Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

Climate Change Impacts

National Marine Sanctuaries West Coast Region

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Photo: Yasmeen Smalley/NPS

Climate Change and the California Large Marine Ecosystem

Extending from British Columbia to Baja California, the California Current Large Marine Ecosystem (CCLME) is a highly diverse and productive marine ecoregion. As such, understanding the impacts of climate change on the CCLME can provide insight and context to the changes occurring and expected to occur in each of the five national marine sanctuaries on the West Coast, which span nearly the entire northern half of the CCLME. While climate change is driving numerous changes throughout the CCLME, the magnitude of those changes will vary from place to place. Thus, when determining the likely impacts of climate change on a particular location, such as an individual sanctuary, it is important to consider local conditions in addition to regional trends. Yet even where local variation is present, the interconnected nature of the CCLME can result in ripple effects and cascades that spread throughout the ecoregion.

The vibrant reefs of Cordell Bank are one of many West Coast ecosystems that could be impacted by climate change. *Photo: Joe Hoyt/NOAA*

Executive Summary of Impacts to the West Coast Region

On a regional scale, climate-driven changes in the intensity and duration of seasonal upwelling and downwelling are a major factor controlling the magnitude of other climate-driven changes.

The region represents one of the most rapidly acidifying and deoxygenating areas of the ocean, partly as a result of seasonal upwelling. The acidity of waters in the region has increased by 60% (decrease of 0.21 pH) since 1895 and could rise another 40% above 1995 levels by 2050.

Many coastal waters in the region are projected to warm more slowly than other regions of the ocean due to the influence of cool upwelled water.

Marine heatwaves, extended periods of abnormally warm water temperatures, are expected to increase in frequency and intensity globally and in the region. As waters warm, some marine species are shifting poleward or deeper to cooler waters, altering ecological communities and ecosystem function and services.

The impacts of past El Niño events and marine heatwaves may provide a window into future ecological conditions in the CCLME.

Decreased global ocean oxygen levels, warming-driven stratification, and changes to the supply of oxygen to deep waters as a result of climate change increase the risk of hypoxia in the region in part by producing upwelled water that is even lower in oxygen than in the past.

Stronger storms and changes in snowpack and precipitation in mountains that feed rivers and streams along the West Coast could lead to changes in the magnitude and timing of freshwater contributions and streamflow. Such changes may exacerbate the coastal erosion impacts of sea level rise as well as stratification, acidification, and coastal hypoxia throughout the region.

Different climate drivers are occurring simultaneously and can result in compounding impacts such as larger, longer lasting, and more toxic harmful algal blooms (HABs).

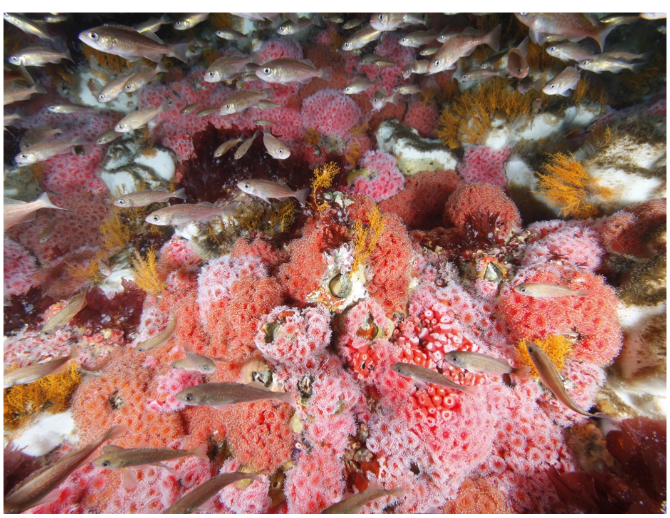
Changing Upwelling and Ocean Chemistry

Kelp forests in Monterey Bay and other sanctuaries are fueled by upwelling-driven nutrients. *Photo: Chad King/NOAA*

