens the well-being of a variety of species, as affects can flow throughout the food web.

and cold water has the potential to hold more gas.

Additional inputs of CO_2 from human sources over time will further reduce the buffering capacity of seawater, leading to more rapid decreases in pH in the future and increases in hypercapnia (biological effects of high pCO_2) that can affect fish behavior. This means we should expect to see, and be able to measure, increases in the magnitude of the daily and seasonal variability of pH and pCO_2. This effect will be greater in Washington coastal waters compared to conditions that would be found in warmer coastal regions, such as the Gulf of Mexico, and will result in crossing key biological thresholds and tipping points more quickly in our region[1].

[1] Feely et al., 2017.



Credit: Simone Alin (NOAA) and Hunter Hadaway (Center for Environmental Visualization-UW)

[13] Miller et al., 2016.

[14] McLaskey et al., 2016.

[15] Martin & Nesbitt, 2015.

Informing tribal shellfish management decisions with stable isotopes

Examining stable isotope ratios in fish otoliths, a calcium carbonate structure in the inner ear used for hearing and directional orientation, can be used to track a fish's life history and environmental conditions. In an innovative twist on this method of biological monitoring, scientists with the Makah Tribe in Washington state are analyzing carbon isotope ratios in bivalve shells to detect the effects of ocean acidification. This research will help the tribe make informed decisions about shellfish resource protection and economic development. In addition to shellfish research, the tribe conducts regular water quality monitoring and obtains environmental parameters (e.g., temperature, salinity, pH, dissolved oxygen concentration and pressure), adding to regional data on ocean conditions.

Olympia oysters provide critical habitat for a variety of marine plants and invertebrates. Photo credit: Benjamin Drummond / benjandsara.com

- Species diversity among benthic foraminifera in Puget Sound appears to be declining and shell dissolution appears to be increasing[15]. Moreover, non-calcified species of foraminfera appear to be replacing calcified species. Forams are prey for many small marine invertebrates and fish; changes in their abundance and distribution could affect marine food webs.

- Shell dissolution in pteropods is evident off Washington's coast and is severe in the Salish Sea[16]. Their ability to build and repair their shells is greatly reduced in corrosive waters, consequently they may be useful indicators of ocean acidification conditions[17].

- Native and non-native seagrass species (*Zostera marina* and *Z. japonica,* respectively) both appear to have the capacity to effect short-term changes to seawater carbonate chemistry via photosynthesis. Notably, elevated total CO_2 appears to enhance photosynthesis in *Z. japonica* but not *Z. marina*[18].

- Numerical models suggest that bottom-dwelling invertebrates (crabs, shrimps, benthic grazers, benthic detritivores, bivalves) in Washington waters will show strong negative responses to ocean acidification. Some bottom-dwelling fish species, sharks, and invertebrates such as Dungeness crab could be subject to strong indirect effects of ocean acidification because they consume species known to be sensitive to changing pH[19].

- Modeling studies indicate that the indirect effects of ocean acidification, as mediated by trophic interactions, are likely to vary by taxon and functional group. Copepods may play a key role in affecting trophic interactions under ocean acidification conditions[20].

Studies are underway to examine:

- The sensitivity of Coho salmon to elevated CO_2. Early findings suggest that juvenile Coho salmon exhibit behavioral sensitivity to CO_2 that may impair their ability to detect predators.

- The sensitivity of adult Olympia oysters to low pH, particularly with respect to reductions in reproductive potential.

[16] Bednaršek et al., 2016. Busch et al., 2014.
[17] Bednaršek et al., 2017b.
[18] Miller et al., 2017.
[19] Marshall et al., 2017.
[20] Busch et al., 2013.

Built capabilities for short-term forecasting and long-term prediction of ocean acidification: Operational models are required to understand hourly, weekly, and seasonal changes in seawater carbon chemistry. Additionally, long-term projections give the "long view" of what conditions may be like decades from now. Researchers are working on forecast models for daily, seasonal, and decadal timescales. On the daily scale, a LiveOcean model was developed by UW modelers showing pH and aragonite saturation state, as well as oxygen, nutrients, phytoplankton, salinity and temperature for today, tomorrow, and the next day. The output is live on the NANOOS data portal (nvs.nanoos.org) and can be compared to real-time data to assess model performance. On the seasonal scale, the J-SCOPE project (www.nanoos.org/products/j-scope) produces forecasts three to six months in the future for variables including pH and aragonite saturation state[21]. This product is being used by state and tribal fisheries managers as one tool to inform their management decisions. On the decadal scale, UW scientists are working to project environmental variables (temperature, pH, oxygen) 50 years into the future and to evaluate the sensitivities of local species under different climate scenarios to understand longer-term regional ecological responses to ocean acidification in Washington.

Established partnerships to advance monitoring and investigation efforts: Since its creation in 2013, WOAC has served to enhance and coordinate efforts across several partners working within the ocean acidification landscape, including government agencies and research programs, tribal groups, shellfish industry representatives and universities. WOAC's coordination has included:

- Bringing a regional focus to research priorities and serving as a regional hub for research endeavors
- Hosting a biennial science symposium to foster sharing of emerging ocean acidification research and hosting an ocean acidification session at the Salish Sea Ecosystem in alternate years
- Training the next generation of scientists, managers, and decision-makers to face the challenges posed by ocean acidification
- Using a distributed network model of organization to join the expertise of UW scientists with that of other regional academic institutions, agencies and organizations
- Engaging with industry representatives, state, local, federal and tribal policy makers, and public opinion makers through specific activities

Seattle Aquarium partnering for ocean acidification innovation

In 2015, the Seattle Aquarium hosted coastal environment pilot testing for the Wendy Schmidt Ocean XPrize competition, where 15 teams from across the globe tested their pH sensors designed to affordably and accurately measure ocean acidification. The aquarium continues to work with scientists at the National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratory (NOAA PMEL) to measure ocean acidification in Puget Sound.

