Office of National Marine Sanctuaries
National Oceanic and Atmospheric Administration

Climate Change Impacts

Greater Farallones National Marine Sanctuary

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National Marine Protected Areas Center

Greater Farallones National Marine Sanctuary is home to a great diversity of life from tiny zooplankton to huge northern elephant seals. *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.

Greater Farallones National Marine Sanctuary

Greater Farallones National Marine Sanctuary protects wildlife, habitats, and cultural resources over an area of 3,295 square miles off the northern and central California coast. Designated in 1981, and expanded in 2015, the sanctuary protects one of the most diverse and bountiful marine environments in the world. From kelp forests to waters around the Farallon Islands, the sanctuary provides feeding and breeding grounds for at least 25 endangered or threatened species, including blue whales and black abalone, and habitat for 350,000 wintering shorebirds, seabirds, and water birds as well as many fish including halibut, salmon, and herring.

The Changing Coastline

Numerous factors contribute to rising global sea levels including melting glaciers and thermal expansion of seawater. Factors such as currents and changing land height cause sea level to rise at different rates in different locations.[2] In the sanctuary, sea level has risen 9 inches since 1854[3] and could rise by another 6 ft by 2100.[1,4]

Sea level rise increases coastal erosion and will eventually drown beaches and rocky intertidal habitats in the sanctuary. This could inundate critical pupping and haul-out habitat for mammals such as northern elephant seals and Steller sea lions as well as nesting areas for birds like the American bittern and the threatened western snowy plover.[5,6] In fact, 1.6 ft of sea level rise would permanently flood 5% of the Farallon Islands, reducing areas vital for seabird nesting and mammal haul-out.[5] Intertidal species like mussels, oysters, and algae are also likely to be impacted by coastal stressors. Projected increases in

The habitats of many species in the sanctuary, such as Steller sea lions, could be degraded by sea level rise. *Photo: Bob Wilson/NOAA*

Case Study 1—Impacts Report Update

NOAA's 2010 Climate Change Impacts Report was the first to systematically assess the impacts of climate change on its resources. The report identified 11 major climate impacts and trends. In the intervening decade, our understanding of climate change has advanced and predictions have been refined. While some trends identified in the 2010 report remain the same, many are accelerating faster than initially expected. The below table summarizes each of the major climate trends from the original report and identifies if the trend remains the same (↔) or has been adjusted upward (↑). Other changes projected in the report have already been, or are being, observed and are expected to increase (⇑). None were adjusted downward. Detailed information on trends can be found throughout this report.

Climate Trend from 2010 report	Change since 2010 report	Source
Up to 75 inches sea level rise by 2100	↔	4
Increase in coastal erosion due to changes in sea level and storm waves	↔	7
Decrease in Spring runoff due to decreases in Sierra snowpack	↑	57
Increased precipitation variability with dryer dry years and wetter wet years	⇑	14,15, 60
Increase in sea surface temperature offshore and on the continental shelf	↑	34
Increase in winds driving upwelling and associated decrease in surface temperature over continental shelf	↔	35,36
Increase in extreme weather events	↔	7,14, 15,60
Decrease in seawater pH	↑	65,72
Northward shift in key species	⇑	40,48
Shift in dominant phytoplankton (from larger to smaller)	⇑	40
Climate impacts compounded by other human impacts	↔	

the intensity of storms and waves[7,8] could reduce the ability of these organisms to stay attached; rising waters may increase exposure to aquatic predators such as sea stars; and rising air temperatures may limit the ability of these organisms to move higher in the intertidal zone, narrowing available habitat.

