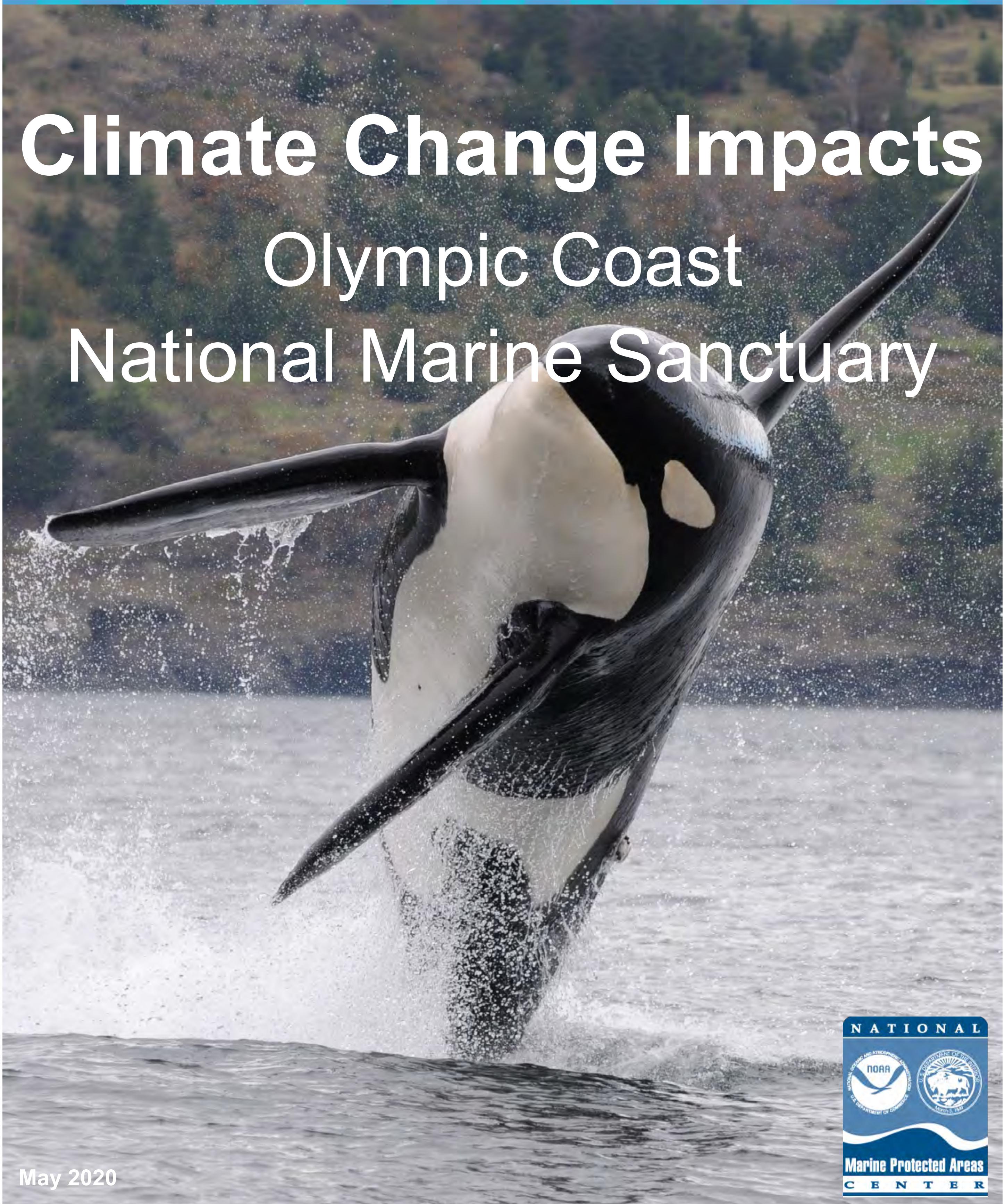
Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

Climate Change Impacts

Olympic Coast National Marine Sanctuary



May 2020

NATIONAL Marine Protected Areas CENTER

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.

