Indicators of Climate Change in California

Fifth Edition













October 2026

OEHHA
SCIENCE FOR A HEALTHY CALIFORNIA

CalEPA
California Environmental Protection Agency

INDICATORS OF CLIMATE CHANGE IN CALIFORNIA

Fifth Edition
September 2026

California Environmental Protection Agency

Office of Environmental Health Hazard Assessment

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The Office of Environmental Health Hazard Assessment (OEHHA) recognizes that our work takes place across the homelands of California Native American Tribes, whose relationships with these lands and waters extend since time immemorial. We offer this acknowledgment in the spirit of our partnerships with Tribes and continued work to honor their relationships with their lands with a commitment to listen, learn, and continue building meaningful collaborations.

Suggested citation:
Office of Environmental Health Hazard Assessment (OEHHA, 2026). Indicators of Climate Change in California, Fifth Edition, California Environmental Protection Agency, OEHHA.

Cover photos (clockwise from top):
California wildfire threatens homes (Attila Adam); Monarch butterflies (Danita Delimon); Buoy on dry Folsom Lake (Chris Allan); Mt. Shasta with glaciers (Michal); Mono Lake Tufa (Eniko Polgar); Oil rig in Bolsa Chica Ecological Reserve (Marcus E. Jones); Redwood tree forest (Jack Bixby). *Background:* Flowers along the coastline of Big Sur (Chris Leipelt).

In memory of Richard L. Stewart (1944-2024) and Virginia “Ginger” Covert (1945-2024)

Richard was an Elder from the Big Pine Band of Paiute Indians and traditional culture expert; he was not only a storyteller, but also a singer, and an expert in the techniques of willow basketry, brown-ware, and lithic tools. He was a professionally trained artist, photographer, and educator to students of all ages. He was proud to have built bridges between his culture and the world around him and dedicated his remaining time passing along his traditional knowledge for preservation.

Virginia "Ginger" Covert, of Nisenan (Nevada City Rancheria) and Miwuk lineage, was a poet, artist, "beautician", teacher, Tribal Chairwoman, and most importantly, an Elder and Culture Bearer. She envisioned a time when the modern world and all the people in it would come to understand the importance of Mother Earth. She worked hard to build visibility for the Tribe and promoted humanity's equality with Nature and all animal kin, not superiority over them. She worked selflessly and without compensation for decades in the fight to restore Federal Recognition to the Nevada City Rancheria Nisenan Tribe. She is greatly missed by her family, friends, and colleagues; the world is a dimmer place without her in it.

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This report would not be possible without the many scientists and analysts who assisted us. In addition to the Climate Indicators and Site Assessment Section staff, OEHHA thanks the following authors and reviewers for their generous contributions to this report:

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Governor's Office of Land Use and Climate Innovation: Bryce Lewis-Smith, Elea Becker Lowe
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OEHHA respects the right of Tribal nations to govern the collection, ownership, and application of their data. Tribal information is included in this report only with the explicit permission of the Tribe.

Message from the Secretary



California continues to lead the nation in science-based climate action. For more than two decades, our state has tracked how climate change is altering our land, water resources, coastlines, and communities. These efforts reflect what many Californians increasingly see and feel in their own lives and demonstrate the importance of sustained climate action. At a time when the federal government is attempting to inject doubt into climate science and roll back climate progress, the findings in the Fifth Edition of the *Indicators of Climate Change in California* report reaffirm the scientific foundation of California's efforts to protect our people and environment from the accelerating impacts of climate change.

This updated report presents 49 indicators and reports from eight California Native American tribes documenting long-term trends in the drivers and impacts of climate change. While earlier work established clear trends, this edition shows more fully what they mean for California's people and natural systems. Many of the changes have intensified and some have crossed thresholds that cannot be reversed. Since the publication of the Fourth Edition in 2022, the Trinity Alps glaciers have disappeared entirely; for the first time, we have sufficient data to confirm an upward trend in average annual heat-related deaths; and from 2020 through 2024, the average annual acreage burned was nearly six times the pre-2000 average. The impacts are deeply interconnected, as warming reduces the natural water storage provided by mountain snowpack and drier vegetation fuels wildfire and smoke that compound health effects from extreme heat.

The tribal reports show how ecological changes affect tribal lifeways. Rising oceans limit access to cultural sites on the coast and impacted salmon fisheries and culturally relevant plants make it harder to continue traditional practices related to food. Eight California Native American tribes authored these reports, offering perspectives in their own words and rooted in generations of experience that extend beyond instrumental scientific records.

Many communities across the state also experience disproportionate impacts from climate change. Rural and low-income communities, farm workers, and other outdoor workers often face the impacts from climate change with fewer resources to prepare and recover. When more than 2,000 domestic wells ran dry during the 2012–2016 drought, they were concentrated in low-income, rural, and Hispanic/Latino communities of the Central Valley and Sierra Nevada foothills. By documenting the disparate impacts of climate change, this report shows why California must continue pursuing climate

actions that directly address inequities and strengthen protections for the communities most affected.

That is why California is advancing measures that help safeguard communities. In 2025, OEHHA launched CalHeatScore, a cutting-edge extreme heat warning system to raise awareness and help Californians prepare when temperatures rise. This tool translates weather and health data into local heat scores and connects Californians to resources, with a focus on protecting the most vulnerable. This summer, OEHHA also updated CalEnviroScreen, California's environmental health screening tool, which helps direct billions of the California Climate Investments toward projects that reduce pollution, build resilience, and support low-income and rural households.

Indicators of Climate Change in California continues California's longstanding efforts to document climate change impacts in the state and is a valuable resource for policymakers, communities, tribes, and academics. By making clear what has happened and what is at stake, this report underscores the importance of our continued commitment to protect all Californians from climate change.

Yana Garcia, Secretary

California Environmental Protection Agency

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This fifth (5th) edition of *Indicators of Climate Change (ICC) in California* Report continues OEHHA's two-decade effort to track changes in the state's climate. The 5th edition presents 49 indicators spanning greenhouse gas emissions, atmospheric and ocean chemistry, snowpack, wildfire, extreme heat, ecosystems, and human health. Several indicators document changes that have reached new thresholds since the 2022 edition.

This edition continues to integrate tribal knowledge. California tribes have observed ecological changes across their ancestral lands over generations. Their knowledge provides a record of environmental conditions that extends beyond instrumental measurement and can reveal changes, relationships, and consequences that quantitative indicators alone do not capture. These perspectives appear throughout the report and in dedicated Tribal Connections sections.

Broad interconnected themes emerge across the indicators. Climate change is altering the systems that store and deliver water, increasing the severity and scale of wildfire, intensifying extreme heat, reshaping terrestrial ecosystems, transforming coastal and ocean environments, and impacting our health and well-being. Warming affects whether precipitation falls as rain or snow, when runoff reaches rivers and reservoirs, how quickly vegetation dries, the conditions under which wildfires burn, and the ability of people to recover from heat overnight. Across land and ocean, species are responding to changes in temperature, habitat, and the timing of seasonal events. The resulting risks are greatest where exposure is high, and the resources needed to prepare, adapt, or recover are limited.