The vibrant ecosystems of the CCLME are fueled by seasonal coastal upwelling, which brings cool, nutrient-rich deep water to the surface. Due to its importance to the CCLME, any changes to upwelling could have dramatic and far-reaching effects. Coastal upwelling in the CCLME is seasonally driven by alongshore winds from the north, which push surface waters offshore through a process called Ekman transport, allowing deep waters to rise to the surface. Models project that alterations to these winds over the next century will lead to changes in upwelling timing and intensity across the CCLME.[1,2] These changes are expected to differ by location and the complexity of the processes that control alongshore winds leads to uncertainty in some predictions for some locations.[1,2] Climate models generally agree that the intensity and duration of spring upwelling in the northern CCLME will increase over the coming century while upwelling intensity will decrease in the southern portion.[2] Thus, upwelling is highly likely to intensify in Olympic Coast National Marine Sanctuary and weaken in Channel Islands National Marine Sanctuary by 2100.[1,2] Projections are more complex and uncertain in North-Central California. Upwelling intensity is likely to increase in Greater Farallones and Cordell Bank national marine sanctuaries overall, though with greater uncertainty in the direction and strength of the change in the southern portion of these sanctuaries and throughout Monterey Bay National Marine Sanctuary.[2] Further, natural variability could make it difficult to observe the influence of climate change on upwelling until later in the century[3] and will continue to play an important role in year-to-year variations in upwelling.[2]

Upwelled water is cold, salty, and rich in nutrients, but is also lower in oxygen and more acidic than surface waters. As a result, upwelling is partly responsible for the rapid rate of ocean acidification in the CCLME. While the average acidity of the ocean has increased by 30-40% (decrease of 0.1 pH) since the beginning of the Industrial Revolution,[4,5] the acidity of CCLME waters has increased by 60% (decrease of 0.21 pH) since 1895[6] and could rise another 40% above 1995 levels by 2050.[7]

In addition to increasing acidity, decreased global ocean oxygen levels and changes to the supply of oxygen to deep waters as a result of climate change increase the risk of hypoxia in upwelling systems by producing upwelled water that is even lower in oxygen than in the past.[8,9] In fact, decreasing oxygen levels in upwelled waters are expected to become the main cause of low-oxygen conditions in the coastal CCLME by the end of the century.[2,10] The concentration of oxygen in the deep waters of the CCLME has already dropped by 20% since 1980[11,12] despite an average global decline in ocean oxygen of only 2% since 1960.[11] The risk of hypoxic conditions in the CCLME is expected to continue to increase in the coming century[1,2,8] and oxygen levels are expected to drop below the range of natural variability as early as between 2030 and 2060 in much of the CCLME.[1,2,13] While upwelling of low-oxygen deep water is one cause of the extraordinary rate of deoxygenation being witnessed in the CCLME, the ultimate mechanism behind global ocean deoxygenation is ocean warming, which decreases the capacity of ocean water to hold oxygen and results in stratification, reducing mixing.[1,2,8] As such, global ocean warming is resulting in deep waters that are lower in oxygen than in the past, exacerbating the impacts of upwelling-driven hypoxia.[2,8,9]