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[21] Siedlecki et al., 2016.

7.2 Updated Actions

Specific revisions to the Panel's 2012 action language are underlined for easy reference.

Action	Original Language	Updated Language	Rationale
7.2.1	Quantify key natural and human-influenced processes that contribute to acidification based on estimates of emission sources, sinks, and transfer rates of carbon and nitrogen	Quantify key natural and human-influenced processes that contribute to acidification based on estimates of [removed emission] sources, sinks, and transfer rates of carbon and nitrogen	• Removed "emission" to broaden the types of sources considered

7.3 New Actions

Action	Language	Rationale
7.5.1	Support coordination at the state level to capitalize on existing data and efforts for monitoring ocean acidification	• Recognizes the importance for continued coordination and collaboration on research efforts • Working together has led to leveraging resources to accomplish more than a single entity would have been able to accomplish alone
7.5.2	Support co-location of observational resources and coordinate lab and field efforts for mutual benefit	• Recognizes the diverse capacity and expertise of various partners, and supports efforts to leverage these resources during research
7.6.1	Identify and share a summary of key findings from monitoring and investigations actions with ocean acidification communicators to support outreach and communications efforts designed to raise public awareness of ocean acidification *(Related to New Action 8.1.6)*	• As part of developing a strong ocean acidification outreach and communications strategy, each topic area is charged with sharing key findings, success stories, and relevant information to ensure communicators can successfully develop accurate key messages

7.4 Continuing Progress

The following have been identified as key steps to continue progress related to monitoring, modeling, and biological response efforts over the next five years:

- Continue support for and expand the Washington state ocean acidification monitoring network to address monitoring gaps
- Continue to test and use predictive relationships and models to assess ocean acidification conditions over space and time; release results to end users and expand user base to other affected and interested parties
- Continue development of new chemical and biological monitoring equipment and methods
- Continue development of mathematical models to be applied to ocean acidification assessment, including testing and results verification, and refine source emission estimates
- Continue development of biological indicators for the extent of acidification in Washington coastal waters and the Salish Sea
- Complete studies now underway, initiate biological studies on additional local species of commercial and ecological importance, and investigate the relationship between ocean acidification and harmful algal blooms
- Identify existing data sets and efforts to monitor ocean acidification to leverage research efforts across Washington
- Coordinate development of more research efforts specific to the Washington coast

8 Inform, Educate, and Engage Stakeholders, the Public, and Decision Makers in Addressing Ocean Acidification

8 Inform, Educate, and Engage Stakeholders, the Public, and Decision Makers in Addressing Ocean Acidification

Students learning about ocean acidification. Photo credit: Washington Sea Grant

Chapter 8 of the original 2012 Panel report outlined the importance of connecting Washingtonians to the problem and impacts of ocean acidification and empowering citizens and businesses to help develop and implement solutions. Increasing understanding of ocean acidification and its consequences among policy leaders, marine industries, interested organizations, and the public is essential to implementing appropriate response measures. The Panel recognized that educating these groups is a prerequisite to action.

To improve understanding of ocean acidification and engage stakeholders in solutions, information needs to:

- Communicate that ocean acidification is already affecting jobs and resources here in Washington state
- Emphasize the importance of the ocean to our health, coastal economies, and well-being
- Explain the rapid change in ocean chemistry, the consequences of this change for marine life in Washington, and what it means for individuals and Washingtonians collectively
- Target key audiences (e.g., policy makers, urban residents, rural communities, etc.) to show the value of early action and highlight the role that Washingtonians can play in developing and implementing solutions

Northwest School earth science students witnessed the effects of ocean acidification during a presentation by Washington Sea Grant ocean acidification specialist Meg Chadsey. Photo credit: Washington Sea Grant

This chapter describes accomplishments related to education and outreach since 2012, revised and new actions, and key next steps to continue progress in this area. Refer to Chapter 8 in the original 2012 Panel report for a full summary of why education and outreach measures are critical and for descriptions of each original action in this area.

8.1 Accomplishments since 2012

Since 2012, sustained focus by state and tribal leaders, the scientific and conservation communities, federal and state resource agencies, and shellfish growers has propelled Washington into becoming an incubator for progressive and creative ocean acidification outreach and education efforts. These efforts have brought acidification to the consciousness of the public. Compared to other areas of the country, Washingtonians have a relatively high level of ocean acidification literacy, and share a broad concern for the health of our state's marine resources. As a result, key audiences are building a strong base of ocean acidification knowledge, which provides critical support for engaging them further in innovative ways towards action.

Increased ocean acidification literacy:

- Developed ocean acidification-focused curricula adapted to meet science standards, which teachers are already beginning to use in the classroom
- Worked with existing institutions to offer trainings and information sharing opportunities
- Shared knowledge through multiple conferences, symposiums, workshops, and other events

Seattle Culinary Academy students offer tempting tastes of sugar kelp at an outreach event about the use of kelp to combat acidification. Photo credit: Washington Sea Grant

Outreach to Washington's communities, stakeholders, and legislators: Early in our education and outreach efforts, the focus was primarily on raising awareness of the threat and impacts of ocean acidification. As awareness has grown, communities and stakeholders are pushing to learn

Positive messaging: Engaging the public through food

Chefs have a unique opportunity to educate people through food. In Washington, outreach specialists are partnering with the culinary world to get the word out about ocean acidification.

