DEPARTMENT of ENVIRONMENTAL SCIENCE, POLICY, AND MANAGEMENT

Chimney Rock overlook at Point Reyes National Seashore (photo S. Wakamiya)

Anthropogenic Climate Change in Point Reyes National Seashore, California, USA

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Summary

Global climate change, caused by human greenhouse gas (GHG) emissions, has led to extensive physical, biological, and societal impacts. To support Point Reyes National Seashore (NS) with science-informed management of the park's natural resources, this climate change assessment presents the results of a scientific literature review of historical climate change trends, impacts, future risks, and carbon solutions with a direct focus on research conducted in the park region. Within Point Reyes NS, average annual temperature from 1950 to 2010 increased at statistically significant rates of 1.3 ± 0.5℃ per century, with the greatest rates of increase occurring in the spring. During the same time period, there were no statistically significant changes in total annual precipitation. Published analyses of field data record several observed changes in the park region that have been attributed to anthropogenic climate change, including sea level rise of ~17-20 cm (7-8 in.) from 1900-2020, decrease of surface-ocean pH by 0.08 ± 0.03 in the California current system since ca. 1750, and maximum dissolved oxygen reduction of 39.9% near the northern central California coast. The four Representative Concentration Pathways (emissions scenarios) of the Intergovernmental Panel on Climate Change that are discussed in this report are RCP2.6 (reduced emissions; assumes strong immediate GHG reduction), RCP4.5 (low emissions), RCP6.0 (high emissions; assumes an increase then stabilization of GHG emissions), and RCP8.5 (highest emissions; assumes GHG emissions continue to increase without reductions). By 2100, under RCP8.5, the average annual temperature in Point Reyes NS is projected to increase by 3.7 ± 0.8 ℃ and total annual precipitation is projected to increase by 7 ± 17%, although aridity may still increase due to higher temperatures. Continued climate change could increase risks to ecosystems within the park, including vegetation shifts, increased frequency of wildfires, potential extirpation of climate-sensitive bird species, and reduced coastal habitat for birds and pinnipeds due to sea level rise. However, the park can help naturally mitigate climate change by storing carbon in coastal forests, chaparral, grasslands, and estuary eelgrass. Energy, waste, transportation, and agricultural activities contribute significantly to the park's GHG emissions, highlighting management-based ways Point Reyes NS can reduce human emissions that cause climate change.

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Introduction

Climate change is caused by greenhouse gasses emissions from transportation, agriculture and land-use change, and industrial processes among other human activities (IPCC 2021). Research shows that anthropogenic climate change has significantly affected ecosystems and human welfare by intensifying disturbances, raising sea level, contributing to biodiversity loss, and causing other consequences at global, national, and regional scales (IPCC 2021). In particular, climate change is affecting the national parks at a disproportionate rate compared to the rest of the United States due to their unique geography (Gonzalez et al. 2018).

To combat the effects of climate change, national parks are developing strategies for ecosystem management and conservation. The objective of this climate change assessment report is to assist Point Reyes National Seashore with the management of natural resources and wildlife under progressing climate change. This report synthesizes published results of historical and projected climate trends, ecological impacts, future risks to ecosystems, and carbon-based solutions specific to Point Reyes National Seashore.

Location Description

Point Reyes National Seashore, located on the Point Reyes Peninsula in Marin County, California, was established in 1962 as one of ten national seashores. It is the only national seashore on the west coast and features a unique combination of coastal dunes, estuaries, and coniferous forests. These varied habitats support a wide range of species from endemic plants to endangered marine and terrestrial animals, such as the western snowy plover, coho salmon, and tule elk. Common native species found at Point Reyes NS include Douglas fir, Bishop pine, coast live oak, northern elephant seals, and western snowy plover. There are also several endemic species, including the Point Reyes rein-orchid, Point Reyes mountain beaver, and Mount Vision ceanothus. The park's Mediterranean climate is characterized by cool, wet winters and dry but foggy summers. Within the park, there are more than 300 historic structures and a variety of archaeological resources linked to the

Coast Miwok. There is also an extensive history of ranching and dairy farms that have been present within Point Reyes NS for over 150 years—well before the area became a national park. These private ranches and farms still operate today with permission from the National Park Service. The park attracts over two million visitors annually, generating a local revenue of approximately $90 million.

Observed Climate Trends

Changes detected in the region and attributed to anthropogenic climate change

Published research that includes data from northern California and the Pacific Ocean off the coast of northern California has detected changes that are statistically significantly different from natural variation. The cause of those changes has been attributed to anthropogenic climate change more than other factors.

Temperature Average annual temperature significantly increased by 0.9 ± 0.2℃ per century (mean ± standard error) in the period 1895-2010 and 1.3 ± 0.5℃ per century in the period 1950-2010 for the area of Point Reyes NS (Figure 1) (Gonzalez et al. 2018). Temperatures increased at the highest rates in the autumn for the 1895-2010 period and in spring for the 1950-2010 period (Table 1). Overall, monthly temperatures increased at statistically significant rates for nine months since 1895 and for five months since 1950 (Table 1).

Precipitation Total annual precipitation in Point Reyes for the periods of 1895-2010 and 1950-2010 did not show significant trends, with slight increases over the shorter time period and slight decreases over the longer time period (Figure 2) (Gonzalez et al. 2018). For the period 1950-2010, only the month of May showed a significant change in precipitation, with an increase of 183 ± 91% per century (mean ± standard error) (Table 2). In general, total annual precipitation decreased in most of the area of Point Reyes (Gonzalez et al. 2018).

Drought Anthropogenic warming is increasing the probability of warm-dry conditions that creates droughts (Williams et al. 2015). Climate change accounted for 8–27% of the observed California drought during 2012-2014, which led to the most severe moisture deficits in the last 1,200 years (Williams et al. 2015, Ackerly et al. 2018). Paleoclimatic records show that longer periods of drought have occurred in California's history (Malamud-Roam et al. 2007, Cook et al. 2015). Marin County and Point Reyes NS, in particular, have experienced two severe droughts since 2013 (NPS 2022).

Sea surface temperature California coastal ocean temperatures have warmed significantly over the last century due to climate change (OEHHA 2022). Data from a Farallon Islands temperature gauge indicates that climate change has increased sea surface temperature in the region of Point Reyes NS by 0.05 ℃ per decade in the time period of 1925-2020, but this change was not statistically significant (OEHHA 2022). Currently, there is no published work on historical sea surface temperature changes within the boundaries of Point Reyes NS.

Marine heatwaves The frequency of marine heatwaves, periods of significantly high regional ocean surface temperatures, has increased by more than 20-fold due to anthropogenic global warming (Laufkotter et al. 2020). A quantitative assessment of greenhouse gas forcing showed that anthropogenic forcing by elevated greenhouse gas levels has caused the persistent 2019-2021 marine heatwave in the North Pacific (Barkhordarian et al. 2022). During 2014–2016, the California coast, along with the broader northeast Pacific experienced a period of unusually high ocean temperatures (>2°C above average levels) associated with an El Niño event (Sanford et al. 2019, Gentemann et al. 2016). This anomaly was characterized as the largest marine heatwave on record and contributed to marine animal strandings, toxic algal blooms, and declines of fisheries and kelp forests (OEHHA 2022).

Ocean acidification Oceans are absorbing an increasing amount of carbon dioxide from the atmosphere, which dissolves in water to form carbonic acid and increases the acidity of the ocean (Feeley 2016). The global ocean has absorbed approximately 26% of anthropogenic carbon dioxide emissions (Friedlingstein et al. 2022), of which, approximately 38% lies in the Pacific Ocean (Carter et al. 2017). Globally, ocean water pH has decreased by 0.1 pH units since the Industrial Revolution (1750), which corresponds to a 30% increase in acidity (IPCC 2021). Model simulations show that the annual mean surface-ocean pH decreased from 8.12 ± 0.03 to 8.04 ± 0.03 for the whole California Current System during the period 1750-2005 (Gruber et al. 2012).

Ocean deoxygenation Dissolved oxygen is necessary for respiration in aquatic and marine organisms. As water temperature increases, the solubility of oxygen decreases, which can lead to dangerously low levels of dissolved oxygen (Levin 2018). The Intergovernmental Panel on Climate Change has attributed ocean deoxygenation to climate change (IPCC 2021). Although there is no published work measuring dissolved oxygen levels over time in Point Reyes NS, studies have been conducted for the Central California Current, which includes the region of the park. Hydrographic cruises in Monterey Bay, California showed that oxygen decreased between 250 and 400m depths during the period 1998-2013, with a dramatic 39.9% decline in oxygen at one isopycnal (Ren 2016).

Changes consistent with, but not formally attributed to anthropogenic climate change

Other published research has recorded changes that are consistent with but not attributed to anthropogenic climate change because the changes are not statistically significantly different than natural variations or potential causal factors have not been analyzed to make a formal attribution.

Fog reduction Analysis of a long-term index of daily maximum land temperatures as an indicator of fog in Northern California suggests a 33% reduction in summer fog frequency since mid-century (Johnstone and Dawson 2010). Several studies indicate that observed fog reductions in coastal California and elsewhere are consistent with climate change, but are also synergistically influenced by factors such as high-pressure winds, Pacific Decadal Oscillation, arctic-cooled ocean currents, and urbanization (Lakra and Avishek 2022, Torregrosa et al. 2014, Bokwa et al. 2018).

Observed Ecological Changes and Impacts

Changes detected in the region and attributed to anthropogenic climate change

Published research that includes data from northern California or the Pacific Ocean off the coast of northern California has detected changes that are statistically significantly different from natural variation. The cause of those changes has been attributed to anthropogenic climate change more than other factors.

