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Ocean Acidification in the PACIFIC NORTHWEST

The evidence for ocean acidification in the Pacific Northwest is compelling. It consists of published scientific literature representing a large number of laboratory and field observations. The scientific evidence comes from investigations of the natural and anthropogenic (human-generated) changes to the biogeochemistry of Pacific Northwest waters, responses of organisms to present-day and future conditions, and observations made in aquaculture settings. This fact sheet summarizes our growing understanding of the causes and consequences of ocean acidification in Pacific Northwest marine waters.

1 **Ocean acidification (OA) is a progressive increase in the acidity of the ocean over an extended period**, typically decades or longer, caused primarily by uptake of carbon dioxide (CO_2) from the atmosphere. OA can also be caused or enhanced by other chemical additions or subtractions from the ocean. Acidification can be more severe in areas where human activities further increase acidity, such as through nutrient inputs that fuel biological production and respiration processes.

2 **Ocean acidification has been well documented** through global observations conducted over several decades by hundreds of researchers. It has been definitively attributed to anthropogenic (human-generated) CO_2 in the atmosphere that has been released primarily by fossil fuel combustion and deforestation.

3 **Acidity can be thought of as simply the hydrogen ion concentration (H^+) in a liquid**, and pH is the logarithmic scale on which this concentration is measured. It is important to note that acidity increases as the pH *decreases*.

4 **Average global surface ocean pH has already fallen** from a pre-industrial value of 8.2 to 8.1, corresponding to an increase in acidity of about 30%. Values of pH 7.8–7.9 are expected by 2100, representing a doubling of acidity.

5 **The pH of the open-ocean surface layer is unlikely to ever become *acidic***, because seawater is buffered by dissolved salts. The term "acidification" refers to a pH shift towards the acidic end of the pH scale, similar to the way we describe an increase in temperature from well below freezing to just above freezing: it's still cold outside, but we say it's "warming."

6 **Ocean acidification causes changes in seawater carbonate chemistry.** As seawater acidifies, concentrations of dissolved CO_2, hydrogen ions, and bicarbonate ions *increase*, and the concentration of carbonate ions *decreases*. As a result, the stability of calcium carbonate ($CaCO_3$) biominerals like aragonite and calcite also decline. The stability of these $CaCO_3$ biominerals in seawater is defined in terms of their saturation state (Ω), which is largely determined by the concentration of carbonate ions. When carbonate ion concentration is high, Ω is correspondingly high and biomineral formation is favored; when carbonate ion concentration is low enough that Ω drops below the threshold level of 1, the biominerals begin to dissolve. In the context of OA, seawater with $\Omega_{aragonite} < 1$ is termed "corrosive" because it is capable of dissolving the aragonite shells of marine organisms.

7 **Areas that could be particularly vulnerable to ocean acidification** include 1) coastal regions that receive large volumes of freshwater, especially when the freshwater contains high levels of dissolved nutrients or organic material; and 2) regions where upwelling brings colder CO_2-rich deep water onto the continental shelves, such as along the west coast of North America. Upwelled water is naturally CO_2-rich due to biological respiration in the subsurface waters, which depletes dissolved oxygen and generates CO_2. During the summer upwelling season in the Pacific Northwest, this deeper CO_2-rich low pH seawater mixes with the surface layer, which carries its own burden of anthropogenic atmospheric CO_2. The combined effect is an approximate reduction in the $\Omega_{aragonite}$ of ~0.25-0.5 units along the outer coast.

8 **Changes in pH and carbonate chemistry force marine organisms to spend more energy** regulating internal chemistry. For some organisms, this may leave less energy for other biological processes like growth, reproduction, or coping with other environmental stresses.

9 **The biological impacts of ocean acidification will vary**, because marine organisms exhibit a wide range of sensitivities to changing seawater chemistry. In particular, many shell-forming marine organisms are sensitive to changes in pH and carbonate chemistry, including corals, bivalves, pteropods (sea butterflies), and phyto- and zooplankton species that build their hard parts out of $CaCO_3$ biominerals. The juvenile stages of many Pacific Northwest shellfish species (e.g. oysters, clams, and mussels) are particularly vulnerable to acidification because the biomineral they use to build their shells—aragonite—has the greatest tendency to dissolve at CO_2 levels currently being observed in Pacific Northwest marine waters.

10 Impacts from ocean acidification at any life stage can reduce the ability of a population to grow or to recover from disturbance or stress. Research clearly indicates that many larval forms are vulnerable to acidification. Juvenile and adult forms also have been demonstrated to be sensitive to OA. Exposure to OA among early life stages can cause detectable effects later in life.

