

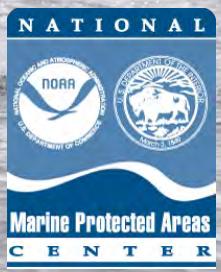


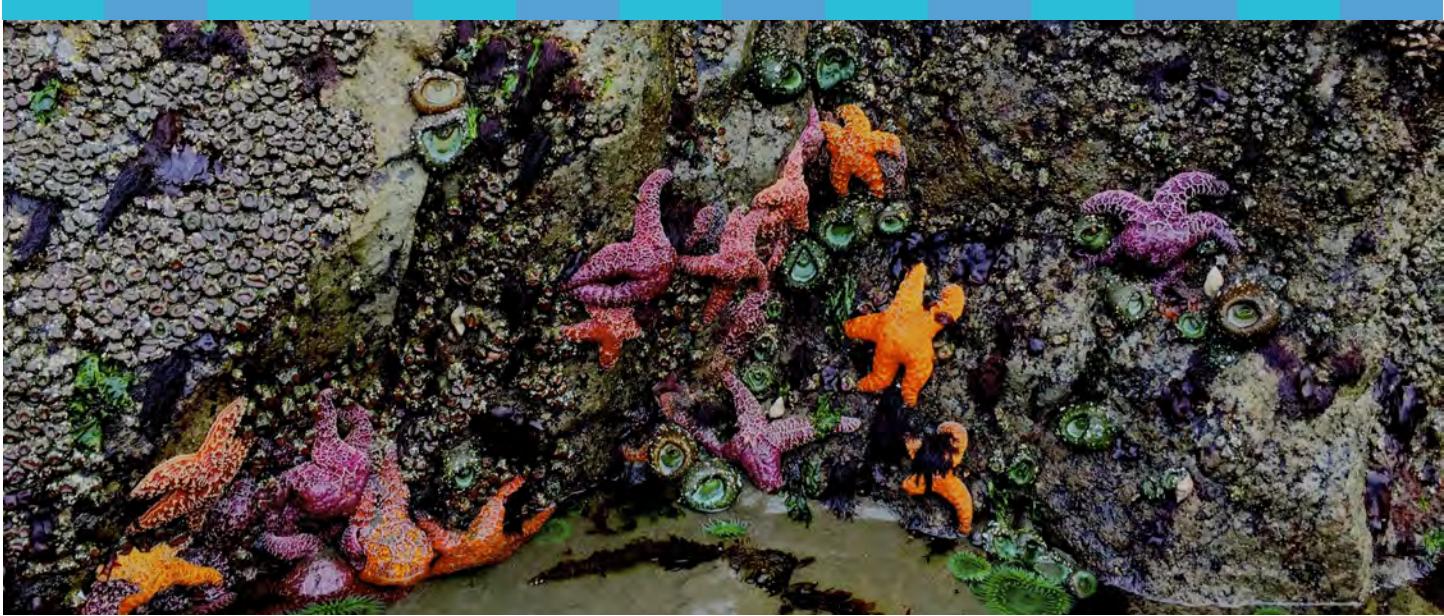
Climate Change Impacts

Olympic Coast National Marine Sanctuary



May 2020





A tide pool in Olympic Coast National Marine Sanctuary is filled with sea anemones and ochre sea stars. Photo: NOAA

Our Changing Ocean

The impacts of [climate change](#) are intensifying both globally and locally, threatening America's physical, social, economic, and environmental [well-being](#)¹. [National marine sanctuaries and marine national monuments](#) must contend with [rising water temperatures](#) and [sea levels](#), water that is [more acidic](#) and [contains less oxygen](#), [shifting species](#), and [altered weather patterns and storms](#)¹. While all of our sanctuaries and national monuments must face these global effects of climate change, each is affected differently.

Olympic Coast National Marine Sanctuary

[Olympic Coast National Marine Sanctuary](#) (OCNMS) contains 3,188 square miles of protected ocean along the northern coast of Washington's Olympic Peninsula within the usual and accustomed area of the Makah, Quileute, and Hoh tribes, as well as the Quinault Indian Nation. Designated by NOAA in 1994, OCNMS protects a highly productive upwelling system that fuels a vibrant ecosystem home to seabirds, fish, and marine mammals, including culturally and economically important salmon, oysters, and mussels. OCNMS protects important habitats, like kelp forests and deep sea coral communities, on which these species depend.