Wildfire Increases in fire weather season length in the U.S. over the last several decades are attributed to earlier snowmelt and warming-driven increases in vapor pressure deficit (Jolly et al. 2015). Areas with significant changes in fire season length occur where changes in temperature, humidity, drought, and wind speeds are most prominent (Jolly et al. 2015). Across western U.S. forests, anthropogenic climate change has accounted for approximately 55% of increases in fuel aridity from 1979 to 2015 (Abatzoglou and Williams 2016). Anthropogenic climate change is estimated to have contributed to an increase in western U.S. forest fire area by 4.2 million ha during 1984–2015 (Abatzoglou and Williams 2016). Evidence from charcoal data collected from Point Reyes NS and historical tree ring data from the Western U.S. show that wildfire occurrences over the past three millennia are explained by variations in temperature and drought (Marlon et al. 2012). Notable fires that have burned through Point Reyes NS include the 1995 Mount Vision Fire and the 2020 Woodward Fire, which burned close to 12,000 and 5,000 acres respectively. The combination of dry vegetation and record-breaking high temperatures consistent with climate change contributed to the circumstances of the Woodward fire ignition, but the fire was not solely caused by climate change (O'Gallagher et al. 2021).

Bird range shifts National bird count data, including count circles in Point Reyes NS showed that 254 bird species shifted their winter ranges northward at an average rate of 0.5 ± 0.3km per year from 1975 to 2004 due to a combination of climate change and regional factors, but this change was attributed more to anthropogenic climate change than local human factors (La Sorte and Thompson 2007). Additionally, analysis of the distribution of western North America raptor species showed that six species found within Point Reyes NS (American kestrel (*Falco sparverius*), golden eagle (*Aquila chrysaetos*), northern harrier (*Circus cyaneus*), prairie falcon (*Falco mexicanus*), red-tailed hawk (*Buteo jamaicensis*), and rough-legged hawk (*Buteo lagopus*) had significant poleward shifts in their winter distributions between 1975-2011 (Paprocki et al. 2014).

Sea level rise The rate of global sea level rise has been increasing over the last century due to anthropogenic climate change (IPCC 2021). Global mean sea level reconstruction shows that the increased rate of sea-level rise since the 1970s is caused by the combination of thermal expansion and increased ice-mass loss (Frederikse et al. 2020). Anthropogenic forcing from the balance between greenhouse gasses and partial offsets by anthropogenic aerosols contributed to 69 ± 31% of global mean sea level rise after 1970 (Slangen et al. 2016). Increases in sea level rise along the California coast have been observed at 0.10-0.20 cm (0.04-0.08 in.) per year due to climate change (OEHHA 2022). A San Francisco tidal gauge measured sea level rise of approximately 17.78-20.32 cm (7-8 in.) over the 20th century (Figure 3) (OEHHA 2018, NOAA 2017). Between 1975-2016, sea level increased by 0.20 cm (0.08 in.) per year at Point Reyes NS (OEHHA 2018, NOAA 2017).

Changes consistent with, but not formally attributed to anthropogenic climate change

Other published research has recorded changes that are consistent with but not attributed to anthropogenic climate change because the changes are not statistically significantly different than natural variations or potential causal factors have not been analyzed to make a formal attribution.

Tule elk Tule elk populations in Point Reyes NS are fluctuating in numbers and changing habitat selection in response to worsening drought conditions consistent with climate change (Bernot and Press 2018, Mohr et al. 2022). In 2013 and 2014 numbers of tule elk in Tomales point declined dramatically due to extreme drought conditions that altered the distribution and availability of water and forage (Bernot and Press 2018, Mohr et al. 2022). On the outer coast at Point Reyes NS, precipitation drives forage availability, which strongly affects tule elk herd productivity. Tule elk were found to localize around water sources and areas with greater forage abundance (Bernot and Press 2018, Mohr et al. 2022). From the early summer to late fall of 2021, the National Park Service provided supplemental water troughs for tule elk at Tomales Point due to unprecedented and extreme drought conditions (NPS 2022). However, climate change is an indirect effect on tule elk populations and other effects, such as disease and human development continue to persist (Bernot and Press 2018).

Endangered fish Tidewater goby (*Eucyclogobius newberryi*), coho salmon (*Oncorhynchus kisutch*), and steelhead trout (*Oncorhynchus mykiss*) occupy wetland, estuary and stream habitats in Point Reyes NS and are protected by the Endangered Species Act. Coho salmon monitoring in the San Francisco Bay Area indicated that juvenile fish health was affected by factors consistent with climate change (NPS 2022). Increasing average water temperatures in creek habitats sparked algae

growth that lowered oxygen levels essential to the survival of coho salmon (NPS 2022). Additionally, increased ocean temperatures and ocean acidification resulted in less nutritious plankton that salmon (an anadromous fish) need to grow (NPS 2022).

Field studies at 18 estuaries along the California coast, including Elkhorn Slough in Point Reyes NS, showed that tidewater gobies that experienced warmer temperatures had shorter larval durations, faster growth rates, and were smaller at settlement (Spies and Steele 2016). Although climate change was not a direct factor influencing the health of tidewater gobies, increased water temperatures are consistent with climate change.

Projected Climate Trends

Temperature Analysis of general circulation models show that, by 2100, average annual temperature (℃ per century) is projected to increase by 1.6 ± 0.7 (mean ± standard deviation) in a reduced emissions scenario and 4.9 ± 1 in the highest emissions scenario in U.S. national parks within the contiguous states (Gonzalez et al. 2018). Within Point Reyes NS, the average annual temperature (℃ per century) is projected to increase less—either 1.4 ± 0.6 in a reduced emissions scenario, 2.1 ± 0.6 in a low emissions scenario, 2.4 ± 0.7 in a high emissions scenario, or 3.7 ± 0.8 in the highest emissions scenario (Table 3) (Gonzalez et al. 2018). Reducing GHG emissions to meet the goals of the Paris Agreement could reduce projected warming by three-fifths.

Precipitation General circulation models project an increase in precipitation for the U.S. national park area. For national parks within the contiguous states, annual precipitation (% per century) is projected to increase by 6 ± 8 (mean ± standard deviation) in a reduced emissions scenario and 7 ± 17 in the highest emissions scenario (Gonzalez et al. 2018). Within Point Reyes NS, total annual precipitation (% per century) is projected to increase either 5 ± 11 in a reduced emissions scenario, 5 ± 9 in a low emissions scenario, 7 ± 13 in a high emissions scenario, or 10 ± 16 in the highest emissions scenario (Table 4) (Gonzalez et al. 2018).

Drought Future temperature increases may cause more prolonged and intense drought in California, regardless of changes in precipitation (Ackerly et al. 2018, Wehner et al. 2017). Two types of general circulation models project an increase in climatic water deficit ranging from 0.5-1.5 standard deviations of current values for northwestern California regions, resulting in more arid conditions in this area by 2100 (Thorne et al. 2015). California drought scenarios produced by downscaled meteorological and hydrological simulations project spring and autumn precipitation could decrease by up to 20% and moisture deficits could increase over much of the state by 2070 under a high emissions scenario. The projected 2051-2070 dry spell under the RCP8.5 scenario would be 78% of historical median annual precipitation averaged over the North Coast and Sierra California Climate Tracker regions (Pierce et al. 2018).

Sea surface temperature Global sea surface temperature is projected to increase between 1995-2014 and 2081-2100 on average by 0.86℃ in a reduced emissions scenario and 2.89℃ in the highest emissions scenario (OEHHA 2022, IPCC 2021). Model simulations for the California current marine ecosystem under the highest emissions scenario project an increase of 0.36 ± 0.62℃ per decade for the period 2070-2099, with projected warming trends generally larger in summer than winter (Alexander et al. 2018).

Marine heatwaves Suites of global climate models project increases in the intensity and duration of marine heatwaves in most regions globally, including the region of Point Reyes NS (Oliver et al. 2019). Additionally, an assessment of future changes in global marine heatwaves using coupled global Earth system models found that the number of marine heatwave days is projected to increase on average by a factor of 16 for 1.5℃ of warming and by a factor of 23 for 2℃ of warming (Frölicher et al. 2018). However, there are no published studies that quantify changes in marine heatwave events for the region of Point Reyes NS.

Ocean acidification By 2100, surface ocean pH is expected to decline by another 0.3–0.4 units under the highest emissions scenario (Gattuso et al. 2015, IPCC 2021). As ocean waters become more acidic, the concentration of calcium carbonate minerals including aragonite decreases. By 2050, seafloor habitats along the California coast are projected to experience year-round aragonite undersaturation, which will negatively affect the survival of calcifying organisms (Gruber et al. 2012).

Ocean deoxygenation Under the highest emissions scenario, ocean models project a rapid decline of dissolved oxygen in the northeastern Pacific Ocean in the 2030s due to anthropogenic climate change (Figure 4) (Phillips et al. 2018). For the California Current Ecosystem, there is a projected 18% decrease in oxygen concentration by 2100 (Rykaczewski and Dunne 2010). Earth system models project increased stratification along with a weakening and poleward shift in westerly winds for the North Pacific, which increase nitrate concentrations and reduce dissolved oxygen concentrations of deep source waters entering the California Current System (Rykaczewski and Dunne 2010).

Future Risks

Vegetation shifts Probabilistic vegetation models of major vegetation types across the San Francisco Bay Area projected that sensitivity of vegetation to climate change is higher closer to the coast (Ackerly et al. 2015). Under higher climatic water deficits due to climate change, grassland and montane and coniferous forests are projected to decline while shrublands and oak woodlands expand (Ackerly et al. 2015). For vegetation types in Point Reyes NS, the fraction of chamise chaparral is projected to increase with temperature and Bishop pine and Douglas fir fractions are projected to decrease with temperature (Figure 5) (Ackerly et al. 2015).