11 Natural and anthropogenic factors combine to intensify ocean acidification in Pacific Northwest waters. Natural and anthropogenic factors that contribute to OA in Pacific Northwest waters include CO_2 emissions, upwelling of CO_2-rich waters, freshwater inputs, and non-CO_2 acidifying gases. Nutrient inputs that fuel biological production add CO_2 through respiration and microbial breakdown of organic matter. The effects of these multiple factors are additive, and explain why acidification in our coastal region is more severe than model predictions based on CO_2 alone. Addressing local factors such as nutrient pollution could offset some of the local acidification impacts, but this needs further study.

12 The human contribution to acidification in the Pacific Northwest is quantifiable and has increased the frequency, intensity, and duration of harmful conditions. In Hood Canal, 24-49% of the total increase in CO_2 in subsurface waters since the industrial revolution is linked to human activity. Off the Oregon coast, undersaturated conditions ($\Omega_{aragonite}$ <1), once rare, now occur 30% of the time during the summer upwelling season. Anthropogenic CO_2 is the largest human-derived source of acidifying pollution in Pacific Northwest waters, adding an amount of CO_2 that can significantly worsen naturally-low $\Omega_{aragonite}$ conditions for shelled organisms. The human contribution essentially 'makes a bad day worse' for shellfish and other organisms, and it causes those bad days to become more frequent.

13 Pacific Northwest shellfish are sensitive to reduced $\Omega_{aragonite}$ within the current range of conditions. Even prior to the industrial revolution, the aragonite saturation state of Pacific Northwest waters was lower than the global ocean average (~2.5 versus ~3.0) because our marine waters are colder, fresher, and contain more CO_2 from respiration processes at depth compared with waters further offshore. Over the last ~150 years, anthropogenic CO_2 emissions have reduced the global ocean average surface $\Omega_{aragonite}$ by 0.5 units, or 17%. For Pacific Northwest shellfish living close to the saturation state threshold of 1.0, this further reduction can—and sometimes does—cause problems now. Significant losses in Pacific oyster production have been observed in shellfish hatcheries in Washington and Oregon under slightly saturated conditions ($\Omega_{aragonite}$ ~1.0 - 1.7), because shell formation in developing larvae requires supersaturated conditions ($\Omega_{aragonite}$ >1.7).

14 Native species are affected. Studies of the native Olympia oyster showed that survival and growth of larvae and juveniles decreased with exposure to low pH and $\Omega_{aragonite}$ in the laboratory and in field settings. The same appears to be true for other native species like pteropods, red sea urchins, northern abalone, and turban snails. Although these calcifying invertebrates seem to be most sensitive during their larval phase, negative effects have been observed in multiple developmental stages, from fertilization through adulthood.

15 Small changes in the environment can cause large responses among living organisms. While most marine organisms can tolerate a range of environmental conditions, at some point their tolerance fails; even small changes in the environment can cause an abrupt biological response when the limits of tolerance are passed. This holds true for exposure to low pH and $\Omega_{aragonite}$. Significant effects of rising anthropogenic atmospheric CO_2 are being observed in Pacific Northwest waters now, and these effects will worsen as CO_2 levels increase. Vulnerable organisms such as pteropods and oyster larvae can suffer mortality or abnormal development following even brief exposures to harmful conditions, with effects persisting even after environmental conditions improve.

16 Long-term decline in pH could exceed the tolerance limits of some marine species that live in coastal waters. Even species that can cope with fluctuating pH on short timescales typical of coastal environments (where the daily and seasonal changes in seawater pH are much greater than in the open ocean) may be unable to tolerate consistently low pH conditions. Although scope for evolutionary adaptation to OA is known to exist, species differ in their adaptive capacity. Marine organisms could be further challenged by multiple stressors that act simultaneously (for example, OA with warmer seawater temperatures).

17 The current rate of acidification may be unprecedented in Earth's history. The rate of acidification is estimated to be 10 to 100 times faster than any time in the past 50 million years. An acidification event that occurred 55 million years ago (at the Paleocene-Eocene Thermal Maximum) was associated with a mass extinction of some marine species, especially deep-sea shelled invertebrates.

18 Contemporary ocean acidification could threaten the flow of goods and services to marine-dependent communities. A new study has shown that the fishing industry in Southeast and Southwest Alaska will be vulnerable to declines in both commercial and subsistence harvests due to ocean acidification in coming decades. Disruptions in Alaska fisheries could have significant economic impacts throughout the Pacific Northwest due to the economic linkages between the two regions.

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NOAA, Ocean Acidification Program
oceanacidification.noaa.gov

Ocean Carbon and Biogeochemistry Project–Ocean Acidification
whoi.edu/OCB-OA

University of Washington
Washington Ocean Acidification Center
coenv.washington.edu/research/major-initiatives/ocean-acidification/

Washington Sea Grant
wsg.washington.edu
WSG AS-14-04
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The West Coast Ocean Acidification and Hypoxia Science Panel
westcoastoah.org

Photo opposite page: Pacific Oysters, credit Pacific Coast Shellfish Growers Association