- On a quarterly basis, Washington Sea Grant teaches Seattle Culinary Academy students about ocean acidification and how it may change what kinds of seafood they are able to serve.
- In April 2017, Washington Sea Grant worked with Puget Sound Restoration Fund and Seattle Culinary Academy to showcase a kelp investigation funded by the Paul G. Allen Family Foundation. Held at the Seattle-based Museum of History and Industry (MOHAI)'s Edible City Science Fair, over 200 people learned about ocean acidification, phytoremediation, the experimental kelp farm on Hood Canal, and the ways kelp cultivation could benefit the environment and shellfish growers in Washington state.
- In July 2017, Puget Sound Restoration Fund partnered with Seattle culinary icon Tom Douglas and his affiliated cooking school, Hot Stove Society, to host a class on edible kelp.
- In Spring 2018, Puget Sound Restoration Fund will partner with a community-based commercial kitchen on Bainbridge Island, Washington to experimentally prepare an array of kelp products using Washington's first licensed kelp crop.

Local collaboration for ocean acidification awareness and action

Since 2013, the Northwest Straits Initiative and affiliated Marine Resources Committees have organized over 20 forums and conference sessions in partnership with researchers, local leaders and shellfish growers. In accordance with the Blue Ribbon Panel recommendations, these events have communicated that ocean acidification is a real and recognized problem in Washington state (Strategy 8.1) and have resulted in increased ocean acidification literacy (Strategy 8.2) among those engaged in coastal issues. The message has reached more than a thousand local residents as well as target audiences, from elected officials and decision makers to chefs and restaurant owners. Volunteer-based Marine Resources Committees have also continued their on-the-ground work with projects such as eelgrass protection, rain garden installation, and Olympia oyster restoration. Projects such as these help buffer seawater, filter nutrients that exacerbate ocean acidification, and maintain native species resilient to ocean acidification.

more and understand what they can do to address the problem. Education and outreach efforts are now shifting in response to present audiences with more detailed information about actions that people can take in their own lives that seem feasible and match the scale of the problem. In these efforts, partners are engaging communities towards action at workshops, conferences, symposiums, and online information campaigns. Some examples include:

- The Northwest Straits Initiative's Ocean Acidification seminar series and volunteer restoration activities
- Public-friendly science forums (e.g., Salish Sea Ecosystem Conference, Seattle Aquarium Discover Science Weekend, NOAA Pacific Marine Environmental Lab Open House)
- Online information and action campaigns such as those put out by The Nature Conservancy and the Surfrider Foundation
- The 2016 NOAA West Coast Ocean Acidification research cruise blog

Additionally, the Marine Resources Advisory Council's efforts to educate and inform Washington legislators about the potential peril of ocean acidification and Washington's unique capacity to fight against it has allowed partners in-state to secure funding for ocean acidification projects and priorities. This has resulted in tangible action that would otherwise not have been possible without legislative outreach.

Outreach to national and international audiences: A significant contribution of Washington's outreach and education efforts around ocean acidification has been in carrying the message to decision makers outside our boundaries and serving as a template for success to other jurisdictions under threat. Maine, Maryland, Massachusetts, New York, and Oregon have looked to Washington for guidance as they take on similar approaches and pass ocean acidification legislation in their jurisdictions.

Over the last five years, members and affiliates from the Blue Ribbon Panel and MRAC have traveled across the globe to represent ocean acidification interests and educate others less informed about changing ocean chemistry within high-profile regional, national, and international forums (e.g., West Coast Ocean Acidification and Hypoxia Science Panel, Our Ocean Conference, and the United Nations Conference of Parties [COP] climate conferences). Their representation in these platforms has elevated the issue as a concern parallel with climate change.

Outreach among tribal communities: Washington Treaty Tribes are uniquely vulnerable to ocean acidification because of their cultural, economic, and spiritual connections to place-based marine resources. Several tribes are engaging with their communities and partnering with non-tribal entities to address ocean acidification impacts to human well-being. Examples of these efforts include:

- The Squaxin Island Tribe's work with Washington Sea Grant and NOAA Northwest Fisheries Science Center to identify ocean acidification impacts to their community
- A two-year Regional Vulnerability Assessment of four Washington coastal tribes funded through the NOAA Ocean Acidification Program