Rare plants Coastal areas such as Point Reyes NS are found to support rare plant species due to their cool, aseasonal climates and high soil heterogeneity (Anacker et al. 2013). A climate change vulnerability assessment of 156 rare plant species in California using life history attributes and species distribution models found that 99 were vulnerable to climate change (Anacker et al. 2013). Of these 99 rare species, 13 are found in Point Reyes NS: Blasdale's bent grass (*Agrostis blasdalei*), Marin manzanita (*Arctostaphylos virgata*), coastal bluff morning-glory (*Calystegia purpurata ssp. saxicola*), Franciscan thistle (*Cirsium andrewsii*), Marin checker lily (*Fritillaria lanceolata var. tristulis*), fragrant fritillary (*Fritillaria liliacea*), blue coast gilia (*Gilia capitata ssp. chamissonia*), short-leaved evax (*Hesperevax sparsiflora var. brevifolia*), Marin western flax (*Hesperolinon congestum*), coast lily (*Lilium maritimum*), marsh microseris (*Microseris paludosa*), Point Reyes checkerbloom (*Sidalcea calycosa ssp. rhizomata*), and San Francisco owl's clover (*Triphysaria floribunda*) (NPS 2012).

Wildfire Climate change directly influences wildfire by favoring conditions that can lead to fire occurrence such as drought, higher temperatures, and winds over a longer fire season. Fire activity will also be indirectly influenced by changes in vegetation and human activity

(Bryant and Westerling 2012). The frequency of extreme wildfires in California is projected to increase by 50% under a high emissions scenario. By 2085, climate change is projected to increase statewide wildfire burned area by 48-94% (mean = 77%) under a high emissions scenario, particularly in forested areas of the state (Westerling et al. 2011, Westerling 2018). Global climate models project an increase of wildfire risk for the region of Point Reyes Seashore under both a low emissions and high emissions scenario (Bryant and Westerling 2012).

Birds A vulnerability assessment of 358 sensitive vertebrate taxa included numerous bird species found in Point Reyes NS as highly vulnerable to drought and climate change (California Department of Fish and Wildlife 2016). Summer climate suitability in Point Reyes NS is projected to improve for 43 species, remain stable for 46, and worsen for 39 under a high-emissions scenario (Wu et al. 2018). Likewise, winter climate suitability is projected to improve for 49, remain stable for 73, and worsen for 59 species (Figure 6). By 2050, potential extirpations are projected for 29 species in the summer season and 24 species in the winter season, including 8 species that are highly climate sensitive (Wu et al. 2018).

Climate suitability is projected to worsen for threatened and endangered species in Point Reyes NS including the marbled murrelet (*Brachyramphus marmoratus*), brown pelican (*Pelecanus occidentalis*), and willow flycatcher (*Empidonax traillii*) (Wu et al. 2018). Additionally, the threatened western snowy plover is vulnerable to losing habitat as sea level rise threatens to inundate more of its coastal habitat (Hutto et al. 2015). Furthermore, climate in Point Reyes NS is projected to become suitable for a number of species in summer and winter, resulting in local colonization (Wu et al. 2018).

Sea level rise Approximately half of the Point Reyes NS shoreline shows high vulnerability to sea level rise based on an assessment of sea level change, mean wave height, geomorphology, historical shoreline change, regional coastal slope, and mean tidal range (Figure 7) (Pendelton et al. 2010). Additionally, sea level rise is projected to account for substantial increase in wetlands within Point Reyes (Heberger et al. 2009). By 2100, sea level rise is projected to increase either 0.36-0.82 m (1.2-2.7 ft) (RCP4.5) or 0.48-1.04 m

(1.6-3.4 ft) (RCP8.5) in the region of Point Reyes NS and there is a 70% probability that sea level rise will meet or exceed 0.6 m (Figure 8) (Griggs et al. 2017). Furthermore, as a consequence of sea level rise in concert with more severe tides, 84% of sandy beaches and mudflats and 69% of coastal dunes in Point Reyes NS fall within the projected coastal erosion hazard area (Hameed et al. 2013).

Elephant seals Sea level rise models within Point Reyes NS indicate that most haul-out sites—areas needed by northern elephant seals for breeding and rest—could be largely inundated by 2050 (Funayama et al. 2012). Maximum entropy (species distribution) models project that nearly 50% of potential haul-out habitats will be flooded by 2050 and approximately 66% inundated by 2099 (Funayama et al. 2012).

Endangered fish Analysis of salmonid conservation status determined that coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*) may face possible extirpation from California within 50 to 100 years due to the rise in river and stream water temperatures caused by climate change (Katz et al. 2013). Additionally, species distribution projections of Northeast Pacific pelagic marine fishes show that by 2050, coho salmon and steelhead trout populations may shift poleward by 300 ± 20 km per century (mean ± standard error) under high emissions due to increased sea surface temperatures (Cheung et al. 2015). The projections also indicate that under high emissions, local extinctions would be highest in the California current region, with a 0.1 extinction rate in the region of Point Reyes NS from 2005 to 2050 (Cheung et al. 2015).

Carbon Solutions

Carbon sequestration by live vegetation is a natural process of removing carbon dioxide from the atmosphere, while decomposition of vegetation naturally emits carbon into the atmosphere. The balance of carbon exchange determines whether particular ecosystems are largely carbon sinks or carbon sources. Point Reyes National Seashore presents unique potential for carbon sequestration since the park possesses three important carbon sinks: coastal forests, grasslands, and wetlands.

Field research shows that seagrasses are a globally significant carbon stock. Soils of coastal seagrass beds can store up to 83,000 metric tons of carbon per square kilometer, which is more than many terrestrial forests (Fourquerean et al. 2012). Submerged aquatic vegetation, such as eelgrass (*Zostera marina*) and kelp (*Macrocystis pyrifera*), are highly efficient in removing carbon from seawater through photosynthesis and sediment burial, which can combat climate change and ocean acidification (Nielsen et al. 2018). However, there is no published research that has estimated the carbon stocks of submerged aquatic vegetation in the park's wetlands and estuaries.

Additionally, Douglas-fir forests have a high potential for carbon storage due to their long life-span and high net primary productivity (Hudiburg et al. 2009). Analysis of Landsat remote sensing data, combined with biomass data collected from field measurements showed that California national parks conserve approximately 5% of the state's above-ground carbon stock (Gonzalez et al. 2015). In 2010, Point Reyes National Seashore's above-ground live vegetation contained 910,000 ± 530,000 tons of carbon (mean ± 95% confidence interval)(Gonzalez et al. 2015). From 2001 to 2010, carbon stock in above-ground vegetation increased by 2 ± 1% in the park, but this was not significant (Gonzalez et al. 2015).

Point Reyes National Seashore has implemented greenhouse gas reduction initiatives as part of the Climate Friendly Parks program. The action plan analyzed greenhouse gas emission inventory for the park, with energy, waste, transportation, and agriculture being four major emissions sources. The analysis estimated that the park's emissions in 2008 totaled 20,000 metric tons of carbon, which is equivalent to the emissions of 1,723 U.S. households annually (NPS 2009). Of the total emissions, 1% comes from energy consumption, 2% from waste, 35% from transportation, and 62% from other sources (primarily agricultural activities) (Table 5).

The *Point Reyes National Seashore Action Plan* (NPS 2009) identifies a number of strategies to dramatically reduce park emissions that are causing climate change. The plan aimed to reduce emissions by switching to renewable energy, replacing conventional vehicles and equipment with electrical, hybrid, or biodiesel versions, and diverting and reducing waste through usage of reusable materials. With cattle management remaining the largest contributor of greenhouse gas emissions, the park aims to reduce emissions from agricultural waste by implementing methane digesters.

The Intergovernmental Panel on Climate Change (2022) affirms that immediate, collective action can reduce greenhouse gas emissions enough to prevent global temperatures from increasing more than the 1.5 ºC threshold set by the Paris Agreement. Reducing emissions, complemented by carbon storage, will limit future climate change imposed risks to the plants, animals, and ecosystems of Point Reyes National Seashore.

Figure 1. Average annual temperature, 1895-2016, for Point Reyes National Seashore (Gonzalez et al. 2018).