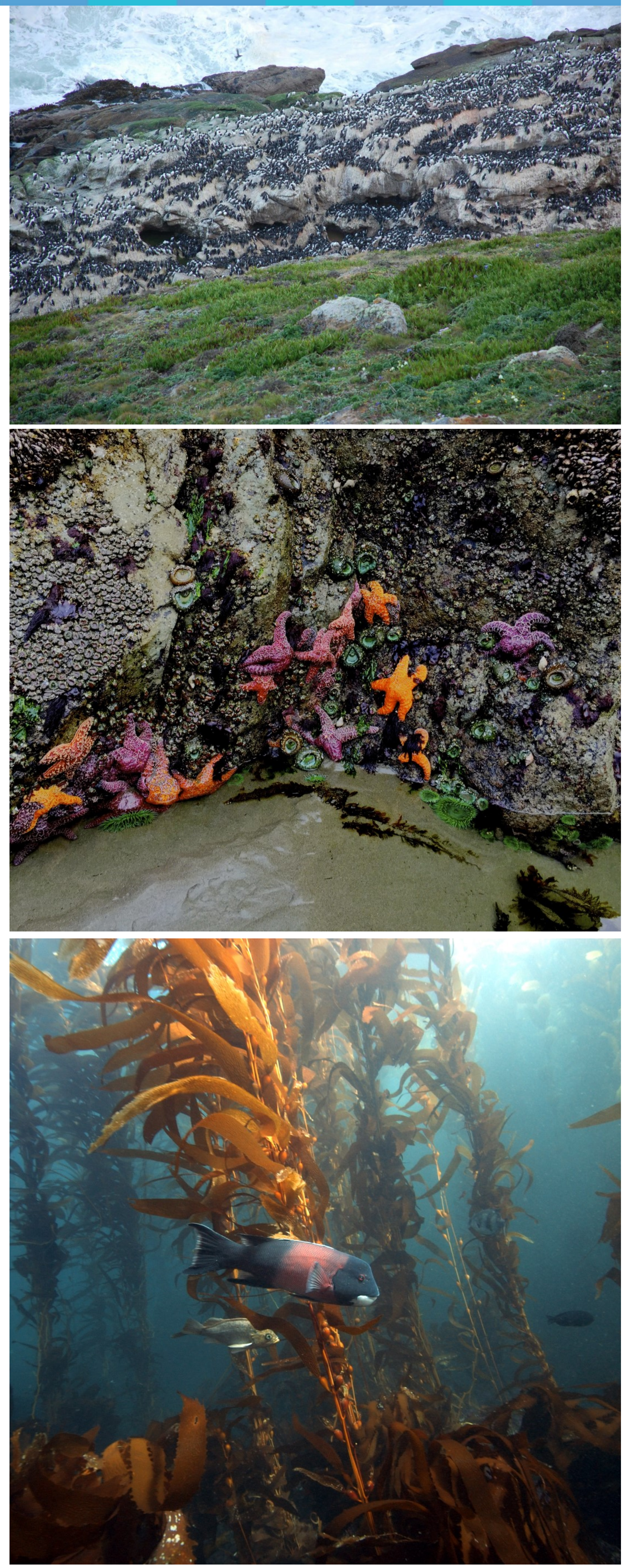


Deepwater habitats in Cordell Bank and other sanctuaries could be affected by lower oxygen concentrations. *Photo: Greg McFall/NOAA*

Warming Waters

While upwelling is often the immediate cause of hypoxic events in the CCLME, hypoxia can also be caused by stratification of the water column, a phenomenon that is becoming more common due to warming ocean temperatures.[8] Waters around the world are warming as the ocean absorbs much of the increased heat in the global system, and the CCLME is no exception. The water temperatures of the CCLME are expected to continue to increase in the coming century.[2,14] However, the degree of warming will vary from location to location, with the greatest warming projected in the southern portions of the CCLME,[2] and many coastal areas are warming comparatively slowly as upwelling drives cool deep water to the surface.[15] Regardless of local variations in average ocean warming, marine heatwaves, extended periods of abnormally warm waters, are expected to increase in frequency and intensity globally and in the CCLME.[16]

Increasing ocean temperatures are expected to force a number of changes throughout the CCLME. Perhaps the most direct result of increasing water temperatures is the geographic shifts of species and ecosystems. As waters warm, some marine species are shifting poleward or deeper to cooler waters,[17] altering ecological communities and ecosystem function and services.[18] Many CCLME species have been documented expanding their ranges northward, especially during marine heatwaves.[19-22] These shifts are also accompanied by alterations of the food web. Warming may lead to a community shift in phytoplankton with smaller, less nutritious species dominating, as occurred in some locations during the 2013-2016 marine heatwave.[19] Further, as species shift north, zooplankton communities could be replaced by smaller and less nutritious warm water species, reducing the energy available for higher trophic levels, a phenomenon observed during past El Niño events[23] and marine heatwaves.[19] In fact, examining the impacts of past El Niño events and marine heatwaves may provide a window into future ecological conditions in the CCLME. The 2013-2016 marine heatwave not only caused many species to temporarily move northward,[19-21] but also fueled a large harmful algal bloom[19] and led to reduced zooplankton prey.[19,20] These changes temporarily altered the food web, causing mass mortalities of seabirds and marine mammals.[19,24,25]



Animals and ecosystems could be impacted by warming waters and its effects. Top to bottom: a colony of common murres in Greater Farallones, a tidepool on the Olympic Coast, a kelp forest in the Channel Islands. *Photos:* Sandra Rhodes/USFWS; NOAA; Robert Schwemmer/NOAA

Precipitation changes could have effect salmon and the southern resident killer whales that feed on them off the Olympic Coast. *Photo: NOAA*

Changes to Atmospheric and Oceanic Processes

While the changes observed in 2013-2016 were largely driven by a marine heatwave, the heatwave itself was triggered by climate-driven alterations to atmospheric and oceanic processes, specifically an abnormally persistent area of high atmospheric pressure south of the Gulf of Alaska that reduced ocean-atmosphere heat transfer and enhanced stratification.[26] Changes to large scale oceanographic and atmospheric processes are likely to continue in the future and will directly affect the CCLME. In fact, changes in the location of atmospheric pressure cells may be one of the driving mechanisms behind alterations in alongshore, equatorward winds projected to force changes in upwelling.[27,28] A projected increase in the frequency and intensity of El Niño[29] and La Niña events[30] could also have drastic impacts on oceanographic and weather conditions throughout the CCLME.