Water System and Snowpack

California's water system developed around predictable mountain snowpack and spring runoff. Warming shifts more precipitation from snow to rain, snow melts earlier, and runoff reaches rivers and reservoirs sooner. This creates a growing mismatch between

when water is available and when agricultural, municipal, and ecological demand is greatest. Across the state's long-term snow courses, 78% show declining April 1 snow-water equivalent trends. April 1 historically marks the approximate peak of seasonal snowpack. Peak runoff occurs earlier in many watersheds, reducing the natural storage function once provided by mountain snowpack. Glaciers in the Trinity Alps disappeared entirely by 2023, marking the complete loss of a feature tracked by an indicator. In the Sierra Nevada, glaciers have lost an average of 75% of their area since 1903.

These changes are affecting ecosystems and communities. Rivers that support salmon are also warming, with the South Fork Salmon River warming at a rate of 1.76°F per decade, contributing to declines in salmon populations and disrupting freshwater ecosystems. California's commercial salmon fishing recently reopened in summer 2026, after an unprecedented three-year sequence of closures in 2023 through 2025. Declines in salmon populations also impact tribes throughout the Klamath and Sacramento watersheds, as salmon are integral to food systems and cultural practices.

Water insecurity is also increasing. During the 2012–2016 drought, more than 2,000 domestic wells ran dry, with failures concentrated in low-income, rural, and Hispanic/Latino communities in the Central Valley and Sierra Nevada foothills. Because securing alternative water supplies or replacing or deepening a well can be costly, well failures may place a greater burden on communities with fewer financial resources.

Wildfire, Extreme Heat, and Health

California's largest wildfires have become larger and more frequent, with average annual acreage burned from 2020 through 2024 reaching 5.7 times the pre-2000 average. All but two of the largest wildfires in California's recorded history have occurred since 2000, including nine in 2020 and 2021. As fires have grown, wildfire smoke has expanded the reach of its health impacts far beyond the fire perimeter. Californians now experience approximately 66 wildfire smoke days per year, nearly twice the average before 2017. Wildfire smoke contains fine particulate matter and other hazardous compounds that can aggravate respiratory and cardiovascular disease and affect mental health.

Extreme heat has also become more frequent with minimum nighttime temperatures rising by about 3.9°F since 1895, faster than daytime temperatures statewide. Warmer nights reduce the body's ability to recover from daytime heat, increasing physiological strain during prolonged heat events.

In 2020, concurrent smoke and extreme heat affected 68% of California's land area, exposing an estimated 16.5 million people to at least one compound event. Smoke impairs respiratory and cardiovascular function, while extreme heat increases physiological strain. Outdoor workers, including farmworkers and firefighters, face occupational exposure with limited ability to reduce work intensity or avoid hazardous conditions. Higher rates are reported among Black Californians, women, adults aged 50 to 64, and young children.

Official death records may underestimate heat-related mortality because heat can worsen underlying health conditions without being identified as the primary cause of death.

Terrestrial Ecosystems and Wildlife

Warming, drought, and wildfire are altering California's forests, wildlife communities, and seasonal cycles. An estimated 243 million trees died in California's forest lands between 2010 and 2024, driven by higher temperatures and reduced water availability. Large tree densities have declined by approximately 50% in the Sierra Nevada highlands, Coast Ranges, and forests across northern California, while small tree densities have increased in many regions. These shifts are associated with greater fuel continuity and can increase the potential for high-severity wildfire.

Wildlife ranges are shifting as well. In the Sierra Nevada, 25 of 34 small mammal species surveyed have shifted their elevational ranges over the past century, with upslope movement occurring more than twice as often as downslope movement. For California tribes, these changes carry cultural as well as ecological consequences: pinyon pines and oaks, whose nuts and acorns are central to food traditions across tribes statewide, are among the species affected.

Ocean Warming, Acidification, and Coastal Impacts

Ocean acidification and marine heatwaves are altering conditions for marine life, while rising seas are reshaping risks along the coast. Six of the last seven years have seen record marine heatwaves. As atmospheric carbon dioxide concentrations increase, the ocean absorbs more of it, which in turn changes ocean chemistry in ways that affect the growth and survival of oysters, mussels, crabs, and other ecologically and economically important shell-forming organisms. Sea levels off California are now rising at three times the 20th-century rate. In southern Humboldt Bay, relative sea level rise is rising at 2-3 times the California coastal average, driven in part by local land subsidence. For the Wiyot Tribe, whose homeland encompasses Humboldt Bay, rising water threatens access to traditional cultural sites, subsistence lifeways, and tribal infrastructure.

Compounding Risks and Uneven Consequences

Taken together, these indicators describe a state in which the consequences of climate change are increasingly visible across water systems, wildfire, human health, terrestrial ecosystems, and the ocean. These changes do not unfold independently. Climate impacts often compound one another, and their consequences are greatest for communities with higher exposure or fewer resources to prepare for and recover from climate hazards, including many tribes, rural, low-income, and historically marginalized communities. Drought and warming contribute to tree mortality and dry vegetation, increasing wildfire risk. Earlier snowmelt alters summer water availability and river temperatures. Extreme heat can coincide with wildfire smoke, increasing physiological stress. Marine heatwaves can disrupt ecological relationships in ways that persist long after ocean temperatures return to more typical conditions.

California has tracked these indicators for more than two decades, and over that period, the nature of the evidence has changed. Earlier ICC editions established clear trends in temperature, snowpack, sea level, wildfire, and other measures of California's changing climate. This edition increasingly documents what follows from those trends: glaciers disappearing, three consecutive years of commercial salmon fishery closures, extensive forest mortality and vegetation change, and millions of Californians exposed to extreme heat and wildfire smoke at the same time. Some systems change gradually; others can

shift rapidly when multiple pressures converge, with recovery remaining limited long after the initial disturbance has passed. The evidence increasingly shows that these trends are becoming more apparent, more interconnected, and in some cases more persistent. Continued tracking provides the observational record needed to understand these changes, identify where risks are accelerating, and determine where adaptation and recovery may become more difficult. It can also show whether efforts to reduce emissions and protect people and ecosystems are keeping pace with the changes already underway.



California's climate continues to change, and the evidence is visible across the state. Temperatures are rising, extreme heat events are becoming more frequent and lasting longer, and wildfires are burning more extensively and producing more smoke. Changes in the timing and form of precipitation are affecting the water supplies that support communities, agriculture, and aquatic ecosystems. These changes often interact, increasing their effects on people, ecosystems, and infrastructure. This fifth edition of the *Indicators of Climate Change in California* documents that evidence.

The Office of Environmental Health Hazard Assessment (OEHHA) prepares this report on behalf of the California Environmental Protection Agency. Under state law (Public Resources Code Section 71080 et seq.), OEHHA is the lead agency responsible for developing and maintaining environmental indicators for the Agency. The report brings together indicators that track climate change, its drivers, and its impacts. Indicators are scientifically based measurements of observed phenomena that describe and facilitate communication about the various aspects of climate change.

