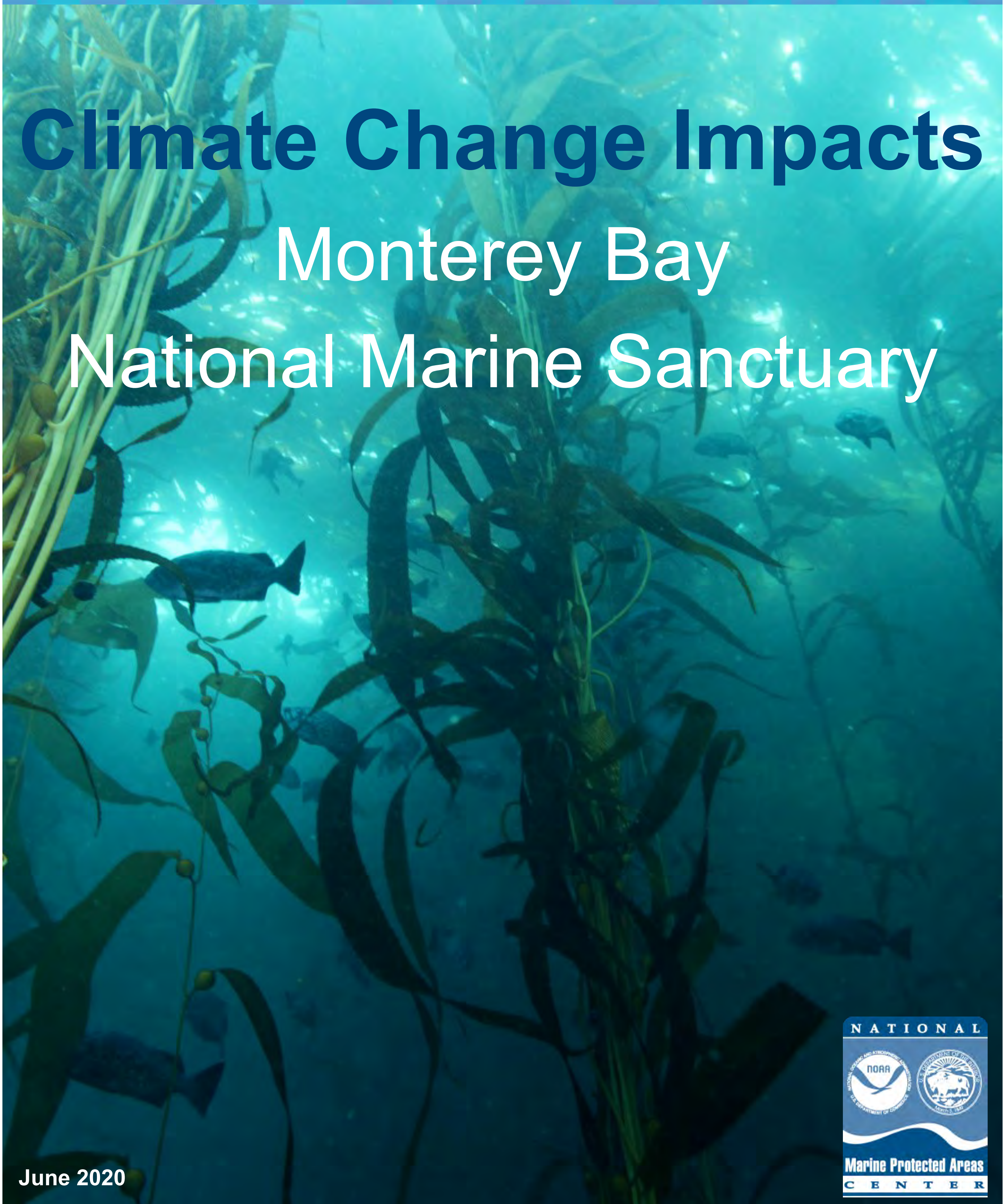
Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration



Climate Change Impacts

Monterey Bay National Marine Sanctuary

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Monterey Bay National Marine Sanctuary protects iconic species and the vibrant marine ecosystem of the central California coast. *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.

Monterey Bay National Marine Sanctuary

Monterey Bay National Marine Sanctuary stretches along 276 miles of coastline and extends an average of 30 miles offshore, protecting 6,094 square miles of ocean. Designated in 1992, the sanctuary protects vibrant and diverse ecosystems from extensive kelp forests to underwater canyons. Fueled by cool, nutrient rich waters rising from the deep, the sanctuary supports an incredible diversity of life including 36 species of marine mammals, more than 180 species of seabirds, hundreds of economically and ecologically important fish species, and some of the most iconic marine species and places in the country.