Ocean Acidification

About [30%](#) of the carbon dioxide (CO₂) released into the atmosphere is absorbed by the ocean² causing a chemical reaction that leads to ocean waters becoming [more acidic](#). Globally, the ocean has become 30% more acidic since the beginning of the industrial revolution.^{3,4} Increasingly acidic waters make it difficult for animals like oysters, crabs, and deep sea corals to maintain shells and skeletons.^{1,5-8}

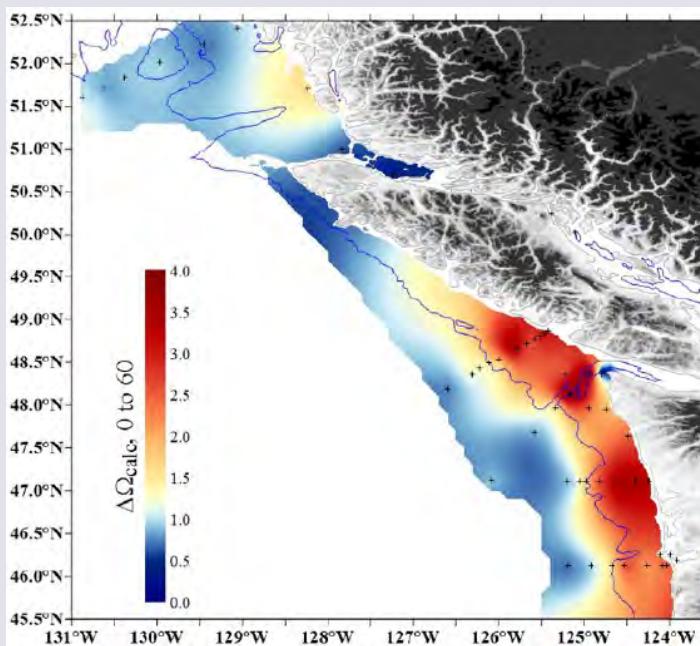
The waters within OCNMS are especially susceptible to acidification due to the process of [upwelling](#).^{1,6,8} Upwelling brings cool, nutrient-rich water from the deep ocean to the surface, driving the vibrant ecosystem of the Olympic Coast. However, upwelled water is also more acidic than typical seawater.^{1,7,8} Ocean acidification from CO₂ absorption, when combined with acidic, [low-oxygen](#) upwelled water, stresses the ability of many organisms to make shells and stony skeletons.^{7,8} The waters of OCNMS are



Deep sea corals, like this bubble gum coral, are particularly susceptible to ocean acidification. Photo: NOAA



Case Study 1—Aragonite Undersaturation



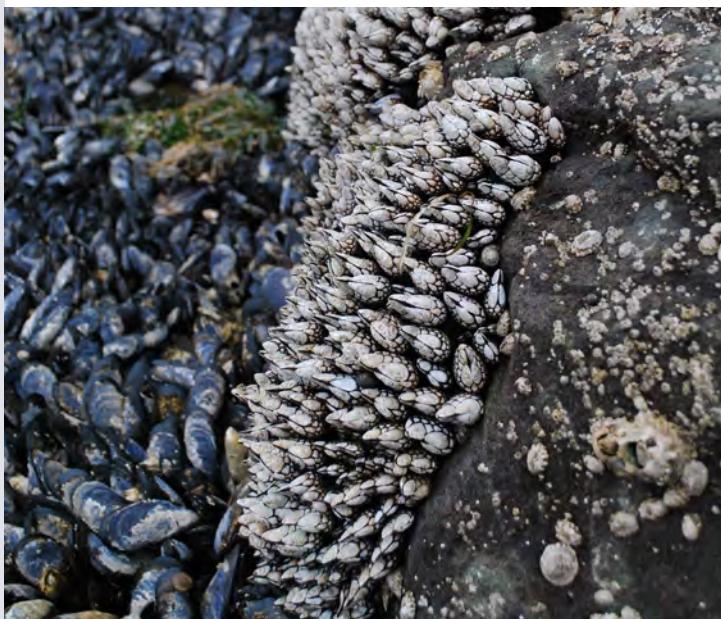
Acidification hot spots on the Washington coast as measured by the calcite (CaCO_3) vertical gradient. Photo: research.noaa.gov adapted from Bednaršek et al. 2020¹⁴