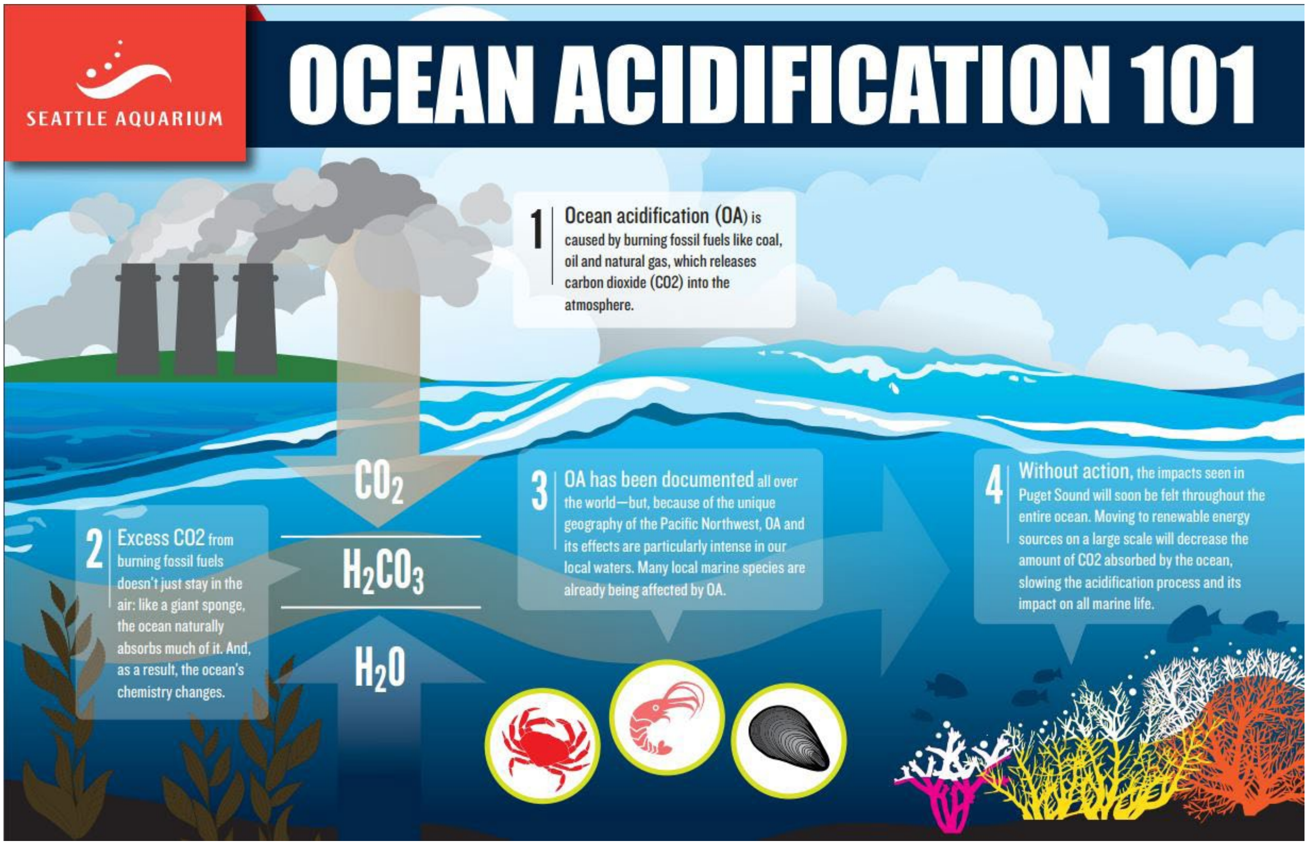
Education for students and teachers: The efforts of partners to integrate ocean acidification into formal and informal education has benefitted from Washington state's receptive audiences. Educators are hungry for curricula and other resources that help them teach fundamental science concepts in the context of a highly-relevant, real-world issue like ocean acidification. Tribes have led the charge in these efforts, and the statewide adoption of the Next Generation Science Standards has facilitated adoption of new ocean acidification materials. Specific examples of these education efforts include:

- The Suquamish Tribe maintains an online collection of ocean acidification-focused K-12 curricula materials (www.oacurriculumcollection.org). In addition, a partnership between Suquamish, the University of Washington's Oceanography Department, and Olympic Educational Services District educators provides workshops on ocean acidification and related topics to teachers from the Olympic Peninsula and surrounding areas.
- Offered teacher trainings and professional development opportunities around ocean acidification, such as the NOAA Sharing Ocean Acidifcation Resources for Communicators and Educators (SOARCE) webinar series, co-coordinated by Washington Sea Grant
- Advanced public education of ocean acidification through programs, exhibits, and online and print materials, such as those offered by the Seattle Aquarium, the Pacific Science Center, the Olympic Coast National Marine Sanctuary, and Washington Sea Grant

Tribal high school students learn about acidification's threats together

In 2016, students at Chief Kitsap Academy (operated by the Suquamish Tribe) participated in the Ecosystem Pen Pal program, a cultural and science exchange connecting high school students from Washington's tribal communities, Hawaii, and American Samoa. Through the program, students from the Makah, Quileute, Quinault, Muckleshoot, and Suquamish Tribes learned and shared with their Pacific pen pals how ocean acidification affects the local ecosystem and threatens their culture, economy, and traditional ways of life. The program was facilitated in partnership with the Olympic Coast National Marine Sanctuary, and was funded by the National Marine Sanctuary Foundation , Hollings Ocean Awareness Trust Fund, and NOAA's B-WET grant programs.

Michelle Marcoe (tribal educator with Puyallup School District) and Jefferson Emm (Western Washington University graduate student and Northwest Indian College graduate) at a tribal educator professional development workshop funded by a NOAA Environmental Literacy grant that has been awarded to Padilla Bay National Estuarine Research Reserve System. Photo credit: Jude Apple



In collaboration with five other aquariums, the Seattle Aquarium developed a strategic Ocean Acidification narrative as well as a comprehensive workshop and toolkit. These have been used both regionally, nationally and globally as an online webinar, reaching the "OA unaware." Photo credit: Seattle Aquarium

Empowering stories about youth taking action

Together with many partners, Philippe Cousteau and his EarthEcho Expeditions team produced Shell Shocked, an online ocean acidification module investigating the problem in the Pacific Northwest and featuring stories of high school students from Neah Bay, Suquamish, Seattle, and Bainbridge Island. Among the many efforts featured, some of these students are monitoring seawater chemistry while others have shared about the threat of ocean acidification to tribal fish resources. The module is available at earthecho.org/expeditions/shell-shocked.