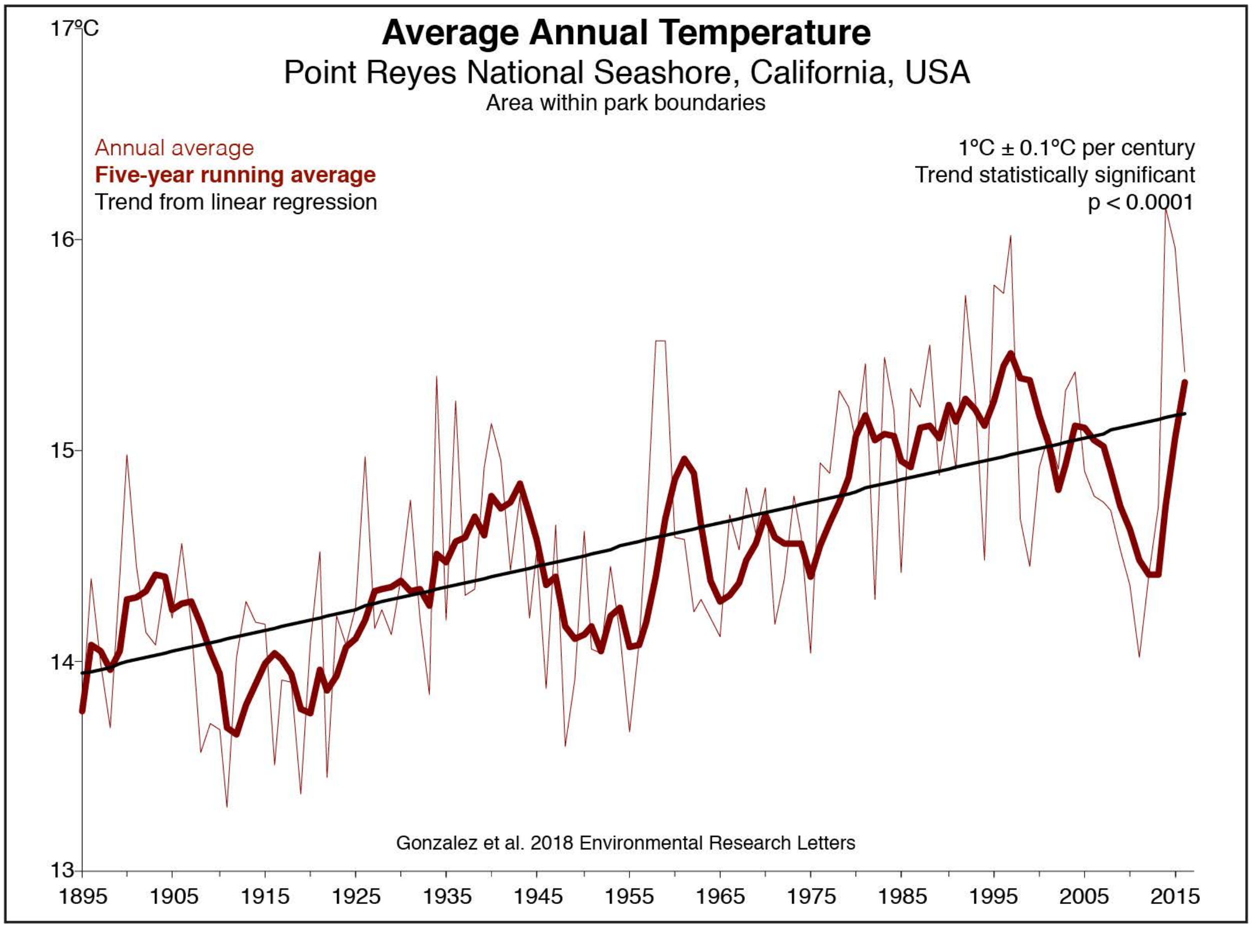

Figure 2. Total annual precipitation, 1895-2016, for Point Reyes National Seashore (Gonzalez et al. 2018).

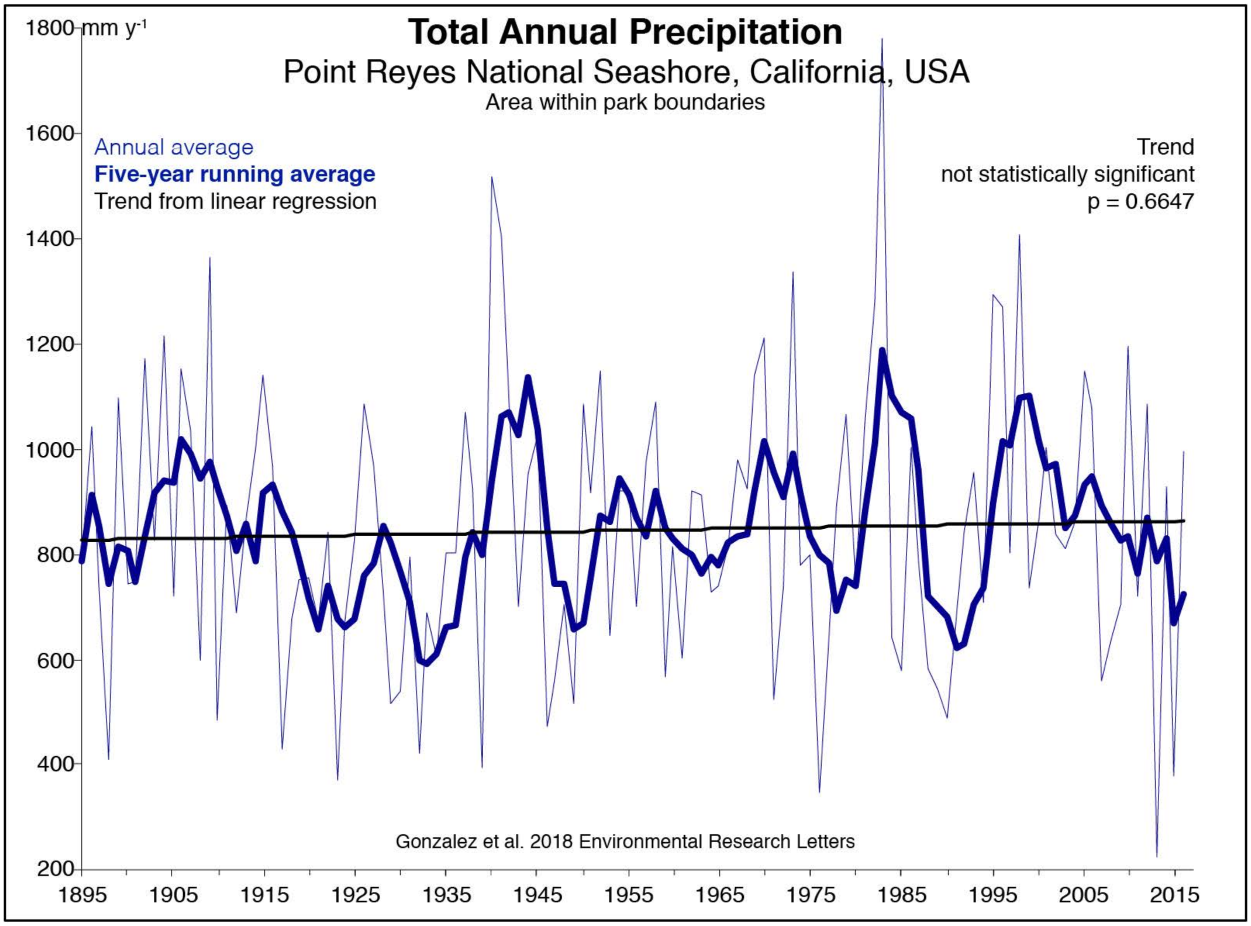

Figure 3. Average sea level measured by tidal gauges along the California coast from 1900-2020 (NOAA 2017)

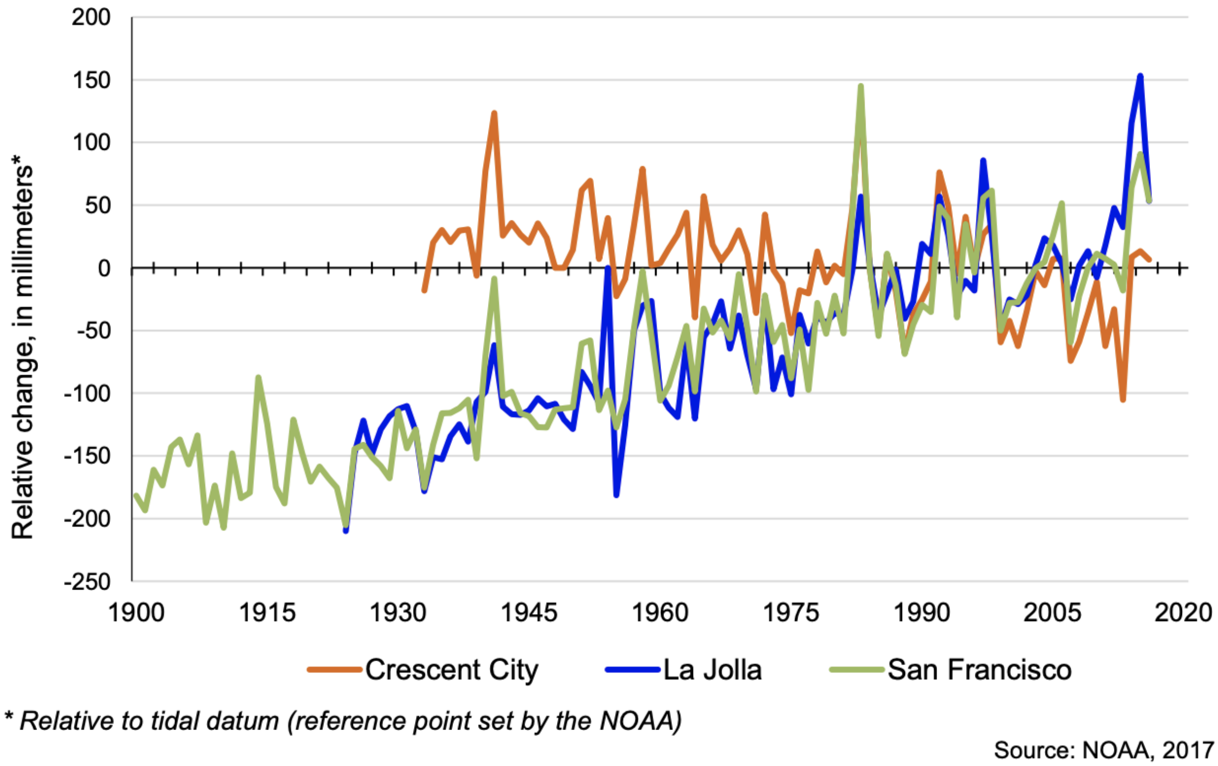

Figure 4. Projected sea surface temperature, pH, and oxygen for the California Current System. (A) The observed sea surface temperature is shown in the black line for 1920-2016, while the average of 28 different climate model simulations is shown by the red line. The gray band indicates the full range of temperatures from the 28 different climate model simulations. The projections include a human-caused warming trend of ~0.5 to 1.5℃ by 2040, and 2-4℃ by 2100, with no clear indication of a change in the range of annual variability. (B)(C) Historical records for pH anomaly and dissolved oxygen are not as complete as those for ocean temperature so are not shown for these variables. The model projections show rapid declines in California Current pH anomaly and dissolved oxygen concentrations. (Phillips et al. 2018 & James Scott, NOAA Earth System Research Lab).