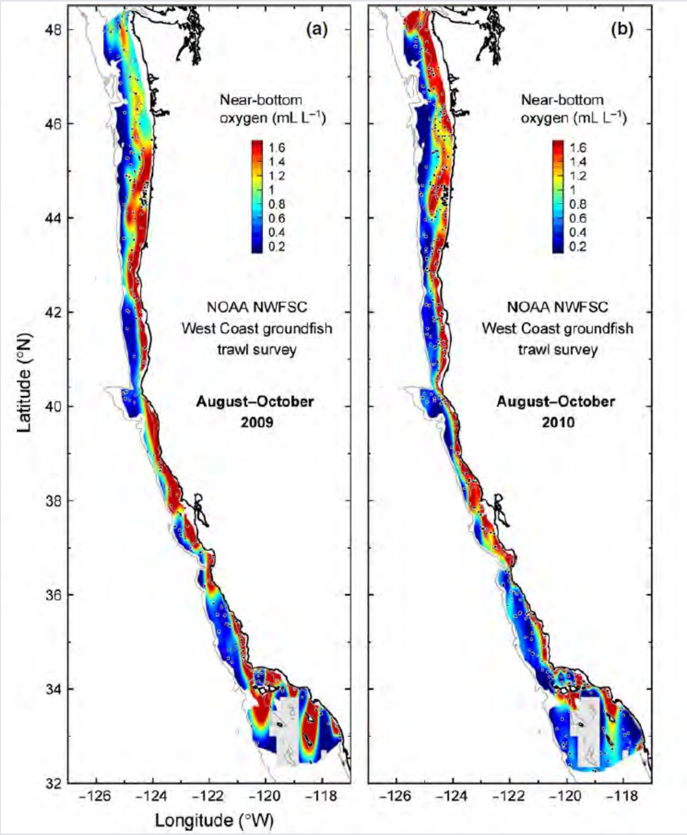
Rising Water Temperatures

As global atmospheric temperatures rise, average oceanic temperatures are also increasing worldwide.[1] Water temperatures in the sanctuary have risen slightly in the past century,[1,2] and offshore waters could warm 7°F by 2100.[3] In addition to rising average temperatures, marine heatwaves are expected to increase in frequency, duration, and intensity.[4]

Rising temperatures and marine heatwaves can cause mortality events of intertidal organisms, such as mussels and oysters, and may increase the incidence of sea star wasting disease.[5,6] Further, warmer waters hold less oxygen and may cause oxygen concentrations to fall below the range of natural variability by 2030,[7] reducing habitat for rockfishes[8] and negatively affecting deep water corals.[9] Warming waters may also reduce the survival and reproduction of kelp[10,11] and create conditions that are too warm for some deep water corals.[12] Warming may force species in the

Sea stars are just one of the many organisms that could be impacted by rising water temperatures. *Photo: Chad King/NOAA*

Case Study 1—California Coast Hypoxia



Low oxygen concentrations along the California coast in 2009 and 2010. *Photo: Keller et al. 2015*[26]

Low oxygen (hypoxic) conditions have become increasingly common on the coast of California in recent years.[26,27] Globally, ocean deoxygenation has already led to a 2% reduction in global ocean oxygen since 1960 and could reduce it a further 3-4% by 2100,[29] primarily due to warming ocean waters that hold less oxygen.[27,28] The concentration of oxygen in California waters is falling even faster than the global average.[1,29,30] Oxygen in California waters has decreased 20% since 1980[29,30] and could fall beyond the range of natural variability by 2030.[7] This rate of deoxygenation is partly due to the influence of upwelling, which brings deep water to the surface that is high in nutrients, low in oxygen, and more acidic than surface waters. Decreased ocean oxygen globally, and changes to the supply of oxygen to deep waters as a result of climate change, increase the risk of hypoxia in upwelling systems, such as the sanctuary, by producing upwelled water that is even lower in oxygen than in the past.[27,31] As climate change continues to cause increases in upwelling intensity[32,33] and reductions in global ocean oxygen,[8,31] the risk of low oxygen conditions on the California coast, and in the sanctuary, is likely to continue to grow.[27]

northern hemisphere to move north or to deeper, cooler waters.[13] Southern species like the volcano barnacle and Humboldt squid could become more common in the sanctuary,[14,15] while some species currently in the sanctuary may decline in number.[16] Warming could also lead to more frequent and intense harmful algal blooms (HABs),[17,18] which produce toxins that can harm humans and wildlife, causing mass mortalities of sea lions, whales, and other animals.[19,20]