Media coverage: Washington's proactive efforts to investigate potential strategies for mitigating corrosive seawater conditions also attract considerable and ongoing media attention. The state has served as a touchstone for journalists covering ocean acidification since the oyster production failures between 2005 and 2009. Shellfish farms around the Pacific Northwest and spotlights on proactive mitigation efforts continue to feature prominently in media pieces in local and national outlets alike – among them the Seattle Times, the New York Times, Huffington Post, and USA Today. This coverage provides an effective means for amplifying outreach on ocean acidification to the public at large, allowing information to reach much broader audiences.

8.2 Updated Actions

Specific revisions to the Panel's 2012 action language are <u>underlined</u> for easy reference.

Action	Original Language	Updated Language	Rationale
8.1.4	Provide a forum for agricultural, business, and other stakeholders to engage with coastal resource users and managers in developing and implementing solutions	Provide a forum for agricultural, <u>forestry</u>, business, and other stakeholders to engage with coastal resource users and managers in developing and implementing solutions	• Recognizes that forestry managers have an opportunity to support and act to address ocean acidification along with already identified key stakeholder groups • Private forestlands provide environmental services such as clean water and carbon sequestration. Engaging forest managers on how their lands might also provide services in the context of ocean acidification mitigation is a critical first step towards developing and implementing solutions with this landowner group.

8.3 New Actions

Action	Language	Rationale
8.1.5	Raise awareness of available ocean acidification tools and resources	• As new tools and resources become available, it is important for managers and users to learn of their release • Provides continued learning opportunities to improve developed tools and ensure users can act based on the information these tools and resources provide
8.1.6	Develop and periodically update an ocean acidification outreach and communications strategy and an annual list of key messages and key findings	• Recognizes that fact-based outreach and communications requires a broad outreach strategy and periodically updated key messaging • Nesting outreach and communications throughout the other action areas ensures key messages can be developed to target key stakeholders and ambassadors

The Northwest Straits Commission has hosted or presented at more than twenty events throughout the region to raise awareness about the issue among community members, local leaders and other key audiences. Pictured – speakers Simone Alin, Betsy Peabody, Cindy Jayne and Jean Walat at an event in Port Townsend. Photo credit: Northwest Straits Commission

University of Washington researcher Chase Williams explaining to Federal Way middle school students how ocean acidification makes it harder for juvenile coho salmon to avoid predators. Photo credit: Washington Sea Grant

8.4 Continuing Progress

In reviewing accomplishments and updated and new actions, the following were identified as key steps to continue progress related to education and outreach efforts over the next five years:

- In pursuit of new Action 8.1.6, use strategic key messages to tell the ocean acidification story clearly and effectively. Work with the MRAC's ad hoc committees to incorporate new findings from their work and update or develop new messaging as needed. Part of these efforts may include:
  - Hiring an outside entity with communications expertise to build an outreach strategy and craft key messages to enhance current communications efforts
  - Identifying a lead to support development and implementation of the outreach strategy
  - Determining methods to measure and quantify the impacts of these activities on behavior change
  - Emphasizing specific actions individuals and communities can take to address ocean acidification
  - Conducting a public opinion poll/survey to get a baseline of the public's ocean acidification awareness
- Connect industry, organizations, and local and regional governments with the International Alliance to Combat Ocean Acidification
- Strengthen partnerships with tribes leading education, outreach, and messaging efforts
- Increase engagement of vulnerable marine industries (e.g., fishing and crabbing) to identify new champions
- Increase engagement of other industries in the position to help address the challenge (e.g., forestry, business, and agriculture)
- Leverage existing networks to access influential local leaders. Some key groups to engage may include the Forest Resource Council, PCC Farmland Trust, American Farmland Trust, and the Farm, Fish, and Floods Initiative.
- Offer training on ocean acidification tools pertinent to user groups, per new Action 8.1.5. Allow users to provide feedback for continuous improvement of tools (e.g., NANOOS and Live Ocean).

9

Maintain a Sustainable & Coordinated Focus on Ocean Acidification

9 Maintain a Sustainable and Coordinated Focus on Ocean Acidification

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

Chapter 9 of the original 2012 Panel report outlined the importance of ongoing collaboration, well-coordinated strategies and actions, and efficient implementation of recommended actions. The state's effectiveness in addressing the impacts of changing ocean chemistry on Washington's marine ecosystems and coastal communities requires sustained leadership and support by the governor and other state officials and a coordinating mechanism to facilitate implementation of the Panel's recommendations. The problem should not be divorced from other ocean and coastal actions and priorities, however. The Panel's recommendations touched on a wide range of ocean and coastal activities involving multiple entities. Coordinating actions related to ocean health and coastal resources should reduce redundancies and inefficiencies. Additionally, coordination and collaboration among scientists, decision makers, and various interests should help the state address the problem.

This chapter describes accomplishments related to coordination since 2012, revised and new actions, and key next steps to continue progress in this area. Refer to Chapter 9 in the original 2012 Panel report for a full summary of why coordination measures are critical and for descriptions of each original action in this area.

9.1 Accomplishments since 2012

Creation and continued investment of the Marine Resources Advisory Council (MRAC):

The 2013 Legislature enacted Engrossed Senate Bill 5603 Section 4 creating MRAC within the Office of the Governor. MRAC's membership includes elected officials, representatives from state and federal agencies, nongovernmental organizations, academic institutions, and the private sector.

MRAC was established with the following powers and duties:

- To maintain a sustainable coordinated focus on ocean acidification
- To advise and work with the Washington Ocean Acidification Center on the effects and sources of ocean acidification
- To deliver recommendations to the governor and Legislature on ocean acidification
- To seek public and private funding resources to support the advisory council's recommendations
- To assist in conducting public education activities regarding ocean acidification

Since its inception, the council has worked to fulfill these duties, coordinating collaborative efforts across many partners, and broadly advancing ocean acidification activities across the state.