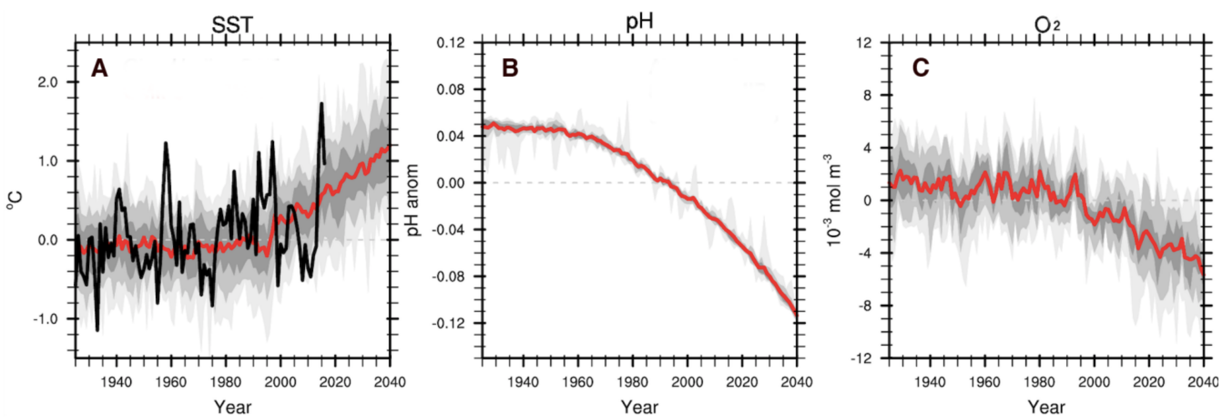

Figure 5. Modeled relative frequency of 22 vegetation types across the San Francisco Bay Area, parameterized for the historical baseline period and then projected for alternative climates based on the recent climate (1981–2010) and 54 possible futures in ascending order of increased warming in mean annual temperature. Changes in mean annual temperature and precipitation, averaged for each climate scenario, are shown on the left (Ackerly et al. 2015).

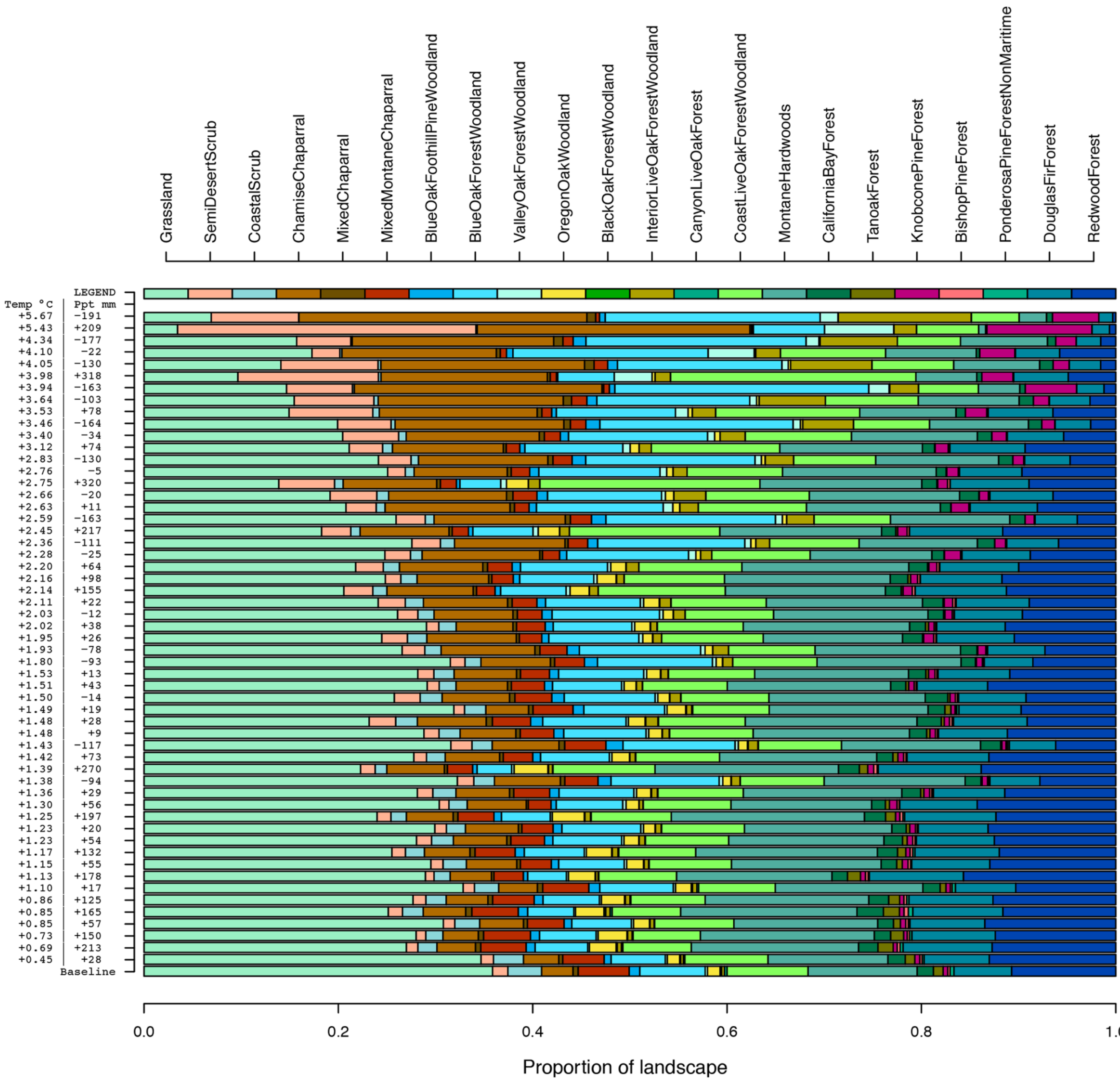

Figure 6. Projected changes in climate suitability for birds at Point Reyes National Seashore, by emissions pathway and season (NPS 2018, Wu et al. 2018).

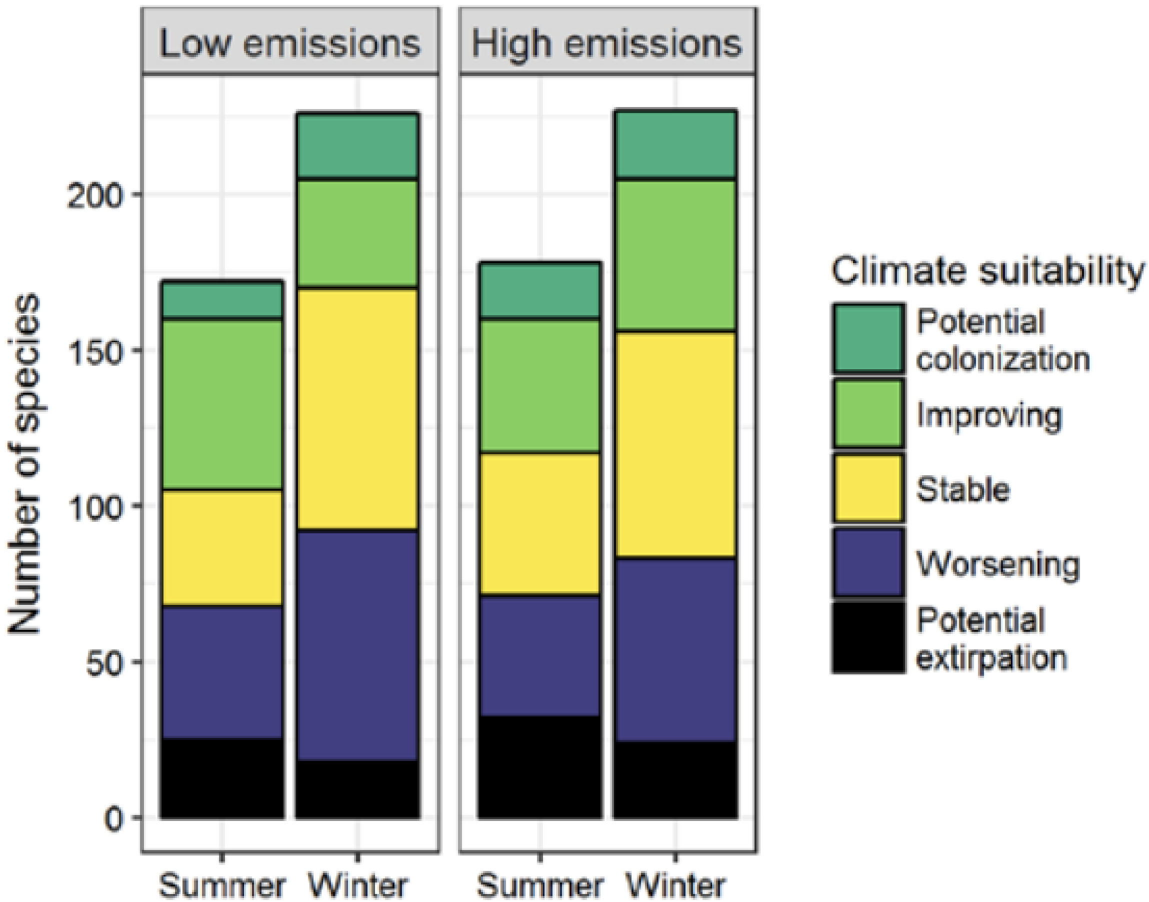

Figure 7. Coastal vulnerability assessment map of Point Reyes National Seashore showing that vulnerability to sea level rise and storm surges are highest along Point Reyes Beach (Pendelton et al. 2010)