Even in non-El Niño/La Niña years, the weather of the CCLME is expected to be altered by climate change. The intensity of storms[31,32] and waves[33] are projected to increase throughout the CCLME while extreme wet[34] and extreme dry[35] events are expected to become more frequent with less time between these extremes.[36] Storm tracks have already shifted northward[37] and are projected to continue to do so,[38] altering precipitation patterns. Further, a shift in precipitation from snow-dominated to rain-dominated is expected in the mountains of the West Coast,[39] causing a decrease in snowpack[40] and leading to alterations in the timing and intensity of the streamflow upon which salmon, a cultural keystone species in the Pacific Northwest, and other species depend.[39] These changes to streamflow, precipitation, waves, and storms could also exacerbate the effects of sea level rise by accelerating coastal erosion.

Sea Level Rise

Average sea level is rising worldwide, but relative sea level (water height relative to land) change differs from location to location due to local factors such as currents, land uplift, and the Earth's gravitational field. While much of the CCLME is expected to experience relative sea level rise, the rate of rise will differ by location. In fact, some areas, such as the northern coast of Washington state, are experiencing a relative drop in sea level due to crustal rebound from the last ice age.[41] Nevertheless, like the climate impacts discussed above, changing sea levels represent a pervasive climate-driven change in the CCLME.

Northern elephant seals at Greater Farallones and other animals could experience reduced haul-out and nesting habitat due to sea level rise. *Photo: Sara Heintzelman/NOAA*

Harmful Algal Blooms

The changes projected to occur in the CCLME do not occur independently, but rather interact with each other to produce effects that one driver alone could not. Such cumulative and synergistic impacts of climate drivers can be difficult to predict, but may be powerful and widespread. The cumulative effect of numerous climate change impacts on harmful algal blooms (HABs) is perhaps the best and most common example of this interaction of multiple climate drivers on the West Coast. Increases in the size, frequency, and intensity of HABs have already caused millions of dollars in environmental and economic damage along the West Coast.[42-44] The toxins produced by these algae accumulate in prey species like zooplankton and forage fish and can have negative effects on human health and sicken or kill predators, such as large fish, seabirds, cetaceans, and other marine mammals.[45-48] West Coast HABs have also caused economic damage through fisheries closures and delays.[44-49] While HABs are not caused by climate change alone, warming air and water temperatures increase the size, duration, and frequency of these events,[50,51] while ocean acidification can increase their toxicity[52] and changes to current flow patterns facilitate their spread and duration.[53] Further, increases in storm intensity and extreme rainfall could lead to greater coastal runoff, introducing nutrients to the ocean that can fuel HABs and increase their toxicity.[54,55] Ultimately, as climate change progresses, HABs throughout the CCLME are likely to increase in frequency, size, and intensity with widespread potential ecological and economic impacts throughout the region.

Harmful algal blooms can harm resources and were one factor leading to increased whale entanglement in Monterey Bay in 2016 by forcing a delay in the opening of the Dungeness crab fishery that led to overlaps between fishery gear and whales feeding close to shore. *Photo: Douglas Croft*