Establishment and continued investment in the Washington Ocean Acidification Center (WOAC): The 2013 Legislature also established and funded WOAC to connect researchers, policymakers, industry, and others across Washington. WOAC advances the science of ocean acidification and provides a foundation for proactive strategies and policies to protect marine ecosystems and the people connected to them. WOAC is charged to lead the state in five priority areas of ocean acidification research:

1. Establish an expanded and sustained ocean acidification monitoring network to measure trends in local acidification conditions and related biological responses. This monitoring will allow detection of local acidification conditions and increase our scientific understanding of local species responses.

2. As part of the monitoring network, ensure continued water quality monitoring at the six existing shellfish hatcheries and rearing areas to enable real-time management of hatcheries under changing pH conditions. The monitoring data have enabled hatchery operators to avoid drawing acidified water into the hatcheries and rearing areas.

3. Establish the ability to make short-term forecasts of corrosive conditions for application to shellfish hatcheries, growing areas and other areas of concern. A real-time online tool has been developed and is accessible to shellfish growers and managers to track acidification on a scale of days to weeks, giving them time to change or adjust their hatcheries' operation.

4. Conduct laboratory studies to assess the direct causes and effects of ocean acidification, alone and in combination with other stressors, on Washington's species and ecosystems. The studies focus on determining the biological responses of species of ecological, economic, and cultural significance to a full suite of stressors to which they are exposed, and will help estimate the genetic potential of these species to adapt to ocean acidification.

5. Investigate and develop commercial-scale water treatment methods or hatchery designs to protect larvae from corrosive seawater. Scientists from the University of Washington (UW) will help shellfish growers assess the effectiveness of the adaptation measures.

WOAC achieves these goals and others by:

- Bringing a regional focus to research priorities and serving as a regional hub for research endeavors

- Training the next generation of scientists, managers, and decision makers to face the challenges posed by ocean acidification

- Using a distributed network model of organization to join the expertise of UW scientists with that of other regional academic institutions, agencies, and organizations

- Engaging with industry representatives, state, local, federal, and tribal policy makers, and public opinion leaders through specific activities and through the formation of an advisory board and a science advisory team, both of which are being used to help guide the activities of WOAC

- Engaging the global research community and elevating ocean acidification science through its participation in international symposia

Representatives from the Washington Governor's Office joined other government and affiliate members of the OA Alliance at UN Headquarters June 5-9, 2017 in New York to attend The Oceans Conference. Photo credit: International Alliance to Combat Ocean Acidification

The World Ocean Summit has traditionally focused on financing and investing in our ocean resources. In 2017, the summit agenda featured an impressive suite of panels on climate impacts to the ocean, climate change risk and financing, and de-carbonization in shipping. Washington Governor Jay Inslee provided remote remarks and Washington's Chief Budget writer, David Schumacher, participated on a panel to discuss the economic risk of ocean acidification to Washington state. Photo credit: International Alliance to Combat Ocean Acidification

Participation in local, regional, and international efforts to address ocean acidification: While advancing important work at home and leading by example in taking action at the state and local levels, Washington state, through the Governor's Office, MRAC, WOAC, and state agencies, has also emerged as a leader in several regional and international efforts to address ocean acidification. These include:

- Washington Shellfish Initiative: The Washington Shellfish Initiative is a powerful partnership between state and federal government, tribes, the shellfish aquaculture industry, and non-government entities to promote critical clean-water commerce, elevate the role that shellfish play in keeping our marine waters healthy, and create family wage jobs. In 2011, following the launch of the National Shellfish Initiative under former Governor Gregoire's leadership, Washington was the first state in the nation to establish a shellfish initiative to advance the state's shellfish goals. Governor Jay Inslee reaffirmed the importance of the initiative when he launched Phase 2 of the Initiative in 2016.

- Pacific Coast Collaborative: The Pacific Coast Collaborative (PCC), representing California, Oregon, Washington, and the Canadian province of British Columbia, was formed in 2008 when the leaders of the participating states and province agreed to work together on energy, climate, ocean health, and other issues as a region. They have been addressing the causes and effects of ocean acidification since 2010. With large-scale oyster hatchery losses in 2007 and 2008, the West Coast has experienced some of the earliest and clearest impacts of acidification in West Coast marine waters. Early efforts by PCC jurisdictions brought together leading scientists, policy makers, tribes and First nations, other government agencies, and non-governmental organizations to address ocean acidification. PCC representatives have been the first to bring ocean acidification into the spotlight as an issue worthy of international dialogue at several United Nations, climate change conferences, including COP 21 in Paris, COP 22 in Marrakesh, and COP 23 in Bonn.

- West Coast Ocean Acidification and Hypoxia Science Panel: From 2013 to 2016, following on the success of the Panel, the California Ocean Science Trust convened the West Coast Ocean Acidification and Hypoxia Science Panel, comprised of 20 leading experts. The Panel developed a body of products that serve as a scientific call to action, synthesizing the state of knowledge and identifying science-based options to address ocean acidification and hypoxia at the regional and local levels.