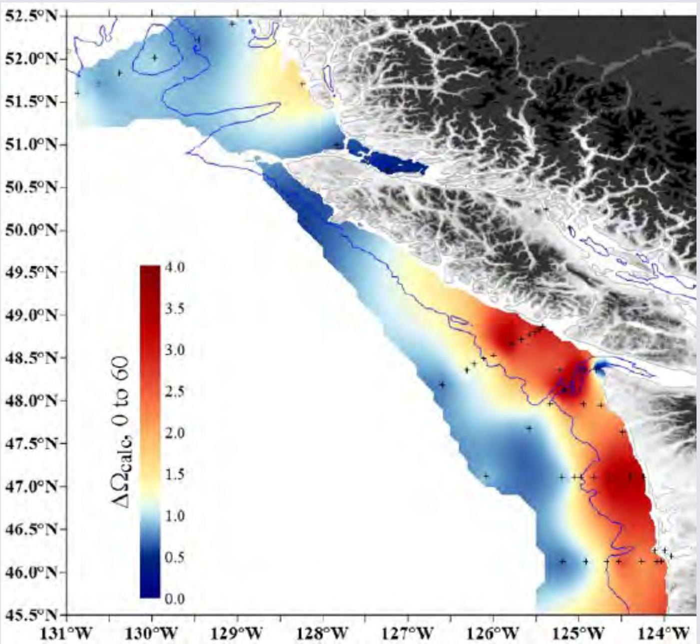
Ocean Acidification

About 30% of the carbon dioxide (CO_2) released into the atmosphere is absorbed by the ocean[2] 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]

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

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 CO_2 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

Case Study 1— Aragonite Undersaturation



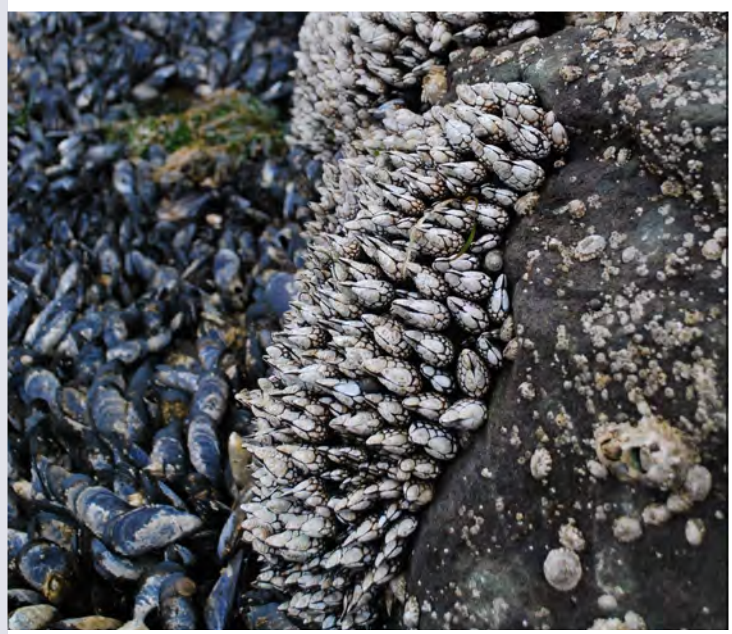
Acidification hot spots on the Washington coast as measured by the calcite ($CaCO_3$) vertical gradient. *Photo: research.noaa.gov adapted from Bednaršek et al. 2020*[14]

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 understaturated, 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 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 migration[19] and juvenile salmon survival[20]. 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 increased[33] 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 riding 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