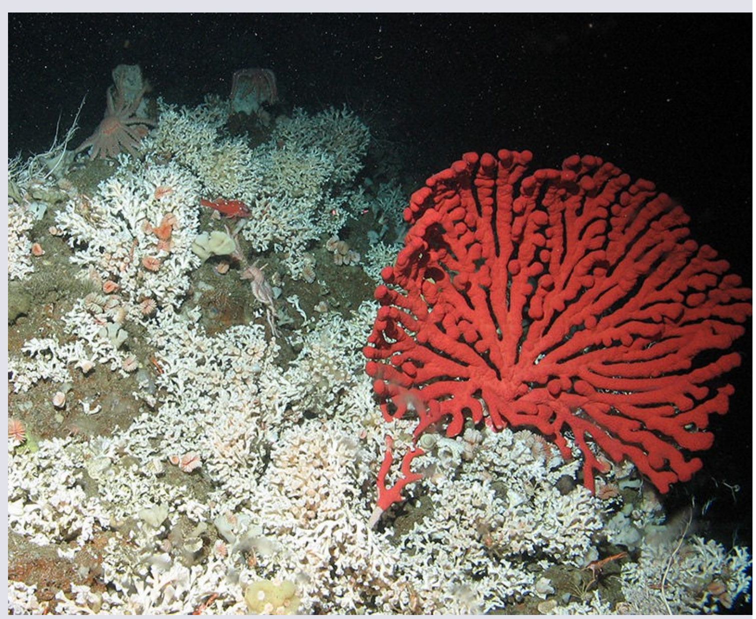
Areas of Particular Impact

A thorough analysis of the areas within national marine sanctuaries on the West Coast at greatest risk from the cumulative impacts of climate change requires an in-depth analysis that is beyond the scope of this summary. However, the review of climate impacts on the West Coast has revealed numerous instances where individual sanctuaries appear to be particularly vulnerable due either to known sensitivities or unknowns that result in challenges to planning and management. Below are examples of climate change impacts to national marine sanctuaries on the West Coast.

Krill, an important link in the food chains of Cordell Bank and other sanctuaries, could be impacted by climate change. *Photo: Shannon Lyday/NOAA*

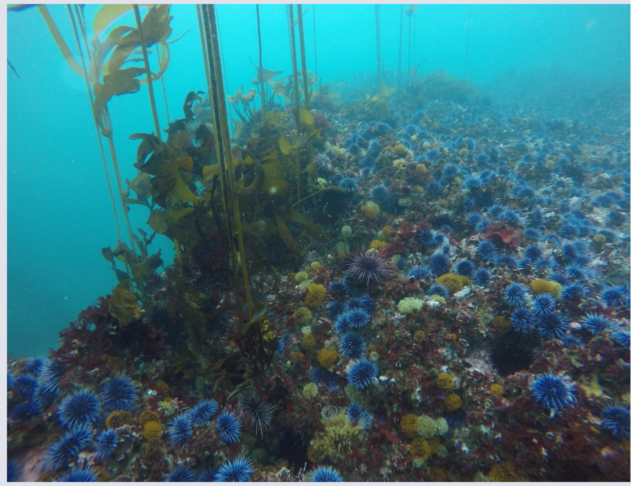
Channel Islands National Marine Sanctuary and the Impacts of Warming Waters

While all national marine sanctuaries on the West Coast are experiencing the impacts of warming waters, Channel Islands National Marine Sanctuary is expected to experience greater warming than other sites[2] and represents a location where projected warming could have disproportionately large impacts. Ultimately, the vulnerability of Channel Islands National Marine Sanctuary arises from two facts of geography. The sanctuary's southern location at a biogeographic transition zone[56] means that some species, such as some deep-water corals,[57] may soon reach thermal tolerance limits and that relatively small changes in temperature could result in large alterations of the biological community towards a greater dominance of southern species.[58] In addition, the east-west orientation of the coast near the northern islands results in lower levels of coastal upwelling than other locations along the coast that, in addition to overall projected decreases in upwelling in the sanctuary,[1,2] may reduce the moderating effect that cool, upwelled water has on warming coastal sea surface temperatures throughout much of the region. While the ultimate vulnerability of the ecological community in Channel Islands National Marine Sanctuary to warming will be determined by the currently unknown thermal tolerances of the species found there, the potential vulnerability is highlighted by past warming-driven shifts in the sanctuary's ecological community.[58] Such community shifts have, in the past, not led to detrimental impacts on ecosystem function, and likely would not in the near future. However, the ecological implications of community shifts are always uncertain and worthy of careful observation.