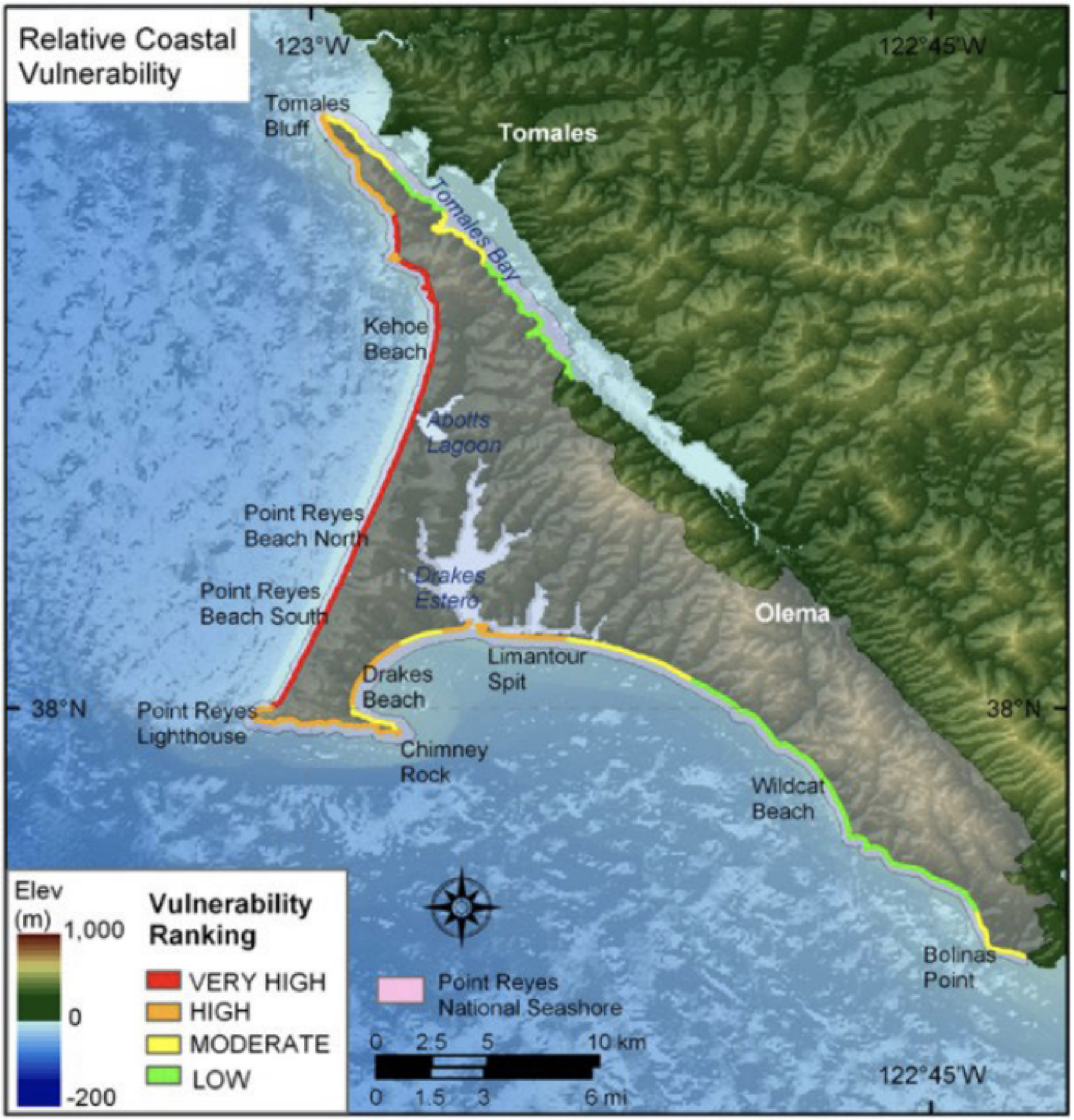

Figure 8. Historical and projected sea level rise for San Francisco, California. The shaded areas bounded by the dashed lines denote the 5th and 95th percentiles. The H++ scenario represents a world consistent with rapid Antarctic ice sheet mass loss (Griggs et al. 2017).

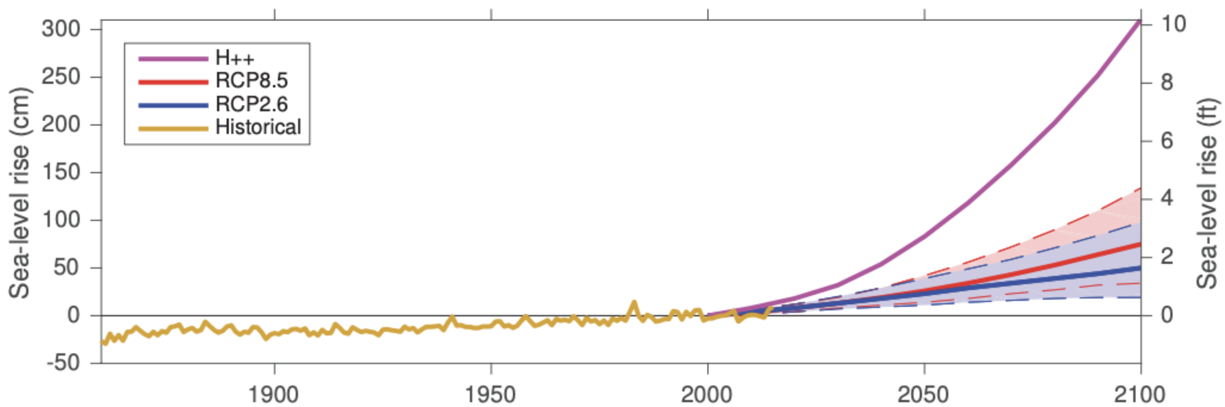

Table 1. Point Reyes National Seashore historical average temperatures and temperature trends of the area within the park boundary. SD = standard deviation, SE = standard error, sig. = statistical significance, * P ≤ 0.05, ** P ≤ 0.01, *** P ≤ 0.001 (Gonzalez et al. 2018).

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	°C		°C century^{-1}			°C century^{-1}		
Annual	13.3	0.5	0.9	0.2	***	1.3	0.5	*
December-February	10.1	0.8	0.7	0.3	**	1.1	0.5	*
March-May	12.7	0.9	0.9	0.3	**	1.9	0.8	*
June-August	15.5	0.5	0.9	0.2	***	1.6	0.6	*
September-November	14.8	0.7	1	0.2	***	0.6	0.5	
January	9.6	1.1	0.9	0.3	*	2.1	0.7	*
February	11.1	1.1	0.7	0.3	*	0.8	0.8	
March	11.9	1.2	0.9	0.4	*	2.7	0.9	**
April	12.5	1.1	0.6	0.3		1.4	0.9	
May	13.6	1.1	1.2	0.3	***	1.8	0.7	*
June	15	0.9	0.7	0.3	*	1.7	0.8	*
July	15.6	0.7	0.7	0.2	**	1.4	0.7	
August	16	0.7	1.3	0.3	***	1.7	0.7	*
September	16.5	1.1	1.3	0.3	***	0.7	0.8	
October	15.4	0.9	1.1	0.3	***	0.7	0.8	
November	12.6	1.2	0.5	0.3		0.4	0.7	
December	9.7	1.3	0.6	0.4		0.2	0.9	

Table 2. Point Reyes National Seashore. Historical average precipitation totals and precipitation trends of the area within the park boundary. SD = standard deviation, SE = standard error, sig. = statistical significance, * P ≤ 0.05, ** P ≤ 0.01, *** P ≤ 0.001 (Gonzalez et al. 2018).

	1971-2000		1895-2010			1950-2010		
	mean	SD	trend	SE	sig.	trend	SE	sig.
	mm y^{-1}		% $century^{-1}$			% $century^{-1}$		
Annual	840	306	-3	9		3	25	
December-February	480	218	-2	13		11	31	
March-May	185	103	-6	16		26	41	
June-August	11	12	-1	32		-95	87	
September-November	173	112	0	19		-42	46	
January	180	126	-26	19		-51	45	
February	153	119	-1	21		78	54	
March	115	89	-14	21		22	54	
April	48	34	15	22		-28	48	
May	23	31	-18	33		183	91	*
June	6	8	-22	39		-53	111	
July	2	7	33	128		-132	370	
August	3	7	76	77		-197	167	
September	11	14	-97	50		-151	129	
October	48	38	7	24		-34	67	
November	115	93	7	25		-37	69	
December	137	98	24	21		25	65	

Table 3. Point Reyes National Seashore projected temperature increases (℃), 2000 to 2100, for the area within the park boundary, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation (Gonzalez et al. 2018).