- International Alliance to Combat Ocean Acidification: In 2016, to advance local and regional strategies to a global scale, the Pacific Coast Collaborative formed the International Alliance to Combat Ocean Acidification (or OA Alliance). Members of the OA Alliance are committed to working collaboratively to bring awareness to the issue of ocean acidification and to taking individual actions that address the environmental and economic threat posed by ocean acidification within their region by creating their own unique Ocean Acidification Action Plan. Alliance members span multiple levels of jurisdictions – from cities to nations – and include Chile, France, New York, Washington, Oregon, California, British Columbia, and several Washington-based tribes.
- Participation in other regional ocean planning partnerships: The West Coast Regional Planning Body, formed in 2015, is a partnership between 13 federally-recognized tribal governments, U.S. federal agencies, and the states of Washington, Oregon, and California. The planning body is focused on coordinating ocean planning efforts and facilitating data- and information-sharing across West Coast ocean managers and stakeholders, including efforts and information that relate to ocean acidification. The West Coast Ocean Partnership, also comprised of federal, state and tribal representatives, facilitates ocean planning dialogue and manages the West Coast Ocean Data Portal, which links together existing data systems to provide an easy-to-use gateway to discover ocean and coastal information.
- Supporting other jurisdictions in developing ways to address ocean acidification: Washington state is a leader in the county and around the world in working to address ocean acidification. Several other states have looked to Washington's efforts as a template for developing a strategy to address ocean acidification in their marine waters, including Maine. Washington's role has helped establish the Pacific Coast Collaborative and researchers, industry representatives, and managers from the state as leaders integrated into national and international research and planning efforts related to ocean acidification.

More on the International Alliance to Combat Ocean Acidification (OA Alliance)

Since 2016, the OA Alliance – created by leaders from Washington's ocean acidification community – has brought together jurisdictions across the globe to combat ocean acidification and changing ocean conditions as an immediate and critical threat to coastal economies and ocean ecosystems. It invites individual members, both governments and affiliates, at all stages of learning about and responding to ocean acidification.

At the United Nations Conference to Implement Sustainable Development Goal 14 (Oceans Conference) hosted in June 2017 in New York, the OA Alliance – joined by representatives from the Washington Governor's Office – registered a voluntary commitment to the implementation of UN Sustainable Development Goal 14.3, addressing ocean acidification and the threats it poses.

As it continues to build momentum, the OA Alliance will work to advance scientific understanding of ocean acidification, take meaningful actions to reduce causes of acidification, protect the environment and coastal communities from impacts of a changing ocean, expand public awareness and understanding of acidification, and build sustained support for addressing this global problem.

It will also work in support of inclusion of ocean health and ocean acidification mitigation, adaptation and resiliency strategies in international climate agreements.

- **Leveraging our resources and securing public and private funds to implement effective strategies:** MRAC is focused on how best to efficiently leverage resources, both money and people, to ensure action on ocean acidification moves forward. Collaboration through MRAC has allowed parties to identify opportunities to work together and leverage resources. This has led to increased monitoring trips, with multiple agencies and scientists coming together to conduct research and collect information. Beyond sharing of data, working groups have formed to focus on implementing key actions called out by the Panel. MRAC and its partners have also been effective at leveraging state funds to secure additional funding from the private sector. State funds have been the incentive to get projects off the ground, and after demonstrating success, leverage additional funding.

9.2 Updated Actions

Specific revisions to the Panel's 2012 action language are <u>underlined</u> for easy reference.

Action	Original Language	Updated Language	Rationale
9.1.1	Charge, by gubernatorial action, a person in the Governor's Office or an existing or new organization to coordinate implementation of the Panel's recommendations with other ocean and coastal actions	<u>Continue to</u> coordinate, <u>through the Marine Resources Advisory Council</u>, implementation of the Panel's recommendations with other ocean and coastal actions	• Clarifies language to note that MRAC leads the coordination around implementation of the Panel's recommendations
9.1.2	Create an ocean acidification science coordination team to promote scientific collaboration across agencies and organizations and connect ocean acidification science to adaptation and policy needs	<u>Continue operation of the Washington Ocean Acidification Center to act as the state's</u> ocean acidification science coordination team to promote scientific collaboration across agencies and organizations and connect ocean acidification science to adaption and policy needs	• Clarifies language to note WOAC is established as an ocean acidification science coordination team

9.3 New Actions

Action	Language	Rationale
9.1.3	Coordinate Washington's efforts to address ocean acidification with those of other regional, domestic, and international groups	• As Washington has solidified our role as leaders in the ocean acidification conversation, it has become increasingly apparent that we have much to offer at broader scales beyond just our state • The new action helps formalize our commitment to a continuing engagement in local, regional, and international efforts to address ocean acidification

9.4 Continuing Progress

In reviewing accomplishments and updated and new actions, the following were identified as key steps to continue progress related to sustaining a coordinated focus on ocean acidification over the next five years:

- Continue maintenance of MRAC and its efforts to identify and secure funds for ocean acidification-related priorities in Washington state
- Continue operations and research support through WOAC
- Continue coordination and collaboration with the PCC, the OA Alliance, and Maine Ocean Acidification Commission, among others

Making connections from local to global for ocean acidification data

Since 2013, WOAC has worked closely with the NOAA-funded Northwest Association of Networked Ocean Observing Systems (NANOOS), part of the U.S. Integrated Ocean Observing System, to expand and sustain the Pacific Northwest's own ocean acidification monitoring network to measure trends in local acidification conditions and related biological variables. This collaboration has enabled data access for PNW stakeholders and at the same time extended benefits beyond the region to a global network, the Global Ocean Acidification Observing Network (GOA-ON).