Rising sea level also has the potential to threaten tidal marshes within the sanctuary. Salt marshes, like those in Tomales Bay, are important habitat for many species and provide ecological services like coastal protection and carbon sequestration.[9-12] These vibrant ecosystems sit at the interface of the land and ocean and depend on a steady supply of sediment from land to keep up with rising sea levels. Altered precipitation patterns, such as changes in snowpack, [13] more intense storms, and increases in the frequency and intensity of both extreme wet and extreme dry events,[14,15] could alter the amount and timing of sediment delivered to tidal marshes in the sanctuary. Partly due to these projected changes in sediment supply, tidal marshes may be unable to keep up with the expected rate of sea level rise.[16,17] In fact, tidal marshes in Bolinas Lagoon and elsewhere in the sanctuary could be completely lost by 2110 under extreme sea level rise projections.[16] Yet, if marshes are allowed to migrate up shore, as proposed in the sanctuary's 2016 climate adaptation plan,[18] a large portion of these important ecosystems could be saved, even under extreme sea level rise.[16]

Threatened western snowy plover depends on beaches that could be degraded or destroyed by climate-driven changes. *Photo: USFWS*

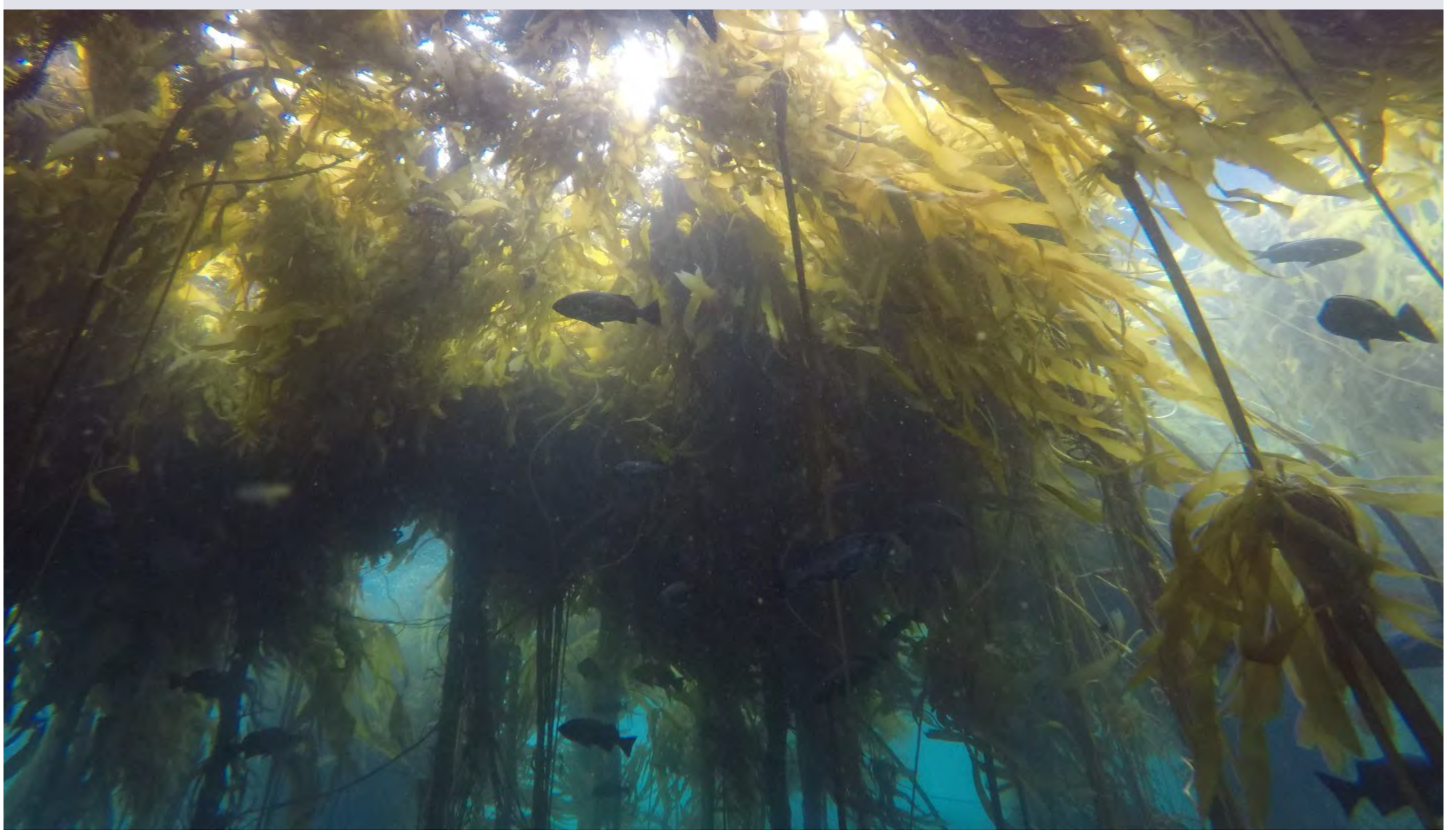
Case Study 2—"Blue Carbon" and Climate Change