	Emissions Scenarios							
	Reductions RCP2.6		Low RCP4.5		High RCP6.0		Highest RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	1.4	0.6	2.1	0.6	2.4	0.7	3.7	0.8
December-February	1.3	0.5	2	0.6	2.2	0.7	3.4	0.8
March-May	1.3	0.5	1.8	0.6	2.2	0.6	3.2	0.8
June-August	1.4	0.7	2.2	0.7	2.6	0.8	3.9	0.9
September-November	1.5	0.6	2.4	0.9	2.7	0.8	4.2	1.1
January	1.4	0.5	2	0.6	2.2	0.7	3.4	0.8
February	1.3	0.5	1.9	0.6	2.2	0.6	3.3	0.7
March	1.3	0.7	1.8	0.6	2.1	0.6	3.2	0.8
April	1.3	0.5	1.7	0.6	2.2	0.6	3.1	0.7
May	1.3	0.6	1.9	0.6	2.3	0.7	3.4	0.8
June	1.4	0.8	2	0.8	2.4	0.8	3.7	0.9
July	1.4	0.7	2.2	0.8	2.6	0.8	3.9	0.9
August	1.5	0.7	2.4	0.7	2.8	0.7	4.2	0.9
September	1.7	0.7	2.5	0.8	2.8	0.9	4.4	1.1
October	1.5	0.7	2.4	1	2.7	0.9	4.3	1.2
November	1.4	0.6	2.2	1.1	2.5	0.7	3.9	1.3
December	1.4	0.5	2	0.8	2.2	0.7	3.5	1.1

Table 4. Point Reyes National Seashore projected precipitation changes (%), 2000 to 2100, for the area within the park boundary, from the average of all available general circulation model projections used for IPCC (2013). RCP = representative concentration pathway, SD = standard deviation (Gonzalez et al. 2018).

	Emissions Scenarios							
	Reductions RCP2.6		Low RCP4.5		High RCP6.0		Highest RCP8.5	
	mean	SD	mean	SD	mean	SD	mean	SD
Annual	5	11	5	9	7	13	10	16
December-February	7	15	11	14	13	18	19	21
March-May	8	16	3	20	2	12	2	26
June-August	24	34	29	61	15	41	39	79
September-November	-2	14	-6	24	-6	19	-12	24
January	9	20	14	19	12	21	24	26
February	7	22	15	23	19	29	27	36
March	7	20	5	20	8	16	9	25
April	8	25	0	25	-5	20	-5	37
May	14	38	1	48	-8	29	-11	47
June	8	37	-8	38	-12	32	-9	47
July	106	239	172	273	172	277	218	357
August	65	113	83	119	54	93	103	143
September	7	57	8	64	3	40	19	78
October	6	31	-8	26	-3	33	-16	32
November	-6	14	-6	29	-8	18	-13	29
December	6	23	4	23	13	26	9	24

Table 5. Point Reyes National Seashore 2008 Total Greenhouse Gas Emissions by Sector and Source (NPS 2009)

	MTCO2E
Energy	**299**
Stationary Combustion	144
Purchased Electricity	156
Transportation	**7,050**
Mobile Combustion	7,050
Waste	**357**
Landfilled Waste	193
Wastewater	164
Other	**12,533**
Refrigeration and Air Conditioning	9
Other	12,524
Total	**20,239**

Note - Totals may not sum due to rounding
Not applicable data sources represented by "-"

References

Ackerly, D., Jones, A., Stacy, M., & Riordan, B. (University of California, Berkeley). 2018. San Francisco Bay Area Summary Report. California's Fourth Climate Change Assessment. Publication number: CCCA4-SUM-2018-005.

Alexander, M. A., Scott, J. D., Friedland, K. D., Mills, K. E., Nye, J. A., Pershing, A. J., & Thomas, A. C. 2018. Projected Sea surface temperatures over the 21st century: Changes in the mean, variability and extremes for large marine ecosystem regions of Northern Oceans. Elementa: Science of the Anthropocene 6. doi: 10.1525/elementa.191

Anacker, B.L., M. Gogol-Prokurat, K. Leidholm, and S. Schoenig. 2013. Climate change vulnerability assessment of rare plants in California. Madroño 60: 193-210.

Barkhordarian, A., Nielsen, D. M., & Baehr, J. 2022. Recent marine heatwaves in the North Pacific warming pool can be attributed to rising atmospheric levels of greenhouse gases. Communications Earth & Environment 3. doi: 10.1038/s43247-022-00461-2

Bernot, T., & Press, D. 2018. Tule Elk Monitoring and Management at Point Reyes National Seashore: 2015–2016 Report (No. Natural Resource Report NPS/SFAN/NRR—2018/1656). National Park Service, Washington, DC.

Bryant, B.P., Westerling, A.L. 2012. Scenarios to Evaluate Long-Term Wildfire Risk in California: New Methods for Considering Links Between Changing Demography, Land Use, and Climate. California Energy Commission, Sacramento, CA.

Bokwa, A., Wypych, A., & Hajto, M. J. 2018. Role of fog in urban heat island modification in Kraków, Poland. Aerosol and Air Quality Research 18:178–187. doi: 10.4209/aaqr.2016.12.0581

California Department of Fish and Wildlife. 2016. A Rapid Assessment of the Vulnerability of Sensitive Wildlife to Extreme Drought. California Department of Fish and Wildlife, Sacramento, CA.

Carter, B. R., Feely, R. A., Mecking, S., Cross, J. N., Macdonald, A. M., Siedlecki, S. A., Talley, L. D., Sabine, C. L., Millero, F. J., Swift, J. H., Dickson, A. G., & Rodgers, K. B. 2017. Two decades of Pacific anthropogenic carbon storage and ocean acidification along global ocean ship-based Hydrographic Investigations Program sections P16 and P02. Global Biogeochemical Cycles 31: 306-327. doi: 10.1002/2016gb005485

Cheung, W.W.L., R.D. Brodeur, T.A. Okey, and D. Pauly. 2015. Projecting future changes in distributions of pelagic fish species of Northeast Pacific shelf seas. Progress in Oceanography 130: 19-31.

Cook, B. I., Ault, T. R., & Smerdon, J. E. 2015. Unprecedented 21st century drought risk in the American Southwest and Central Plains. Science Advances 1: e1400082. doi: 10.1126/sciadv.1400082

Feely, R. A., Alin, S. R., Carter, B., Bednaršek, N., Hales, B., Chan, F., Hill, T. M., Gaylord, B., Sanford, E., Byrne, R. H., Sabine, C. L., Greeley, D., & Juranek, L. 2016. Chemical and biological impacts of ocean acidification along the west coast of North America. Estuarine, Coastal and Shelf Science, 183, 260–270. doi: 10.1016/j.ecss.2016.08.043

Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marbà, N., Holmer, M., Mateo, M. A., Apostolaki, E. T., Kendrick, G. A., Krause-Jensen, D., McGlathery, K. J., & Serrano, O. 2012. Seagrass ecosystems as a globally significant carbon stock. Nature Geoscience 5: 505–509. doi: 10.1038/ngeo1477

Frederikse, T., Landerer, F., Caron, L., Adhikari, S., Parkes, D., Humphrey, V. W., Dangendorf, S., Hogarth, P., Zanna, L., Cheng, L., & Wu, Y.-H. 2020. The causes of sea-level rise since 1900. Nature 584: 393–397. doi: 10.1038/s41586-020-2591-3

Friedlingstein, P. et al. 2022. Global Carbon Budget 2022. Earth System Science Data 14: 4811-4900.

Frölicher, T.L., E.M. Fischer, and N. Gruber. 2018. Marine heatwaves under global warming. Nature 560: 360-364.

Fumo, J. T., Carter, M. L., Flick, R. E., Rasmussen, L. L., Rudnick, D. L., & Iacobellis, S. F. 2020. Contextualizing Marine Heatwaves in the Southern California Bight under Anthropogenic Climate Change. Journal of Geophysical Research: Oceans 125:5. doi: 10.1029/2019jc015674

Gentemann, C. L., Fewings, M. R., & García-Reyes, M. 2017. Satellite sea surface temperatures along the west coast of the United States during the 2014-2016 Northeast Pacific Marine Heat Wave. Geophysical Research Letters 44: 312–319. doi: 10.1002/2016gl071039

Funayama, K., Hines, E., Davis, J., & Allen, S. 2012. Effects of sea-level rise on northern elephant seal breeding habitat at Point Reyes Peninsula, California. Aquatic Conservation: Marine and Freshwater Ecosystems 23: 233–245. doi: 10.1002/aqc.2318

Gattuso, J.-P., Magnan, A., Billé, R., Cheung, W. W., Howes, E. L., Joos, F., Allemand, D., Bopp, L., Cooley, S. R., Eakin, C. M., Hoegh-Guldberg, O., Kelly, R. P., Pörtner, H.-O., Rogers, A. D., Baxter, J. M., Laffoley, D., Osborn, D., Rankovic, A., Rochette, J., … Turley, C. 2015. Contrasting futures for ocean and society from different anthropogenic CO2 emissions scenarios. Science 349:6243. doi: 10.1126/science.aac4722

Gonzalez, P., J.J. Battles, B.M. Collins, T. Robards, and D.S. Saah. 2015. Aboveground live carbon stock changes of California wildland ecosystems, 2001-2010. Forest Ecology and Management 348: 68-77.

Gonzalez, P. 2016. Climate Change in the National Parks of the San Francisco Bay Area. National Park Service, Berkeley, CA. https://irma.nps.gov/DataStore/Reference/Profile/2230389

Gonzalez, P., Wang, F., Notaro, M., Vimont, D. J., & Williams, J. W. 2018. Disproportionate magnitude of climate change in United States national parks. Environmental Research Letters 13: 104001. doi: 10.1088/1748-9326/aade09

Gruber, N., Hauri, C., Lachkar, Z., Loher, D., Frölicher, T. L., & Plattner, G.-K. 2012. Rapid progression of ocean acidification in the California current system. Science 337: 220–223. doi: 10.1126/science.1216773

Hameed, S.O., K.A. Holzer, A.N. Doerr, J.H. Baty, and M.W. Schwartz. 2013. The value of a multi-faceted climate change vulnerability assessment to managing protected lands: Lessons from a case study in Point Reyes National Seashore. Journal of Environmental Management 121: 37-47

Heberger, M., H. Cooley, P. Herrera, P. Gleick, E. Moore. 2009. The Impacts of Sea-Level Rise on the California Coast. California Climate Change Center.