The nearshore waters of Washington state, are more acidic than most of the global ocean.⁹ As ocean water becomes more acidic, the concentrations of aragonite and calcite (CaCO_3), the minerals used by organisms to make and maintain shells and stony skeletons, available to organisms decreases. If waters become undersaturated in these minerals, the shells and stony skeletons of organisms can begin to dissolve. Deep ocean waters, like those that are brought to the surface by upwelling, are often undersaturated in these minerals. Since the beginning of the industrial revolution in 1750, the depth at which North Pacific Ocean waters become undersaturated, known as the aragonite saturation horizon, has migrated 100–300 ft [closer to the surface](#).^{6,9,18} Further, there is already evidence of repeated seasonal periods of aragonite undersaturation in the surface waters of OCNMS.^{6,13} These periods of aragonite undersaturation are driven by the strong coastal upwelling that occurs along the Olympic Coast. Although upwelling has always been a feature of the Olympic Coast, ocean acidification has lowered the aragonite concentration in surface waters to a point where the acidic deep water brought to the surface by upwelling can push surface waters into an undersaturated state.

naturally more acidic than most of the ocean and may [increase in acidity](#) up to 50% by 2100.⁹

Further acidification could impact ecologically, economically, and culturally important species. Deep sea corals, which create habitat for many species, are particularly vulnerable.^{6,10} [Pteropods](#), small sea snails that are important prey for salmon, may be unable to survive in the region.^{1,11,12} Larval Dungeness crab are already being impacted by acidification on the Olympic Coast, with potential consequences for the reproductive success of this economically important species.¹⁴ Further, by some estimates, 80% of intertidal organisms are vulnerable to acidification, including [mussels and oysters](#).⁸ In fact, larval shortages of mussels and oysters have been reported on the Olympic Coast since 2007 due to highly acidic waters,⁷ conditions expected to be the norm by 2050.^{7,13}

Many species will also experience indirect impacts of ocean acidification. Reductions in prey availability due to acidification are expected to have major impacts on sea otters,⁶ Dungeness crab,¹⁵ and salmon.¹² Increasing acidification has also been linked to a shift in intertidal communities from mussel-dominated to a community dominated by fleshy algae and other species without shells,^{6,16} a transformation that took only eight years on Tatoosh Island.¹⁶ Further, increased acidification may make harmful algal blooms ([HABs](#)) more toxic with negative effects for resources critical to coastal communities.^{6,17}



Gooseneck barnacles, mussels, and other shellfish such as oysters are highly susceptible to ocean acidification. Photo: Elizabeth Weinberg/NOAA



Case Study 2—Salmon and Climate Change



Pteropods, important prey for salmon, are small sea snails which are highly vulnerable to the impacts of ocean acidification. *Photo: NOAA*

Salmon are [ecologically](#), [economically](#), and [culturally](#) important to the Olympic Coast. Higher stream temperatures, driven by increasing air temperature and reduced snowpack, can affect both salmon migration¹⁹ and juvenile salmon survival²⁰. In fact, [increased stream temperatures](#) could reduce salmon habitat in Washington up to 22% by 2100, leading to over \$3 billion in economic losses.^{1,21} Salmon appear to be adapting to these increasing stream temperatures by changing the timing of their migration into and out of fresh water.^{12,22,23} While this allows salmon to minimize the negative effects of increasing stream temperatures, it may cause a mismatch in timing between the arrival of juvenile fish to the ocean and the spring zooplankton blooms they depend on for food.^{17,24} If climate change impacts the plankton on which salmon feed, or the

timing of the bloom, it will likely affect their ability to grow and survive.^{1,11,12,24}

Of particular concern are the microscopic sea snails called [pteropods](#), which are a critical food source for salmon.¹² Pteropods are highly vulnerable to ocean acidification and conditions on the Olympic Coast are already at the edge of their ability to survive.^{1,11,12} As the waters of the Olympic Coast become more acidic, pteropods may no longer be able to survive in the region, leading to the loss of an important food source for salmon.^{11,12}