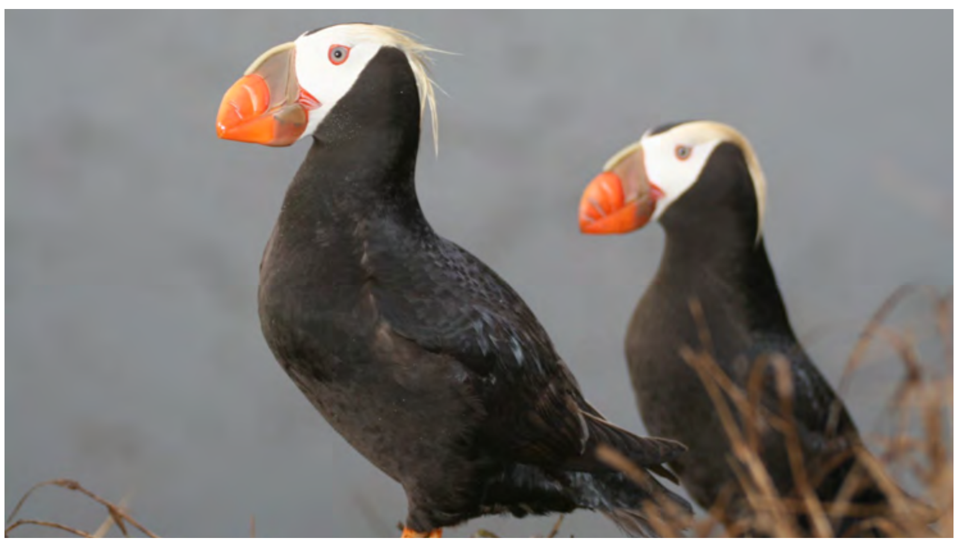
Climate change is predicted to impact the coast of OCNMS through changes in storm intensity and sea level. Average sea level is rising worldwide.[1] However, factors such as currents and changing land height from tectonic activity cause changes in relative sea level to vary by location. As a result, 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 acidification[37] and high water temperature[38] 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.



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*

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]