WOAC has coordinated and supported regional cruises, moorings, and nearshore monitoring throughout Washington's marine waters, including at shellfish sites, to measure physical, chemical, and biological variables relevant to OA. WOAC and its partners directly benefit from the federally-funded and user-friendly data portal "NVS" that NANOOS provides (www.nanoos.org) for visualizing and downloading data, some of which are transmitted in near real-time. The portal also delivers the WOAC-funded LiveOcean forecast model output, with the ability to compare model output to buoy data. Multiple regional entities provide data to this ocean data hub and collaborate with WOAC, including the Olympic Coast National Marine Sanctuary, the NOAA Pacific Marine Environmental Laboratory, Padilla Bay National Estuarine Research Reserve, Washington Departments of Ecology, Health, and Natural Resources, King County, Northwest Indian College, Seattle Aquarium, Taylor Shellfish, Penn Cove Shellfish, Oregon Health and Science University, and Western Washington University, among others. Because the NANOOS data portal is part of the U.S. Integrated Ocean Observing System (IOOS) it is interoperable with and discoverable from national IOOS data holdings, including a NOAA-funded west-coast wide collaboration among Alaska, Washington, Oregon, California, and British Columbia, Canada (www.ipacoa.org) focused on OA data that NANOOS leads. WOAC leadership coordinates these efforts with the West Coast Ocean Acidification and Hypoxia Task Force, sponsored by Pacific Coast Collaborative, and WOAC is a contributing partner.

WOAC serves as a liaison to GOA-ON, ensuring that the broader ocean dataset is available across the world. Via WOAC leadership, the NANOOS system has been adapted to provide GOA-ON with a global data portal (www.goa-on.org), enabling OA data availability on local through global scales. This is critical for understanding ocean acidification, a global issue with locally-diverse responses. WOAC and U.S. West Coast leadership on ocean acidification have been recognized world-wide and is a clear benefit of Washington's investment. Further, WOAC is a science support partner with the International Alliance to Combat Ocean Acidification, relating OA information from Washington and the West Coast, and provides coordination with GOA-ON. WOAC participates in global-scale events to relate the success and progress Washington has made within this context.

10 Conclusions

10 Conclusions

Facing the threat of ocean acidification is no easy feat. Yet Washington has risen to the occasion, setting the stage since the Panel's initial work to make significant strides to protect our economy, coastal communities, and quality of life. The work between 2012 and 2017 of State Legislators, agencies, tribes, local jurisdictions, industry, and nongovernmental organizations has demonstrated impressive collaboration and coordination to combat ocean acidification directly.

In 2012, we knew ocean acidification was occurring and posed a significant threat. However, we did not have the information necessary to take definitive, on-the-ground action. Now we can move forward with action. Our scientists and researchers have focused on tackling the important questions managers and decision makers needed to know the answers to in order to effectively act. We know ocean acidification is occurring at greater severity than anticipated in Washington, humans have contributed significantly to the problem through CO_2 emissions, and we've started to understand how local sources and pollutants exacerbate ocean acidification.

Managers and decision makers are using this new knowledge to great effect. Shellfish growers can use predictive and real-time models of ocean acidification variables to make operational decisions, which has improved cultivation. State agencies are coming together to share data and identify solutions and strategies to implement on state lands. We have never been better equipped to move forward with on-the-ground action. By combining continued research and new scientific findings in how managers and decision makers address the problem, Washington is poised to take significant strides towards addressing ocean acidification.

Washington has the expertise it needs to respond. We have world-class scientists and organizations that can develop and define new innovative solutions. Our shellfish industry is committed to protecting native ecosystems and the resources they depend on for their livelihood. Tribes are engaging the next generation of resource managers to be informed about ocean acidification and its impacts. Continued coordination and attention on ocean acidification is critical for maintaining Washington's ability to address the issue and show the country and the world what an effective response can look like.

MRAC is focused on how best to efficiently leverage resources, to ensure action on ocean acidification moves forward. Collaboration through MRAC has allowed partners to identify opportunities to work together, and to leverage state funds to secure additional funding from the private sector.

The Time to Act is Now

MRAC has shown that the more we work together, the more successful ocean acidification projects can be. We've proven that collaboration is key to getting the most out of research and on-the-ground programs. Work at shellfish hatcheries highlights this as scientists and industry leaders have come together to collect data, communicate it to managers, and identify new techniques and technologies to implement in order to ensure continued shellfish production and ongoing health of our marine economies.

Collaboration also reduces duplication as it cultivates awareness of each other's work. This allows entities to work together to enhance projects based on individual needs, while coordinating efforts, leading to better use of funding and resources.

It is time to harness these resources and continue to tackle the many challenges to come. It is time to continuing transforming our knowledge into action.

Oyster grounds on Willapa Bay. Photo credit: Benjamin Drummond / benjandsara.com

Appendix 1 | Blue Ribbon Panel "Refresh" Participants

The recommendations included in this report were developed through several working groups and broad meetings with the Marine Resources Advisory Council and others.

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Appendix 3 List of Acronyms

AnNeMoNe	Acidification Nearshore Monitoring Network
$CaCO_3$	Calcium carbonate
CO_2	Carbon dioxide
Ecology	Washington Department of Ecology
EPA	Environmental Protection Agency
KEA	Key Early Action
The Legislature	Washington State Legislature
MOHAI	Museum of History and Industry
MRAC	Marine Resources Advisory Council
NANOOS	Northwest Association of Networked Ocean Observing Systems
NOAA	National Oceanic and Atmospheric Association
OA Alliance	International Alliance to Combat Ocean Acidification
OAH	West Coast Ocean Acidification and Hypoxia Science Panel
PCC	Pacific Coast Collaborative
pCO_2	Partial pressure of carbon dioxide
The Panel	Washington State Blue Ribbon Panel
TMDL	Total Maximum Daily Load
UW	University of Washington
WOAC	Washington Ocean Acidification Center