The first edition, published in 2009, presented 27 indicators of climate change in California that were consistent with observations worldwide. Since then, evidence that human activities are causing climate change has become unequivocal, and advances in monitoring, satellite observations, paleoclimate records, and computer modeling have improved scientists' understanding of the climate system and extreme events. California has continued to experience the trends documented in earlier editions, including rising air, ocean, and freshwater temperatures; greater year-to-year variability and extremes in precipitation; rising sea levels; declining spring snowmelt; and increasing wildfire activity. This edition documents the longer-term effects on water resources, fire regimes, forests, ocean conditions, and human health. For some indicators, gradual trends have become persistent conditions, with little recovery towards prior baselines after extreme events (e.g., heat waves, longer droughts, large wildfires) have passed.

Tribal knowledge and experience are an important part of this report. California tribes have observed ecological conditions across their ancestral lands for generations, providing records of environmental change that extend well beyond the period of instrumental measurement. This edition includes a dedicated volume presenting knowledge, observations, and perspectives contributed by California tribes on the direct and indirect effects of climate change on their lives, livelihoods, and ecosystems. Tribal Connections also appear throughout the report to highlight tribal knowledge and observations for specific indicators.

More than 100 scientists and researchers from state and federal agencies, academic institutions, and research organizations, and 8 California tribes contributed to this report.

Their work reflects California's continued reliance on scientific evidence to inform climate policy. This report adds to the scientific record on climate change and its effects in California. It complements California's Fifth Climate Change Assessment, also to be released this year, which presents research and projections on climate-related risks and vulnerabilities; the California Climate Adaptation Strategy, which describes the state's efforts to prepare for climate impacts; and the AB 32 Climate Change Scoping Plan, which sets out California's approach to reducing greenhouse gas emissions and reaching carbon neutrality. The report is also intended as a resource for scientists, educators, decision-makers, and the public.

Report Structure and Content

The report is organized into seven volumes. Volume 1 addresses the human drivers of climate change, including greenhouse gas emissions and atmospheric concentrations. Volume 2 presents observed changes in temperature, precipitation, drought, extreme heat, and degree days. Volumes 3 through 5 examine impacts on coastal and freshwater resources, terrestrial and vegetation, and human health. Volume 6 presents knowledge, observations, and perspectives contributed by California tribes. Volume 7 covers emerging climate change issues, which are environmental changes that may be influenced by climate change but for which the relationship has not yet been fully established.

Of the 49 indicators presented in the first five volumes of this report, 6 are new, 28 have been updated with new data (including nine indicators with additional metrics), 8 have been updated with relevant information but no new data, and 7 are unchanged from the Fourth Edition (2022).

Each indicator contains one or more graphs or maps showing changes over time, followed by sections addressing:

- What does the indicator show?
- Why is the indicator important?
- What factors influence the indicator?
- Technical considerations
- Contributors
- References

Where applicable, indicators also include Tribal Connections sections describing how tribal knowledge and observations relate to the indicator. The Impacts on Tribes Volume is organized as eight standalone reports: three are new in this edition, four are updated with data that have become available since 2022, and one is a returning report with no new updates. Three tribal reports from the prior 2022 edition are retained as archived references for continuity with earlier assessments.

The Emerging Indicators Volume examines environmental changes that may be influenced by climate change but for which the available evidence is not yet sufficient to establish the relationship. The potential connection is supported by scientific hypotheses, models, or limited observational data. Other influences, including land use, environmental pollution, and natural climate variability, can make attribution difficult. Additional data and analysis are needed to determine the role of climate change.

OEHHA continually reviews scientific literature and publications from government agencies, research organizations, and academic institutions to update existing indicators and identify new ones. OEHHA will continue to update this report periodically and welcomes input from researchers, government agencies, tribal governments, nongovernmental organizations, and other interested parties. The indicators are intended to track the major dimensions of climate change in California and support informed discussion of the state's efforts to monitor, prepare for, and reduce its impacts.



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Introduction

Earth's climate is a complex, interactive system influenced by the atmosphere, land surfaces, water bodies, snow and ice, and living organisms. Natural factors such as solar radiation and volcanic eruptions have driven climate fluctuations throughout Earth's history, but since the mid-20th century, human activities have become the dominant force. Widespread combustion of fossil fuel, industrial processes, and land use have dramatically increased concentrations of greenhouse gases (GHGs), altering the climate at a pace unlike any natural cycle.

Carbon dioxide (CO_2) is the largest contributor to the human-induced climate change. Atmospheric CO_2 concentrations have increased approximately 150 parts per million (ppm) since the Industrial Revolution, rising from 315 ppm in 1958 to 426 ppm in 2025. Because CO_2 can persist in the atmosphere for centuries, these elevated levels will likely stay above 400 ppm even if GHG emissions were to stop today, contributing to continued warming for generations (Forster et al., 2026; IPCC, 2023). Increases in other GHGs, such as methane and hydrofluorocarbons, in addition to black carbon emissions, also contribute to warming. In California, rising GHGs concentrations are reshaping air temperatures, snowpack and water resources, wildfire fuels, and public health.

The environmental impacts of climate change are increasingly affecting people's lives, experienced disproportionately by low-income populations and communities of color, and California has moved aggressively to address the drivers. The state reached its target of reducing GHG emissions to 1990 levels by 2020, and emissions have continued to decline. The 2022 California Air Resources Board (CARB) Scoping Plan

charts a sector-by-sector pathway to carbon neutrality by 2045 or earlier, with co-benefits that include meaningful reductions in co-pollutant burdens and improved health outcomes for overburdened communities. California is also advancing nature-based solutions to enhance the capacity of natural lands to remove carbon from the atmosphere while supporting biodiversity and building community resilience.

The three chapters that follow – Greenhouse Gas Emissions, Atmospheric Greenhouse Gas Concentrations, and Atmospheric Black Carbon Concentrations – document the current state of these drivers and California's ongoing efforts to reduce them.