Some deep-sea corals of Channel Islands National Marine Sanctuaries may reach thermal tolerance with continued warming. *Photo: NOAA*

Ecological Vulnerability of Kelp Forests in Greater Farallones National Marine Sanctuary



Purple sea urchins can have large effects on heat-stressed kelp forests. *Photo: Steve Lonhart/NOAA*

During the 2013-2016 Pacific marine heatwave, kelp canopy cover declined throughout the region.[59,60] However, these losses were highest and longest lasting throughout Greater Farallones National Marine Sanctuary and in the northern portion of Monterey Bay National Marine Sanctuary.[59,60] While the vulnerability of kelp to high temperatures was likely one factor in this decline,[61,62] a recent study suggests that ecological factors in the north-central California region exacerbated the impacts of temperature and will likely continue to result in enhanced vulnerability of kelp forests in this region.[60] This study suggested that reduced kelp production due to warming led to a decrease in the drift production (pieces of kelp breaking off) on which purple urchins normally depend.[60] This forced urchins to switch to active, direct foraging on kelp which, in combination with a predator decrease due to the loss of sunflower stars from sea star wasting disease,[63] led to runaway feeding and declines of giant and bull kelp.[60,64] An increase in crustose coralline algae in these new urchin barrens then led to additional urchin settlement, further increasing urchin densities.[60,65] The study suggests that the runaway urchin population bloom was possible in this area due to the lack of alternative sea urchin predators, as can be found in central (sea otters) and southern California (sheephead and spiny lobster) kelp forests.[60] This inherent ecological vulnerability, tied with continued projected increases in ocean temperature,[2] could lead to wholesale community reorganization of kelp forests towards urchin barrens on the north-central California coast.[60]

Pteropod Vulnerability to Ocean Acidification in Olympic Coast National Marine Sanctuary

Pteropods are important links in the food chain of Olympic Coast National Marine Sanctuary and the West Coast more broadly, representing important prey for predators from forage fish to salmon.[66,67] As such, significant alterations to pteropod populations could alter food web dynamics and salmon productivity. Unfortunately, these small sea snails are highly susceptible to the impacts of ocean acidification.[67,68] While it is possible that pteropods could adapt to future conditions over time, they have shown little capacity for acclimation to acidified conditions, and the rapid rate of acidification projected for the West Coast may make adaptation difficult.[67] As such, these important zooplankton may even be at risk of local extinction in some parts of the West Coast, including Olympic Coast National Marine Sanctuary.[67] The exceptionally low aragonite saturation state of Olympic Coast National Marine Sanctuary waters during some parts of the year makes the sanctuary particularly susceptible to reductions or losses of pteropods.[67] These low aragonite waters have also been shown to be detrimental to Dungeness crab larvae in sanctuary waters[69] and could have negative impacts on other calcifying zooplankton, although such effects are highly species-specific. Given their importance to food web dynamics, significant declines or losses of pteropods and other zooplankton populations could lead to reduced productivity for salmon, and ocean food webs more broadly, if their production is not replaced by other adequate zooplankton prey.

Pteropods in Olympic Coast National Marine Sanctuary are highly vulnerable to ocean acidification. *Photo: NOAA*

A Cross-Region Collaboration to Address Climate Impacts

NOAA is committed to working collaboratively, sharing lessons learned, and leveraging expertise to address the impacts of climate change on coastal and marine resources, using the West Coast Region Climate Change Strategy. The Strategy identifies five goals and 22 objectives to increase the resilience of West Coast sanctuaries to climate change through increased awareness, collaboration, action, and leadership, and is informing climate change strategy throughout the National Marine Sanctuary System.

Climate change impact profiles have been completed for each sanctuary on the West Coast. These profiles are publicly available on the national marine sanctuaries website and their findings have been shared with all five sanctuary advisory councils. NOAA has also sought to improve the long-term climate-smart management of sanctuaries, in part through assessing and addressing their climate science and information needs.

NOAA is also providing educational opportunities for staff and members of the public on climate impacts; collaborating and sharing information on integrating climate change into site condition reports and supporting site climate vulnerability assessments and adaptation plans and focusing on carbon emissions from its operations, with recommendations for emissions reduction strategies to reach carbon neutrality.

Many iconic animals, such as this sea otter in Monterey Bay, could be affected by changes to the food web. *Photo: Douglas Croft*

Site-Specific Impacts

While this summary is an overview of the region-wide impacts of climate change, each site is, and will continue to experience local climate impacts. Summaries of site-specific climate impacts can be found in the climate change impacts profiles linked below.

- Olympic Coast National Marine Sanctuary Climate Change Impacts Profile
- Greater Farallones National Marine Sanctuary Climate Change Impacts Profile
- Cordell Bank National Marine Sanctuary Climate Change Impacts Profile
- Monterey Bay National Marine Sanctuary Climate Change Impacts Profile
- Channel Islands National Marine Sanctuary Climate Change Impacts Profile

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This profile was developed using the best available science as of the date of publication

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