Elelgrass beds are vibrant ecosystems that also act as important blue carbon habitats within the sanctuary. *Photo: George Clyde*

Within the sanctuary, plants such as eelgrass and salt marsh grasses collect carbon in their leaves, stems, and roots. When these plants die, some of this material is buried in the soil, where it can stay for hundreds or thousands of years.[12,19,20] In this way, these "blue carbon" ecosystems pull carbon out of the atmosphere. Globally, blue carbon ecosystems could sequester 866 million tons of carbon per year,[20] more than double the annual emissions of California.[21] While plants have mostly been identified as sources of blue carbon, there is growing recognition that soil and ocean animals also contribute to carbon storage and sequestration.[22-24]

The sanctuary is a reservoir of blue carbon habitats such as eelgrass and salt marshes, which collect and store carbon in sediments,[12,20] as well as kelp.[19] As pieces of kelp break off, they can float up to 150 miles offshore[25] and sink to the deep ocean where their carbon can be stored for thousands or millions of years.[19] In the region of the sanctuary, more than 100,000 tons of kelp can be transported through offshore canyons to the deep-sea every year.[19,26] Globally, kelp and other macroalgae could sequester 200 million tons of carbon annually,[19] more than 35 times the annual emissions of San Francisco.[27]

While plants and algae may help mitigate climate change, blue carbon ecosystems are not immune to its impacts. Further, their disturbance or destruction could release stored carbon.[28,29] Sea level rise may drown tidal marshes and eelgrass beds[16,30] and warming waters threaten kelp reproduction.[31] Anomalously warm waters from 2014-2016 caused a cascade of events resulting in the loss of 90% of the region's kelp canopy cover.[32] Such climate impacts could alter the ability of blue carbon ecosystems to store carbon in the future.



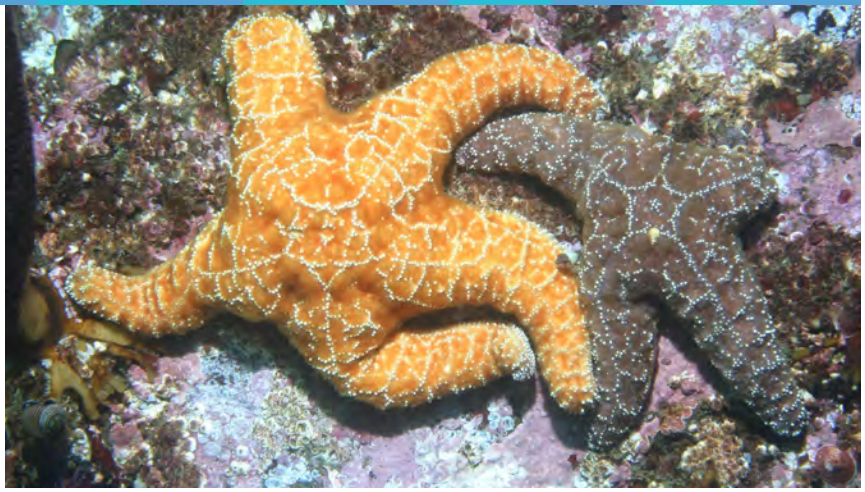
The kelp forests in the sanctuary are important blue carbon habitats and vibrant ecosystems. *Photo: Steve Lonhart/NOAA*