Many impacts of warming waters were observed during the 2014-2016 marine heatwave known as "The Blob."[21] Water temperatures in the sanctuary reached 7.2°F above normal[14,21] causing southern species to move north,[14,15] fueling a large HAB,[22] and leading to reduced zooplankton prey.[14,22] These changes altered the food web, causing mass mortalities of seabirds and marine mammals,[14,22,23] while the HAB caused the early closure and delayed opening of the Dungeness crab fishery.[14,22] The Blob also drove a series of effects that led to massive declines in kelp in the region[14] and may be a good predictor of future conditions.[22]

Globally, increasing temperatures are the primary cause of sea level rise through melting glaciers and thermal expansion of seawater.[1] Rising waters could threaten coastal habitats in the sanctuary including the salt marshes of Elkhorn Slough,[24] which are important for coastal protection and carbon sequestration, and beaches that are critical nesting and haul-out habitat for mammals like northern elephant seals and sea birds like the threatened western snowy plover.[25]

Increasing water temperatures could create conditions that are too warm for some deep water coral communities. *Photo: MBARI/NOAA*

Case Study 2—Kelp Forests and Climate Change

Sea otters are one of the many species in the sanctuary that depend on kelp forests. *Photo: Steve Lonhart/NOAA*

The vibrant kelp forests of the sanctuary are home to hundreds of ecologically, economically, and culturally important species including rockfishes, abalone, and sea otters. Kelp forests also act as "blue carbon" habitats. As kelp grows, it stores carbon in its structures. As pieces of kelp break off, they can float up to 150 miles offshore[34] and sink to the deep ocean where their carbon can be buried for thousands or millions of years.[36] In the sanctuary, more than 100,000 tons of kelp can be transported through offshore canyons to the deep sea every year.[35,36] Globally, kelp and other macroalgae could sequester 200 million tons of carbon annually,[35] more than 35 times the annual emissions of San Francisco.[37]

While kelp may help mitigate climate change through carbon burial, it is not immune to its impacts. Warming waters can reduce kelp survival and reproduction[10,11] and kelp can be damaged by the strong waves associated with El Niño events,[7] which are projected to increase in frequency and intensity.[38] Kelp can also be impacted by ecological changes triggered by climate change.[39] In fact, anomalously warm waters from 2012-2016 appear to have contributed to a cascade of ecological events leading to the loss of 90% of the kelp canopy cover in some northern areas of the sanctuary.[39,40] This loss impacted species like rockfishes and sea otters and led to the closure of the valuable recreational red abalone fishery in 2018.[14] While climate change likely played a role in the kelp die off,[10,11] the immediate cause was a boom in purple sea urchin population. Ecological cascades, such as the sea urchin population boom and its impacts on kelp and other species, and other ecological changes, like shifting species, are likely to continue as the climate continues to change. These changes, together with other climate change impacts, could continue to alter kelp forest ecosystem functions and services.

The vibrant kelp forests of the sanctuary provide habitat for hundreds of species. *Photo: NOAA*

Ocean Acidification

Globally, the ocean has become 30% more acidic since the beginning of the industrial revolution.[41,42] Acidification in California waters is being further accelerated by upwelling. Cool, nutrient-rich upwelled water fuels the region's ecosystem but is also more acidic than surface waters. Upwelling intensity has increased in recent decades and is projected to continue to increase in the coming century.[32,33] As a result, California waters have increased in acidity by up to 60% since 1895 and could rise another 40% above 1995 levels by 2050.[43,44] By this time, large portions of the sanctuary's nearshore waters could be acidic enough to impair the growth of shell-forming animals.[44] Some locations already experience these conditions for up to 53% of the year and could experience them up to 68% of the year by 2100.[44] Further, projected increases in the frequency of extreme rain events[45,46] and a shift towards increased precipitation, such as rain in the Sierras,[47] could lead to more runoff of fresh water, which is more acidic than seawater.