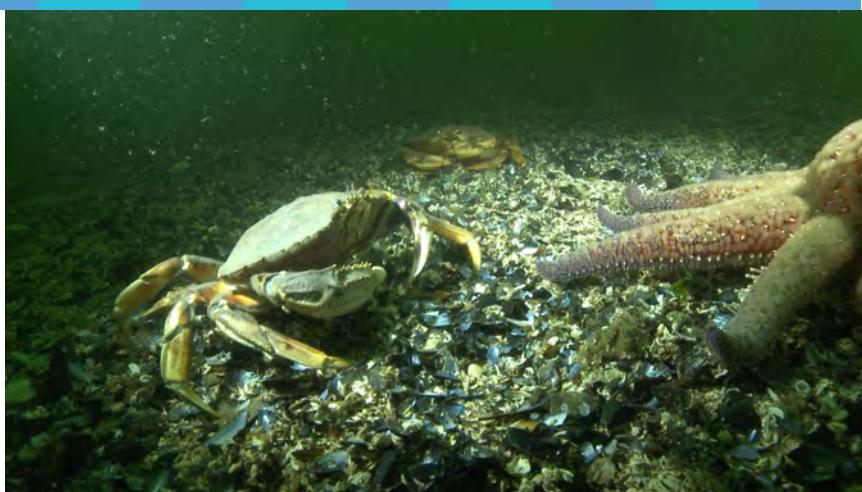
Coho salmon are just one of the many salmon species being impacted by climate change. *Photo: NOAA*



Rising Ocean Temperatures

As global temperatures rise, the ocean has [absorbed much of the heat](#) causing the average ocean temperature to [increase world-wide](#).¹ In OCNMS, water temperatures are [expected to increase](#) 2°F by 2050.²⁵ As temperatures rise, many species in the northern hemisphere are moving northward or deeper to cooler waters.^{1,26} Scientists predict that southern species, such as hake and sardine, will become more common in OCNMS while anchovy and herring will be less abundant.^{6,27} Warming waters are also projected to increase the success of non-native species, such as the Pacific oyster, at the expense of native species, like the Olympia oyster.²⁸ Sea birds, mammals, and large fish will also be impacted by changes in prey.¹ Economically important species like Dungeness crab are expected to experience reductions in prey^{6,14} while changes in food availability may drive sea otters out of OCNMS.⁶ Rising temperatures also impact species directly. Intertidal communities are particularly vulnerable as high temperatures stress oysters and mussels^{6,28} while increasing the occurrence of sea star wasting disease.^{29,30}

In 2015, a marine heat wave known as [“The Blob”](#) led to water temperatures up to 5°F above normal.^{31,32} Many predictions of the impacts of future temperatures on the region came true as sea star wasting increased³³ and species like the Humboldt squid moved in from the south. The warm water also fueled harmful algal blooms ([HABs](#)), which produced toxins that killed hundreds of whales, sea lions, and birds and led to the closure of the Dungeness crab fishery.^{1,34} As temperatures warm, such HABs may become more common, last longer, and be more toxic.^{1,35}



Many different species in OCNMS may be affected by rising ocean temperatures and climate change impacts. Species IDs (top to bottom): Dungeness crab, sea otter, California sea lions. Photos: Paul Hillman/NOAA; NOAA; Heidi Pederson/NOAA



The intertidal communities of the Olympic Coast are likely to be impacted by changes in sea level. Photo: Kate Thompson/NOAA

The Changing Coastline



Climate change is predicted to impact the coast of OCNMS through changes in storm intensity and sea level. Average sea level is [rising worldwide](#).¹ However, factors such as currents and [changing land height](#) from tectonic activity cause changes in relative sea level to vary by location. As a result, relative sea level is falling in the northern part of OCNMS and rising on the southern coast.⁶ Rising sea level on the southern coast reduces intertidal habitat for oysters and mussels by exposing them to more predation from oceanic predators at the same time that [warming air temperatures](#) limit their ability to move higher in the intertidal zone.⁶

The impacts of rising sea levels are also being worsened by changes in storm patterns. Strong winter storms are expected to become more common, increase in intensity, and move closer to shore.^{1,6,36} Storm surge and large waves produced by these storms compound the effects of sea level rise and increase coastal erosion.¹ Storms may also have an increasing impact on mussels as thinner shells and weaker attachments resulting from acidification³⁷ and high water temperature³⁸ increase the risk that storms will kill or detach these animals.⁶

Changes in precipitation patterns are also predicted along the Olympic Coast. Snow pack is expected to decrease^{1,39} and rain is predicted to become more irregular and intense.^{1,40} As a result, [100-year floods](#) will likely occur more often^{6,41} while the summer flow in rivers important to salmon is expected to decrease.^{1,6,42}



Changes to Upwelling

[Upwelling](#), when cool, nutrient-rich deep water rises to the surface, provides the nutrients that fuel the Olympic Coast ecosystem. While this water provides vital nutrients, it is also low in oxygen and more acidic than surface waters.^{1,6,8}

Changes in the timing or intensity of upwelling events could have consequences for the OCNMS ecosystem. However, the impacts of climate change on upwelling are difficult to predict.