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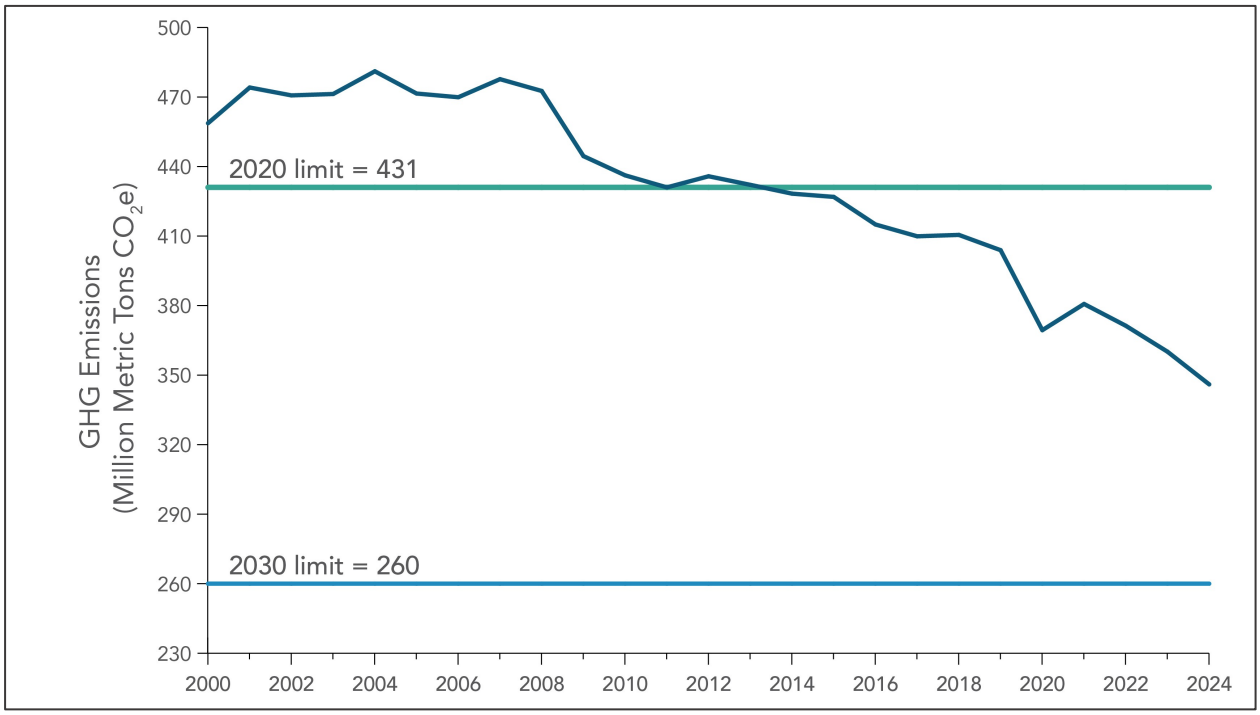
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1.1 Greenhouse Gas Emissions

California has made sustained progress in reducing greenhouse gas (GHG) emissions. Statewide emissions peaked in 2004 and have since declined, while California's economy has grown, demonstrating that economic growth and environmental protection can go hand in hand. Statewide emissions have remained below the 2020 GHG emissions reduction target since 2014, six years before the target year, and the downward trend continued through 2024. This progress stands in contrast to global GHG emissions, which reached a new peak in 2023. California's statutory targets require statewide GHG emissions to be reduced to at least 85% below 1990 levels and for the state to achieve economywide carbon neutrality by 2045.

Figure 1.1.1. Annual Statewide GHG Emissions (2000-2024).



The graph shows statewide GHG emissions in California. Emissions of GHGs other than carbon dioxide (CO_2) are converted to carbon dioxide equivalents, or CO_2e, based on their global warming potential (GWP)*. The 2020 GHG emissions limit of 431 million metric tons of CO_2e and 2030 emissions limit of 260 million metric tons of CO_2e are shown as well.

*GWP represents the warming influence of different GHGs relative to CO_2 over a given time period and allows the calculation of a single consistent emission unit, CO_2e. Current international practice, as defined by the Intergovernmental Panel on Climate Change (IPCC) Guidelines, uses 100 years as the GWP timeframe for GHG Inventories. GWPs are updated

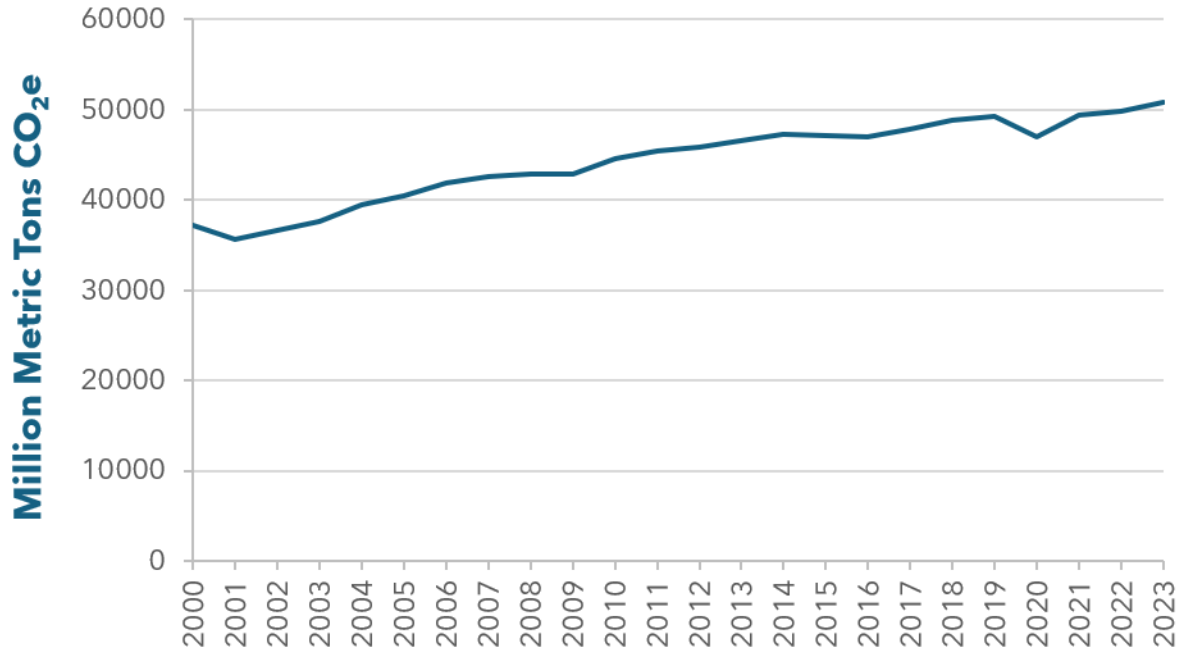
periodically to reflect the latest science. This report uses GWPs from the IPCC's Fourth Assessment Report (IPCC, 2006) unless otherwise noted.

Source: California Air Resources Board (2026)

What does the indicator show?

Statewide GHG emissions in California are trending downwards (**Figure 1.1.1**). However, worldwide GHG emissions continue to trend upwards (**Figure 1.1.2**; WRI, 2026).