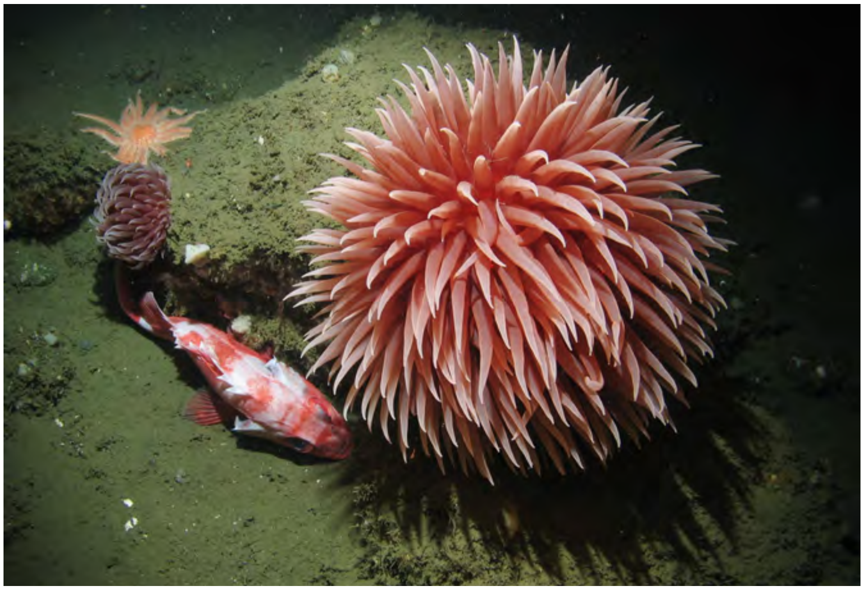
Changing Ocean Temperatures

As global temperatures rise, the average ocean temperature is increasing world wide.[1] Water temperatures in the sanctuary have increased slightly over the past century,[1,33] and offshore waters could warm 7°F by 2100.[34] Nearshore waters have cooled slightly, due to increased upwelling of cool deep water,[5] and are expected to warm but remain cooler than offshore waters in the coming decades.[35,36]

Warming waters hold less oxygen and could fall below the range of natural variability by 2030,[37] reducing habitat for species like rockfish.[38,39] Higher temperatures can also cause shifts to smaller and less nutritious phytoplankton,[40] increase sea star wasting disease,[41,42] and lead to more frequent and more intense harmful algal blooms (HABs).[43,44] HABs produce toxins that can harm wildlife, causing mass mortalities of sea lions, whales, seabirds, and other animals.[45,46] Warming also encourages species to move to northern or deeper, cooler waters,[47] and could cause some species to decline in number.[48] Southern species like volcano barnacle and Humboldt squid could become more common in the sanctuary.[49]

Many impacts of warming waters were observed during the 2014-2016 marine heatwave known as "The Blob."[50] Water temperatures in the sanctuary reached 7.2°F above normal[49,50] causing many southern species to move northward,[48] fueling a large HAB,[40] and leading to reduced zooplankton prey.[40,48] These changes altered the food web, causing mass mortalities of seabirds and marine mammals.[40,49,51] The Blob also drove a series of effects that led to massive declines in kelp in the region, negatively impacting abalone,[48] while the HAB caused the early closure and delayed opening of the Dungeness crab fishery.[40,49] Marine heatwaves are expected to increase in frequency and intensity,[52] and The Blob may be a predictor of future conditions.[40]