Increasingly acidic waters make it difficult for animals to make and maintain shells and stony skeletons. Deep water corals are particularly susceptible as deep waters are naturally more acidic than surface waters and some areas may already be acidic enough slow their growth.[48] Further acidification could also reduce larval survival in Dungeness crab,[49] abalone,[50] and krill.[51]

Acidification also affects species without shells. Increasingly acidic waters could increase stress and decrease larval survival in rockfishes and other species.[8,52-55] Fishes, seabirds, and mammals can also be affected through their prey. More acidic waters could impact pteropods,[56] important prey for salmon, and other zooplankton prey with consequences for the entire food web from deep water corals and Dungeness crabs to seabirds and whales.[51,56,57]

The sanctuary protects a great diversity of life, much of which is impacted by climate change. Species IDs (top to bottom): Pinot abalone, opalescent nubranch, feeding humpback whales. *Photos: Steve Lonhart/NOAA; Steve Lonhart/NOAA; Douglas Croft*

Conversion from kelp forest to urchin barren is one of the ecological changes that has occurred in some parts of the sanctuary. *Photo: Steve Lonhart/NOAA*

Changing Ecological Communities

Climate change is creating ecological communities in many places that are different from those that existed in the past, largely as warming encourages species to move poleward.[13] These changes impact ecosystem functioning and services.[58]

Monterey Bay sits at an ecological transition zone that is the northern range edge of many warm water species. This makes the sanctuary vulnerable to future range shifts as waters warm. An increase in the dominance of warm water species like Humboldt squid is just one of the changes to ecological communities expected in coming decades.[59] Humboldt squid already expand into the sanctuary in warm years, where it preys on local species,[59] and could become more common as waters warm and low-oxygen conditions become more frequent.[60] A shift in zooplankton towards smaller, less-nutritious warm water species is also expected,[22] which could impact predators like marine mammals and seabirds.

Many of these changes occurred during The Blob marine heatwave. Economically valuable market squid, one of many species to shift further north than ever before,[15] moved into Monterey Bay in large numbers.[22] Further, warmer temperatures caused a shift in species composition towards smaller zooplankton, disrupting the food web,[14,22,23] and kelp die-off led to large areas of kelp forest being converted to urchin barrens.[39,40] Such changes to ecological communities are difficult to predict but are likely to continue as the climate continues to change.

Changing Oceanographic and Atmospheric Processes

Climate change is altering large-scale processes such as atmospheric circulation and El Niño. During El Niño events, the sanctuary experiences large waves, increased rainfall, reduced upwelling, and warmer water.[61,62] These effects could intensify in the future as the frequency and intensity of El Niño events are expected to increase.[38] The winds that drive upwelling are also expected to become stronger, increasing the frequency and intensity of upwelling, which could escalate ocean acidification.[32,33]

Black footed albatross and other predators, like whales and sea lions, could be affected by impacts to prey due to changing oceanographic processes. *Photo: Robert Schwemmer/NOAA*

Changes to atmospheric processes also affect the sanctuary. In 2013, an area of unusually high pressure south of the Gulf of Alaska led to the formation of The Blob.[62,63] In addition to causing abnormally warm waters, The Blob compressed upwelling, and the associated nutrients, closer to shore.[64] This and other changes led to low numbers of krill and high numbers of anchovy, which were found closer to shore.[64] Humpback whales followed the anchovy into Monterey Bay in 2016 and their foraging areas overlapped with fishing gear from the Dungeness crab fishery that was delayed by a HAB.[22,64] These events led to record levels of whale entanglement, demonstrating the cascading and interacting effects that can result from changing oceanographic and atmospheric processes.[64]

What is Being Done?

NOAA is addressing the impacts of climate change on Monterey Bay National Marine Sanctuary through regional collaboration and coordination, research, education, and outreach. NOAA is working closely with regional and local partners and governments to understand and prepare for the impacts of climate change including sea level rise and ocean acidification. NOAA has developed a west coast ocean acidification action plan which includes strategies for monitoring and researching ocean acidification as well as mitigating its impacts on sanctuary resources. NOAA is also actively working with partners and local governments to address the impacts of sea level rise on the iconic coast of Monterey Bay. This includes the development of sediment management plans and beach replenishment projects designed to reduce shoreline erosion now and in a future of higher sea levels.

Sanctuary staff and managers also actively participate in outreach and education with local and regional communities. NOAA incorporates climate change into its training of volunteers and its outreach and education materials and presentations. Through these efforts, NOAA is increasing public understanding and awareness of the impacts of climate change.

Northern elephant seals are just one of the many iconic species protected by the sanctuary. *Photo: Robert Schwemmer/NOAA*

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