Projections suggest upwelling in the region of OCNMS will become

more intense in some seasons and less intense in others.⁴³ More intense upwelling events could stress ocean life by worsening the effects of ocean acidification and lowering water oxygen levels.^{7,10} Less intense upwelling reduces the availability of food sources for salmon and other animals.^{44,45} Further, changes in the timing of upwelling could cause mismatches between the plankton bloom fueled by upwelling and the fish, mammals, and seabirds that often migrate hundreds of miles to feed on the prey it supports.⁴⁶ In the past, decreased and delayed upwelling has led to reductions of plankton and forage fish, resulting in reduced survival of the species that feed on them, such as coho and chinook salmon.⁶



Hundreds of species of fish, mammals, and seabirds, including tufted puffins, depend on blooms of prey fueled by upwelling events along the Olympic Coast. Photo: Mary Sue Brancato/NOAA

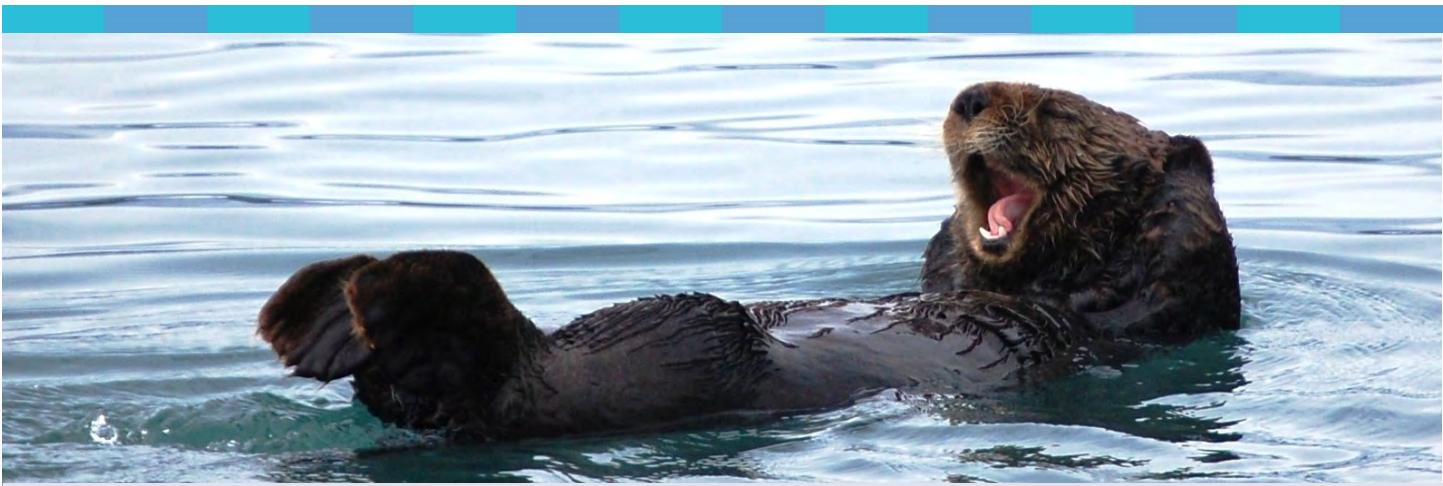
What are We Doing?

Since 2000, NOAA and research partners have tracked and investigated climate change impacts including ocean acidification, [hypoxia](#), and changing ecological communities. In 2013, these efforts produced an OCNMS [climate change report](#). Partnerships with government, tribal, academic, and citizen scientists are allowing NOAA to expand its research, including projects to track the health of key species, like pteropods, and monitor changes to seabird populations on the Olympic Coast. Due to their sensitivity to changing ocean conditions, monitoring seabird populations allows managers to receive early warnings of ecosystem changes. Further, the OCNMS [education team](#) works in collaboration with partners to educate the public about the growing threats of climate change and ocean acidification. Efforts include K-12 science [education programs and curricula](#), teacher workshops, outreach tools and resources, public outreach events and speaker series, and citizen science projects.

The sanctuary has been designated as an ocean acidification “[Sentinel Site](#).” As a sentinel site, OCNMS managers and partners focus on acidification science and inform managers and coastal communities by telling the story of ocean acidification and its impacts on coastal resources, cultures, communities, and economies. The sentinel site seeks to ensure that Washington’s Olympic Coast is prepared for changing ocean conditions.



From deep sea coral to intertidal algae, OCNMS protects a highly diverse assortment of ocean life. Photo: Jenny Waddell/NOAA



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