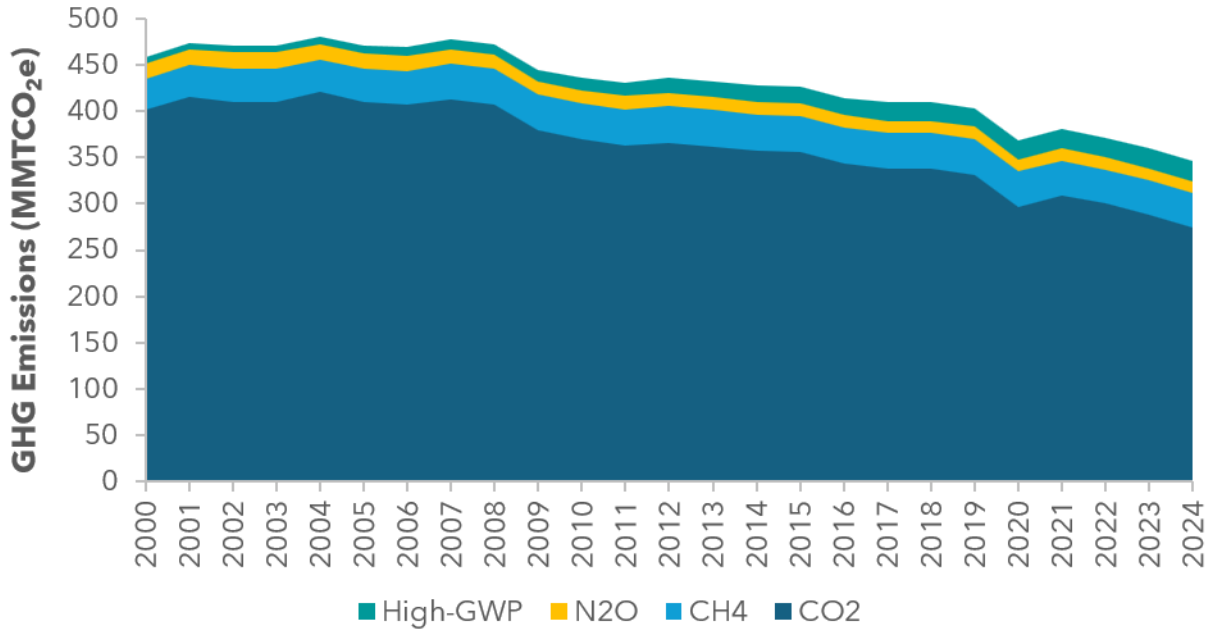
Figure 1.1.2. Global GHG Emissions: 2000-2023.



The graph shows global GHG emissions in million metric tons CO_2e based on their 100-year global warming potential (GWP) values. Source: WRI (2026)

Figure 1.1.3 shows California's combined emissions of GHG carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and others with a high global warming potential (high-GWP) (CARB, 2026).

Figure 1.1.3. GHG Emissions in California, 2000-2024, Disaggregated by Pollutant.



Source: CARB (2026)

CO_2 accounted for the largest proportion of GHG emissions, making up about 80% of the total in 2024. In comparison, CH_4 and N_2O accounted for about 10% and 4% of total GHG emissions, respectively. The remaining 6% of GHG emissions consisted of high-GWP gases including hydrofluorocarbons (HFC), perfluorocarbons (PFC), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).

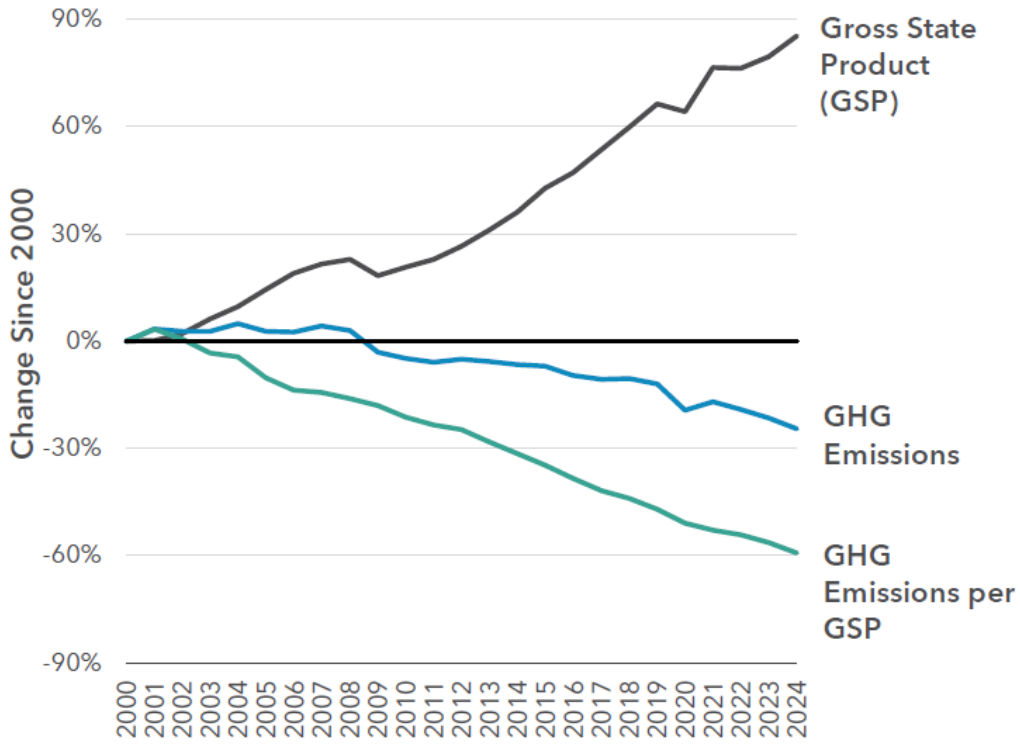
Methane and a subset of HFCs[1] are also considered short-lived climate pollutants (SLCPs), which are powerful climate forcers that remain in the atmosphere for a much shorter time period than longer-lived climate pollutants such as CO_2. Black carbon, a class of particulate matter, is also considered a SLCP. Black carbon causes warming, not because it's a GHG that traps infrared radiation, but because it absorbs sunlight and converts it to heat, directly warming the atmosphere. Unlike long-lived gases like CO_2,

[1] These include HFC-152a, HFC-32, HFC-245fa, HFC-365mfc, HFC-134a, HFC-43-10mee, HFC-125, HFC-227ea, and HFC-143a.

its warming effect is immediate, making it a key target for fast-acting climate solutions (see the *Atmospheric Black Carbon Concentrations* chapter).

Figure 1.1.4 shows that California's GHG emissions per dollar of gross state product (GSP, a measure of the state's economic output) declined between 2000 and 2024. California's 2024 GHG emissions were over 20% lower than in 2000, and emissions per dollar of GSP (carbon intensity) have declined by about 60%. A combination of factors contributed to this decrease in carbon intensity of the California economy. These factors include growth in renewable energy sources, carbon pricing from the Cap-and-Invest and Low Carbon Fuel Standard Programs, a reduced vehicle emissions rate, incrementally higher energy efficiency standards, and other regulations, programs, and initiatives.

Figure 1.1.4. Change in California's GSP and GHG Emissions Since 2000.