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*

Citations

1. USGCRP (2018) Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II. *U.S. Global Change Research Program*
2. DeVries et al. (2018) Coral reefs will transition to net dissolving before end of century. *Science*
3. Haugan & Drange (1996) Effects of CO2 on the ocean environment. *Energy Conv. Manag.*
4. Doney et al. (2009) Ocean acidification: The other CO2 problem? *Annu. Rev. Mar. Sci.*
5. Davies & Guinotte (2011) Global habitat suitability for framework-forming cold-water corals. *PLoS One*
6. Miller et al. (2013) Climate Change and the Olympic Coast National Marine Sanctuary: Interpreting Potential Futures. *Marine Sanctuaries Conservation Series ONMS-13-01.*
7. Barton et al. (2015) Impacts of coastal acidification on the Pacific Northwest shellfish industry and adaptation strategies implemented in response. *Oceanography*
8. Jones et al. (2018) Characterizing the vulnerability of intertidal organisms in Olympic National Park to ocean acidification. *Elementa-Sci. Anthrop.*
9. Feely et al. (2012) Scientific Summary of Ocean Acidification in Washington State Marine Waters. *NOAA OAR Special Report.*
10. Guinotte et al. (2006) Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals? *Front. Ecol. Environ.*
11. Bednaršek et al. (2017) Exposure history determines pteropod vulnerability to ocean acidification along the US West Coast. *Sci. Rep.*
12. Crozier & Siegel (2018) 2018 Impacts of climate change on salmon of the Pacific Northwest. *Technical Review, National Marine Fisheries Service.*
13. Gruber et al. (2012) Rapid progression of ocean acidification in the California current system. *Science*.
14. Bednaršek et al. (2020) Exoskeleton dissolution with mechanoreceptor damage in larval Dungeness crab related to severity of present-day ocean acidification vertical gradients. *Sci. Total Environ.*
15. Hodgson et al. (2018) Consequences of spatially variable ocean acidification in the California Current: Lower pH drives strongest declines in benthic species in southern regions while greatest economic impacts occur in northern regions. *Ecol. Model.*
16. Wootton et al. (2008) Dynamic patters and ecological impacts of declining ocean pH in a high-resolution multi-year dataset. *Proc. Nat. Acad. Sci.*
17. Tatters et al. (2012) High CO2 and Silicate limitation synergistically increase the toxicity of *Pseudo-nitzschia fraudulenta. PLoS One.*
18. Feely et al. (2004) Impact of anthropogenic CO_2 on the $CaCO_3$system in the oceans. *Science*
19. Weinheimer et al. (2017) Monitoring climate impacts: Survival and migration timing of summer chum salmon in Salmon Creek, Washington. *Trans. Am. Fish. Soc.*
20. Gosselin & Anderson (2017) Combining migration history, river conditions, and fish condition to examine cross-life-stage effects on marine survival in Chinook salmon. *Trans. Am. Fish. Soc.*
21. Niemi et al. (2009) An overview of potential economic costs to Washington of a business-as-usual approach to climate change. *Climate Leadership Initiative*
22. Kovach et al. (2009) Earlier migration timing, decreasing phenotypic variation, and biocomplexity in multiple salmonid species. *PLoS One*
23. Dempson et al. (2017) Influence of climate and abundance on migration timing of adult Atlantic salmon (*Salmo salar*) among rivers in Newfoundland and Labrador. *Ecol. Freshw. Fish*
24. Asche et al. (2019) Climate change impacts on mismatches between phytoplankton blooms and fish spawning phenology. *Globl. Change Biol.*
25. Mote and Salathe (2012) Future climate in the Pacific Northwest. *Clim. Change*
26. Poloczanska et al. (2013) Global imprint of climate change on marine life. *Nature*
27. King et al. (2011) Climate forcing and the California Current ecosystem. *ICES J. Mar. Sci.*
28. Valdez & Ruesink (2017) Scales of recruitment variability in warming waters: Comparing native and introduced oysters in Hood Canal, Washington, USA. *Mar. Ecol.*
29. Bates et al. (2009) Effects of temperature, season and locality on wasting disease in the keystone predatory sea star *Pisaster ochraceus. Dis. Aquat. Organ.*
30. Eisenlord et al. (2016) Ochre star mortality during the 2014 wasting disease epizootic: role of population size structure and temperature. *Phil. Trans. R. Soc. B.*
31. Bond et al. (2015) Causes and impacts of the 2014 warm anomaly in the NE Pacific. *Geophys. Res. Lett.*
32. Gentemann et al. (2017) Satellite sea surface temperatures along the West Coast of the United States during the 2014–2016 northeast Pacific marine heat wave. *Geophys. Res. Lett.*
33. Harvell et al. (2019) Disease epidemic and a marine heat wave are associated with the continental-scale collapse of a pivotal predator (*Pycnopodia helianthoides*). *Sci. Adv.*
34. McCabe et al. (2016) An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions. *Geophys. Res. Lett.*
35. Karl et al. (2017) Climatic regulation of the neurotoxin domoic acid. *Proc. Nat. Acad. Sci.*
36. Salathé (2006) . Influences of a shift in North Pacific storm tracks on western North American precipitation under global warming. *Geophys. Res. Lett.*
37. Pfister et al. (2016) Historical baselines and the future of shell calcification for a foundation species in a changing ocean. *Proc. Roy. Soc. B*
38. Clements et al. (2018) Elevated seawater temperature, not pCO2, negatively affects post-spawning adult mussels (*Mytilus edulis*) under food limitation. *Conserv. Physiol.*
39. Ahmadalipour & Maradkhani (2017) Analyzing the uncertainty of ensemble-based gridded observations in land surface simulations and drought assessment. *J. Hydrol.*
40. Rupp et al. (2017) Projections of 21st century climate of the Columbia River Basin. *Clim. Dyn.*
41. Tohver et al. (2012) Using physically based hydrology models to improve fine scale estimates of Q100 in complex mountain terrain. *Final project report. Climate Impacts Group, Department of Civil and Environmental Engineering, University of Washington, Seattle.*
42. Mantua et al. (2010) Climate change impacts on streamflow extremes and summertime stream temperature and their possible consequences for freshwater salmon habitat in Washington State. *Clim. Change*
43. Brady et al. (2017) Emergent anthropogenic trends in California Current upwelling. *Geophys. Res. Lett.*
44. Hinch et al. (1995) Potential effects of climate change on marine growth and survival of Fraser River sockeye salmon. *Can. J. Fish. Aquat. Sci.*
45. Thompson et al. (2011) Linking predators to seasonality of upwelling: Using food web indicators and path analysis to infer trophic connections. *Prog. Oceanography*
46. Bakun et al. (2015) Anticipated effects of climate change on coastal upwelling ecosystems. *Curr. Clim. Change Rep.*

To view the full report online visit: https://sanctuaries.noaa.gov/management/climate/impact-profiles.html