Many species in the sanctuary could be impacted by increasing water temperatures. Species IDs (top to bottom): Ochre sea stars, blackgill rockfish and pom pom anemone, black abalone. *Photos: Steve Lonhart/NOAA; NOAA; NOAA.*

Beaches in the sanctuary may be at risk from increased erosion as a result of stronger storms. *Photo: Matt McIntosh/NOAA*

Changing Weather and Storms

In the region of the sanctuary, winter storms have increased in frequency and intensity since 1950.[5,53] However, changes to atmospheric circulation are expected to move future storms north, reducing the number to hit the region.[54,55] While the total number of storms may decrease, their strength is expected to increase,[1,56] and years with many storms are projected to become more common.[7] Strong waves driven by these storms cause coastal erosion, exacerbating sea level rise impacts.[5,7,8]

Climate change is also altering precipitation. Snowpack in the Sierras has declined in recent decades[57,58] and areas historically dominated by snow could receive only rain by 2050.[59] Increases in the frequency and intensity of both extreme rain and dry events are also expected,[14,15] as well as more rapid transitions between wet and dry years.[60] The shift from snowpack to rain-dominated runoff, along with increases in extreme wet and dry events, could alter the timing and intensity of runoff and sediment into the sanctuary, impacting organisms that depend on streamflow, such as salmon, and ecosystems like marshes that require a steady sediment supply to keep up with sea level rise.

Weather in the sanctuary is also impacted by El Niño, which often exacerbates climate impacts by bringing large waves, occasionally wet conditions, reduced upwelling, and warmer water.[61,62] These effects could intensify as the frequency and intensity of El Niño events are expected to increase in the coming century.[63]

Ocean Acidification

Since the beginning of the industrial revolution, ocean waters globally have become 30% more acidic.[64,65] Acidification in the sanctuary is being further accelerated by upwelling. Cool, nutrient-rich upwelled water fuels the sanctuary'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.[34,35] As a result, California waters have increased in acidity by up to 60% since 1895 and could increase 40% above 1995 levels by 2050.[66,67] Portions of the sanctuary's nearshore region are already acidic enough to impair the growth of shell-forming animals.[68,69] Some locations experience these conditions for up to 55% of the year and could experience them up to 70% of the year by 2100.[69]

Deep sea corals provide habitat for many species in the sanctuary but may be threatened by the impacts of ocean acidification. *Photo: NOAA*

Increasingly acidic waters make it difficult for organisms like coral and mussels to make and maintain their shells and stony skeletons. Deep-sea corals are particularly susceptible as the deep waters where they live are naturally more acidic than the surface.[70] Further, Dungeness crab could experience reduced larval survival[71] and species from salmon and crabs to otters and whales could be indirectly affected through impacts on prey.[72,73]

A Leader in a Changing Ocean

Greater Farallones National Marine Sanctuary provides a globally important example of how climate change can be successfully integrated into marine protected area management. Through the Center for Collaboration on Ocean Climate, a partnership with the Greater Farallones Association, NOAA has become a leader in ocean climate change assessment and adaptation. In 2016, NOAA published its Climate Adaptation Plan, which built on the results of the 2010 Climate Impacts Report and 2015 Climate Vulnerability Assessment. Sanctuary staff are also doing their part to mitigate climate change by evaluating and working to reduce their emissions.

In addition to working to mitigate, assess, and adapt to the impacts of climate change in California, NOAA has embraced its role as a national and global leader in sharing information and training other marine protected area managers on how to address climate change impacts. The sanctuary's leadership and accomplishments have been recognized through partnerships with the North American Commission for Environmental Cooperation and featured at the United Nations Convention on Climate Change Conference. By working at the local, state, national, and global levels, the sanctuary highlights marine protected areas as important tools for addressing climate change.

The staff and researchers of Greater Farallones work to understand the effects of climate change and share adaptation strategies. *Photos: NOAA*

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