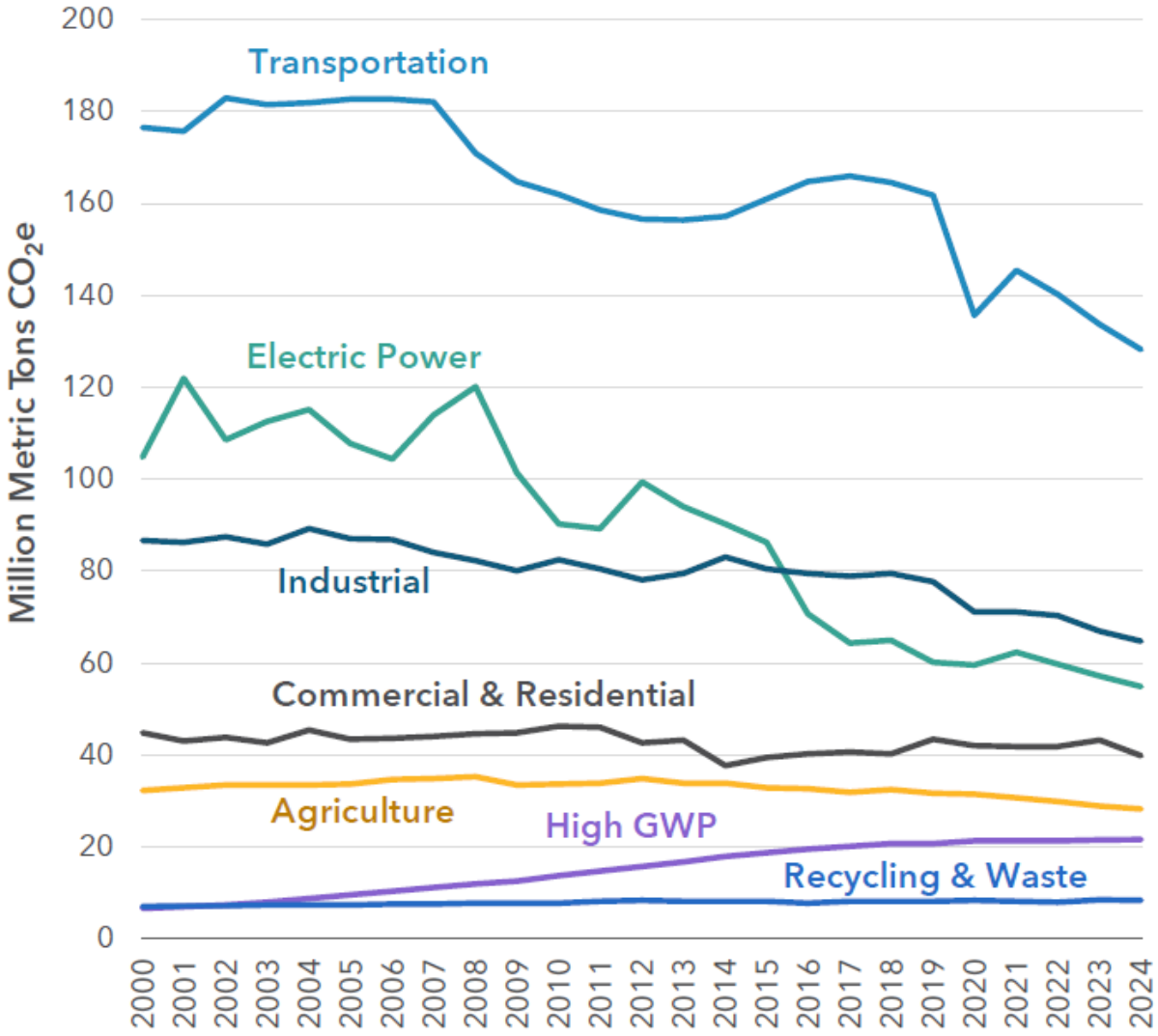
Sources: CARB (2026); DOF (2026)

Figure 1.1.5 shows GHG emissions from 2000 to 2024, organized by sector as defined in the California Air Resources Board's (CARB) 2022 Scoping Plan for Achieving Carbon Neutrality (*2022 Scoping Plan*) (CARB, 2022). The transportation and electric power sectors are the primary drivers of year-to-year changes in statewide emissions. Some of the factors affecting emissions from these sectors are discussed below. A detailed discussion of factors affecting emissions trends in all sectors can be found in CARB's annual report titled "California GHG Emissions from 2000 to 2024: Trends of Emissions and Other Indicators" (CARB, 2026).

Transportation sector emissions have generally decreased since their peak in 2002 but have experienced periods of both emissions growth and decline. Several factors can influence transportation sector emissions. These include vehicle miles traveled, vehicle GHG emissions rates, the number of zero-emission vehicles on the road, and the amount of fuel derived from non-fossil resources. Year-to-year changes in economic conditions can also impact the amount of transportation fuel used across the state.

Emissions from the electric power sector include both emissions from in-state generation and imported electricity. Electricity sector emissions are primarily driven by fossil gas combustion such that years with low hydropower availability typically lead to increased emissions, as more fossil gas is required to fulfill the remaining demand. The increased production of zero-GHG resources, such as solar and wind, in California, along with imports from other western states, has also reduced demand for fossil gas generation over time.

Figure 1.1.5. Trends in California GHG Emissions Disaggregated by Scoping Plan Sector.



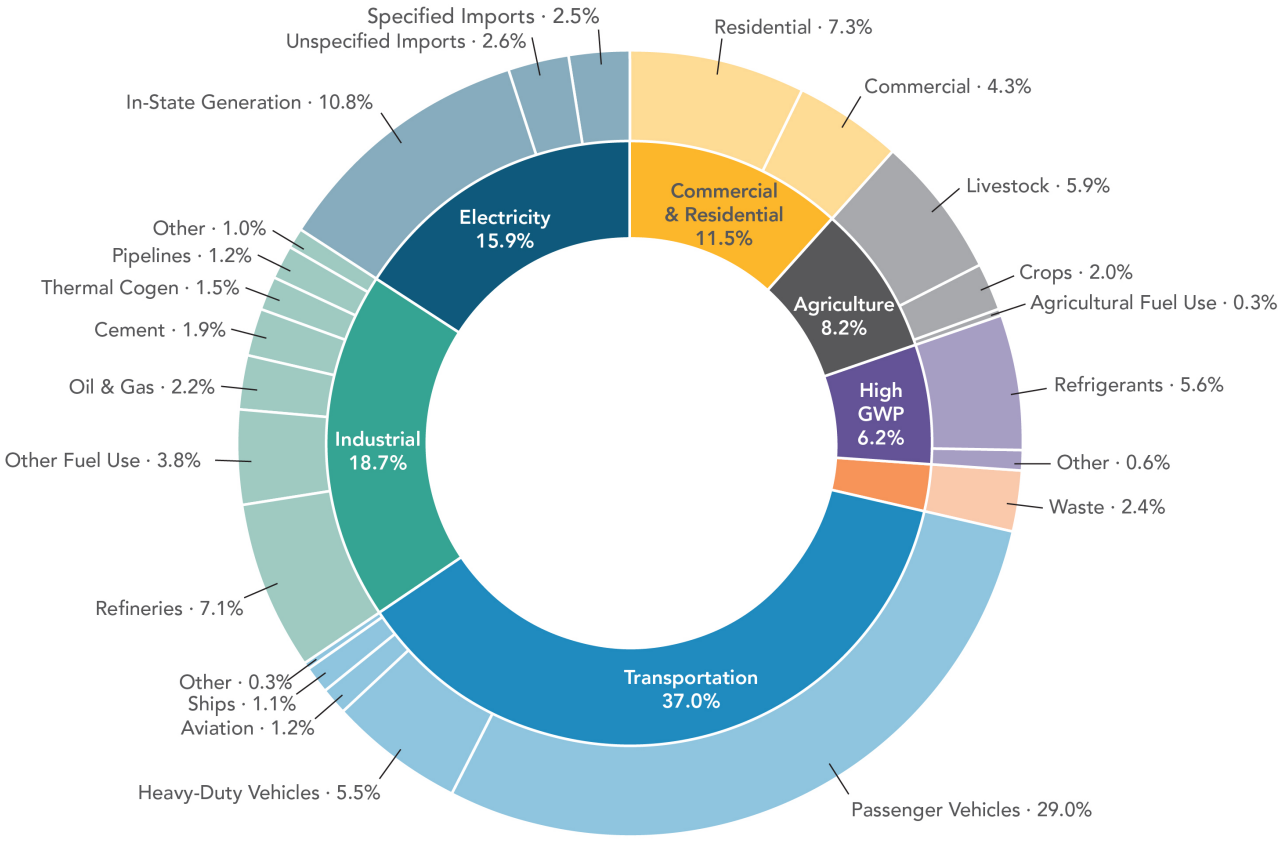
Note: High-GWP gases do not represent an "economic sector," but are grouped into a single Scoping Plan sector for purposes of organizing and tracking emissions, sources, and emissions reduction strategies.