Hudiburg, T., Law, B., Turner, D. P., Campbell, J., Donato, D., & Duane, M. 2009. Carbon Dynamics of Oregon and Northern California forests and potential land-based carbon storage. Ecological Applications 19: 163–180. doi: 10.1890/07-2006.1

Hutto, S.V., K.D. Higgason, J.M. Kershner, W.A. Reynier, and D.S. Gregg. 2015. Climate

Change Vulnerability Assessment for the North-central California Coast and Ocean. Marine Sanctuaries Conservation Series ONMS-15-02. National Oceanic and Atmospheric Administration, Silver Spring, Maryland.

Intergovernmental Panel on Climate Change (IPCC). 2021. Climate Change 2021: The Physical Science Basis. Cambridge University Press, Cambridge, UK.

Intergovernmental Panel on Climate Change (IPCC). 2022. Climate Change 2022: Mitigation of Climate Change. Cambridge University Press, Cambridge, UK.

Johnstone, J. A., & Dawson, T. E. 2010. Climatic context and ecological implications of summer fog decline in the Coast Redwood Region. Proceedings of the National Academy of Sciences 107: 4533–4538. doi: 10.1073/pnas.0915062107

Katz, J., P.B. Moyle, R.M. Quiñones, J. Israel, and S. Purdy. 2013. Impending extinction of salmon, steelhead, and trout (Salmonidae) in California. Environmental Biology of Fishes 96: 1169-1186

Lakra, K., & Avishek, K. 2022. A review on factors influencing fog formation, classification, forecasting, detection and impacts. Rendiconti Lincei. Scienze Fisiche e Naturali 33: 319–353. doi: 10.1007/s12210-022-01060-1

La Sorte, F.A. and F.R. Thompson. 2007. Poleward shifts in winter ranges of North American birds. Ecology 88: 1803-1812.

Laufkötter, C., Zscheischler, J., & Frölicher, T. L. 2020. High-impact marine heatwaves attributable to human-induced global warming. Science 369: 1621–1625. doi: 10.1126/science.aba0690

Levin, L. A. 2018. Manifestation, drivers, and emergence of open ocean deoxygenation. Annual Review of Marine Science 10: 229–260. doi: 10.1146/annurev-marine-121916-063359

Malamud-Roam, F., Dettinger, M., Ingram, L., Hughes, M., & Florsheim, J. 2007. Holocene climates and connections between the San Francisco Bay Estuary and its watershed: A Review. San Francisco Estuary and Watershed Science 5:1. doi: 10.15447/sfews.2007v5iss1art3

Marlon, J.R., P.J. Bartlein, D.G. Gavin, C.J. Long, R.S. Anderson, C.E. Briles, K.J. Brown, D. Colombaroli, D.J. Hallett, M.J. Power, E.A. Scharf, and M.K. Walsh. 2012. Long-term perspective on wildfires in the western USA. Proceedings of the National Academy of Sciences of the USA 109: E535-E543.

Mohr, A. S., Stafford, R., & Bean, W. T. 2022. Tule elk selection of surface water and forage is mediated by season and drought. Proceedings of the 14th Biennial Deer and Elk Workshop 108:3. doi: 10.51492/cfwj.108.19

National Oceanic and Atmospheric Administration (NOAA). 2023. Center for Operational Oceanographic Products and Services: Tides and Currents. https://tidesandcurrents.noaa.gov/stationhome.html?id=9414290

National Park Service (NPS). 2009. Climate Friendly Parks. Point Reyes National Seashore Action Plan. National Park Service, Washington, DC.

National Park Service (NPS). 2012. Threatened, Rare, and Endangered Plants of Point Reyes (and Golden Gate National Recreation Area). https://www.nps.gov/pore/learn/nature/upload/plantspecieslist_rare.pdf

National Park Service (NPS). 2015. Climate friendly parks. National Parks Service. https://www.nps.gov/pore/learn/nature/climatechange_climatefriendlyparks.htm

National Park Service (NPS). 2022. Ongoing drought prompts point reyes national seashore to provide supplemental water for tule elk at Tomales Point for a second year. National Parks Service. https://www.nps.gov/pore/learn/news/newsreleases-20221012-second-year-of-supplemental-water.htm

National Park Service (NPS). 2022. Coho Salmon's upstream battle against climate change (U.S. National Park Service). National Parks Service. https://www.nps.gov/articles /000/sfanblog_coho-salmons-upstream-battle-against-climate-change.htm

Nielsen, K., J. Stachowicz, H. Carter, K. Boyer, M. Bracken, F. Chan, F. Chavez, K. Hovel, M. Kent, K. Nickols, J. Ruesink, J. Tyburczy, and S. Wheeler. 2018. Emerging understanding of the potential role of seagrass and kelp as an ocean acidification management tool in California. California Ocean Science Trust, Oakland, California.

Office of Environmental Health Hazard Assessment (OEHHA). 2022. Indicators of Climate Change in California, Fourth Edition, California Environmental Protection Agency, OEHHA.

O'Gallagher, M. J., Jones, G. A., Parsons, L. S., Press, D. T., Rehlaender, W. E., Skartvedt, S., &

Forrestel, A. B. 2021. 2020 Woodward fire case study: Examining the role of fire as an ecological process in a coastal California ecosystem. Parks Stewardship Forum 37:2. doi: 10.5070/p537253239

Oliver, E. C., Burrows, M. T., Donat, M. G., Sen Gupta, A., Alexander, L. V., Perkins-Kirkpatrick, S. E., Benthuysen, J. A., Hobday, A. J., Holbrook, N. J., Moore, P. J., Thomsen, M. S., Wernberg, T., & Smale, D. A. 2019. Projected Marine Heatwaves in the 21st century and the potential for ecological impact. Frontiers in Marine Science 6. doi: 10.3389/fmars.2019.00734

Paprocki, N., Heath, J. A., & Novak, S. J. 2014. Regional distribution shifts help explain local changes in wintering raptor abundance: Implications for interpreting population trends. PLoS ONE 9:1. doi: 10.1371/journal.pone.0086814

Pendleton, E.A., E.R. Thieler, and S.J. Williams. 2010. Importance of coastal change variables in determining vulnerability to sea- and lake-level change. Journal of Coastal Research 26: 176-183.

Phillips, J., Sievanen, L., Colgan, C., Griggs, G., Hart, J.F., Hartge, E., Hill, T., Kudela, R., Mantua, N., Nielsen, K., Whiteman, L. 2018. California's Coast and Ocean Summary Report. California's Fourth Climate Change Assessment. Publication number: SUMCCC4A-2018-011.

Pierce, D. W., Kalansky, J. F., & Cayan, D. R. 2018. Climate, drought, and sea level rise scenarios for California's Fourth Climate Change Assessment: A report for California's Fourth Climate Change Assessment. California Energy Commission, Sacramento, CA.

Ren, A. S., Chai, F., Xue, H., Anderson, D. M., & Chavez, F. P. 2018. A sixteen-year decline in dissolved oxygen in the central California current. Scientific Reports 8:1. doi: 10.1038/s41598-018-25341-8

Rykaczewski, R. R., & Dunne, J. P. 2010. Enhanced nutrient supply to the California Current Ecosystem with global warming and increased stratification in an earth system model. Geophysical Research Letters 37:L21606. doi:10.1029/2010GL045019

Slangen, A. B., Church, J. A., Agosta, C., Fettweis, X., Marzeion, B., & Richter, K. 2016. Anthropogenic forcing dominates global mean sea-level rise since 1970. Nature

Climate Change 6: 701–705. doi: 10.1038/nclimate2991

Spies, B., & Steele, M. 2016. Effects of temperature and latitude on larval traits of two estuarine fishes in differing estuary types. Marine Ecology Progress Series 544: 243–255. doi: 10.3354/meps11552

Torregrosa, A., O'Brien, T. A., & Faloona, I. C. 2014. Coastal Fog, climate change, and the environment. Eos, Transactions American Geophysical Union 95: 473–474. doi: 10.1002/2014eo500001

Thorne, J.H., R.M. Boynton, L.E. Flint, and A.L. Flint. 2015. The magnitude and spatial patterns of historical and future hydrologic change in California's watersheds. Ecosphere 6:24. doi:10.1890/ES14-00300.1.

Wehner, M.F., J.R. Arnold, T. Knutson, K.E. Kunkel, and A.N. LeGrande. 2017. Droughts, floods, and wildfires. Climate Science Special Report: Fourth National Climate Assessment 1:231-256. doi: 10.7930/J0CJ8BNN.

Westerling, A.L., B.P. Bryant, H.K. Preisler, T.P. Holmes, H.G. Hidalgo, T. Das, and S.R. Shrestha. 2011. Climate change and growth scenarios for California wildfire. Climatic Change 109: S445-463.

Westerling, A.L. 2018. Wildfire Simulations for California's Fourth Climate Change Assessment: Projecting Changes in Extreme Wildfire Events with a Warming Climate. California Fourth Climate Change Assessment, Report CCCA4-CEC-2018-014, Sacramento, CA.

Williams, A.P., R. Seager, J.T. Abatzoglou, B.I. Cook, J.E. Smerdon, and E.R. Cook. 2015. Contribution of anthropogenic warming to California drought during 2012–2014. Geophysical Research Letters 42: 6819-6828.

Wu, J. X., Wilsey, C. B., Taylor, L., & Schuurman, G. W. 2018. Projected avifaunal responses to climate change across the U.S. national park system. PLOS ONE 13:3. doi: 10.1371/journal.pone.0190557