Source: CARB (2026)

Figure 1.1.6 shows 2024 GHG emissions by *Scoping Plan* sector and sub-sector. Transportation was the largest emitting sector, accounting for 37.0% of the total emissions. Cars, light duty trucks, and sport utility vehicles are the highest contributor to

transportation emissions. Industrial activities accounted for 18.7% of emissions and include fossil fuel combustion and fugitive emissions from a wide variety of sources such as petroleum and alternative fuels refineries, oil and gas production and processing, and cement plants. The electricity sector (in-state generation and electricity imports) accounted for 15.9% of emissions. Commercial and residential sources collectively accounted for 11.5% of emissions. Emissions from the agricultural sector, which are mainly from livestock, contributed 8.2%. High-GWP gases, which are primarily used in refrigeration and air conditioning, comprised 6.2% of emissions. Finally, waste contributed 2.4% with most of this sector's emissions coming from landfills.

Figure 1.1.6. 2024 GHG Emissions by Scoping Plan Sector and Sub-Sector.



Source: CARB (2026)

Together, these trends indicate that while global GHG emissions continue to rise, California has made measurable progress toward its statutory climate targets. This progress is guided by the *2022 Scoping Plan*, which lays out a path to achieve targets for carbon neutrality and reduce statewide anthropogenic GHG emissions by 85% below 1990 levels no later than 2045, as directed by Assembly Bill 1279.

Why is this indicator important?

Atmospheric concentrations of GHGs have increased since the Industrial Revolution, enhancing the heat-trapping capacity of the Earth's atmosphere. Global temperatures are directly linked to GHG levels in the atmosphere. Atmospheric GHG concentrations are determined by the balance between GHG emissions and removals on a global scale. The most recent data from the National Oceanic and Atmospheric Administration indicate that global CO_2 concentrations are over 50% higher than pre-industrial levels, with June 2025 measurements reaching approximately 426 parts per million (ppm), compared to the pre-industrial average of around 280 ppm. Accurately tracking GHG emissions trends, both globally and in California, provides critical information to policymakers as they assess climate change mitigation options and track the progress of GHG emissions reduction programs.

GHG emissions reduction targets are intended to prevent atmospheric concentrations from reaching levels at which catastrophic and irreversible impacts occur. Fossil fuels are the largest contributor to global climate change, accounting for around 68% of global GHG emissions and nearly 90% of CO_2 emissions (UN, 2025). The 2015 Paris Agreement aims to limit warming to below 3.6°F (2°C) above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 2.7°F (1.5°C) (UNFCCC, 2016). These efforts would significantly reduce the risks and impacts of climate change (Xu and Ramanathan, 2017). However, if global emissions continue to increase at the current rate, global warming is likely to reach 2.7°F (1.5°C) by the 2030s, and no later than 2040 (IPCC, 2023).

While California is responsible for a relatively small percentage of global GHG emissions, the state must do its part to reduce them. California plays an important role in exporting both political will and technical solutions to address the climate crisis

globally and many of our environmental policies have served as models for other localities. California's pioneering efforts in the adoption and implementation of policies are reducing our GHG emissions.

In 2024, nearly three-quarters of California's GHG emissions came from the combustion of fossil fuels. Globally, the combustion of these fuels is a primary contributor to climate change. The combustion of fossil fuels emits not only GHGs, but also harmful localized air pollutants such as particulate matter (PM) 2.5, volatile organic compounds including air toxics, and nitrogen oxides, which pose known risks to public health and can combine in the atmosphere to form other pollutants. Health hazards from air pollution include increased risk of asthma and other respiratory illnesses, hospitalizations and emergency department visits, cardiovascular disease, and premature death. Low-income communities and communities of color are often located adjacent to major roadways and large stationary sources of emissions; thus, these communities are disproportionally exposed to the effects of these localized pollutants. Overburdened communities may also be exposed to multiple pollution sources and factors such as less access to health care. Therefore, eliminating our dependence on fossil fuels through actions like moving to zero-emission cars and trucks and decarbonizing local industries and the electricity sector will advance our climate goals and deliver health benefits to the most impacted communities. The *2022 Scoping Plan* lays out a sector-by-sector roadmap for California to achieve carbon neutrality by 2045 or earlier. CARB conducted a health analysis of the proposed actions in the *2022 Scoping Plan* roadmap to estimate statewide health benefits by 2045 of implementing those actions. CARB estimated $200 billion in health benefits by 2045 including avoided early deaths, illnesses, hospitalizations, and other positive health outcomes. In addition, CARB also developed a Public Health Appendix (Appendix G) in the *2022 Scoping Plan* to evaluate co-benefits of proposed climate actions and discuss ways to reduce vulnerability in communities. The co-benefits evaluated included reduced traffic pollution, increased access to urban green spaces, reduced exposure to wildfire smoke, increased mobility and physical activity through active transportation, and reduced heat related illnesses. CARB found that climate actions and related co-benefits could provide large public health benefits and increase community resilience to climate effects.



Because the impacts of climate change will be highly unequal across California's communities, the *2022 Scoping Plan* also introduced a Climate Vulnerability Metric (CVM). CVM aggregates the impacts of climate change across nine components (e.g., human mortality, flood-related property damage). The impacts can be quantified at the census tract level to show how human welfare in communities will be affected by a warming climate. The impacts on human welfare through 2050 are shown as a percentage of census tract-specific incomes. The CVM metric can be used by policymakers to identify vulnerable communities and direct funding.

What factors influence this indicator?

Statewide GHG emissions reflect activities across all major economic sectors, which are influenced by a variety of factors, including population growth, vehicle miles traveled, economic conditions, consumer behavior, technological changes, drought and heat events, regulations, and other factors.

GHGs are emitted from a variety of sources, but most notably from the combustion of fossil fuels used in the electric power, industrial, commercial, residential, and transportation sectors. GHG emissions also occur from the use of high-GWP gases and non-combustion activities in the recycling and waste and agriculture sectors. A detailed discussion of emissions trends by *Scoping Plan* sector is provided on CARB's GHG Emission Inventory Data webpage (CARB, 2026).

Technical considerations

Data characteristics

A GHG inventory is an estimate of GHG emissions over a specified area and time period from known sources or categories of sources. Emission inventories generally use a combination of two basic approaches to estimate emissions. The "top-down" approach utilizes nationwide or statewide data from various federal and state government agencies to estimate emissions. The "bottom-up" approach utilizes facility-level activity data to compute facility-level emissions that are then aggregated to the state level for a particular source category. In either approach, calculation assumptions are made to estimate statewide GHG emissions from different levels of activity data. California's

GHG Inventory uses California-specific data and methods to the extent possible. When not possible, the methods used typically reference either the 2006 IPCC Guidelines for National GHG Inventories (IPCC, 2006) or the U.S. Environmental Protection Agency's Inventory of U.S. GHG Emissions and Sinks (US EPA, 2024).
Atmospheric measurements and modeling can also be used to estimate total emissions across a broad area. This approach can serve as an independent check on inventory estimates, helping to identify opportunities for improvement.

Strengths and limitations of the data

The methods used to develop the California GHG Inventory are consistent with international and national inventory guidelines to the greatest extent possible. Emission calculation methods are continually evaluated and refined over time, incorporating the latest scientific research and monitoring activities. Much of the data used for the California GHG Inventory – including statewide fuel consumption totals for major fuels and facility-level data for the largest emitting industrial sectors – is reported and verified pursuant to the Regulation for the Mandatory Reporting of GHG Emissions (CARB, 2019).

The California GHG Inventory includes emissions from anthropogenic sources located within California's boundaries. Pursuant to the California Global Warming Solutions Act of 2006 (Nuñez, Chapter 488, Statutes of 2006), also known as Assembly Bill 32, California's GHG Inventory also includes emissions from the generation of imported electricity. In accordance with international practice, California's GHG Inventory excludes emissions that occur outside the state during the manufacture and transportation of products and services consumed within the state (except for electricity). While those emissions are not included, it should be noted that California is a net exporter of multiple products, especially agricultural commodities, and California's GHG Inventory includes the in-state GHG emissions associated with these products. In addition, California's GHG Inventory does not reflect reductions outside California's boundaries achieved as part of international and sub-national collaboration efforts, or as a natural result of implementation of state programs.

OEHHA acknowledges the expert contribution of the following to this report:

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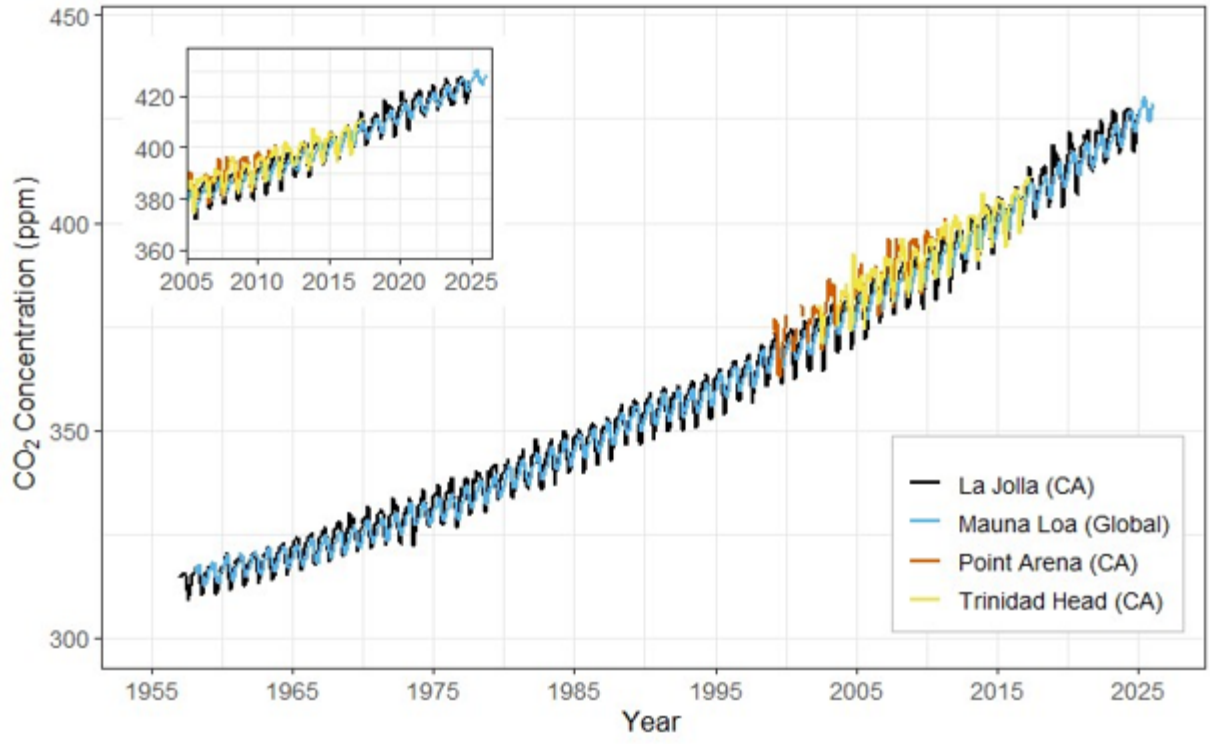
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1.2 Atmospheric Greenhouse Gas Concentrations

Atmospheric concentrations of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and certain fluorinated gases (F-gases) continue to increase globally and in California. The annual global average concentrations of CO_2 were 417 parts per million (ppm) in 2022, 419 ppm in 2023, 423 ppm in 2024, and 426 ppm for 2025 (NOAA, 2026a).

Figure 1.2.1. Monthly Average Atmospheric CO_2 Concentrations.



This graph shows CO_2 measurements at Mauna Loa (1958-present), and three coastal sites in California: La Jolla, Point Arena (1999-2011), and Trinidad Head (2002-2017). Source: NOAA (2026a), and Conway et al. (2011) (Mauna Loa, Point Arena, and Trinidad Head); SIO (2025) (La Jolla)

What does the indicator show?

Atmospheric concentrations of greenhouse gases are increasing globally (**Figure 1.2.1** through **Figure 1.2.4**). The ambient concentrations of the following greenhouse gases at the global background site of Mauna Loa on the island of Hawaii, as well as at regional background sites in California, are presented:

- carbon dioxide (CO_2),
- methane (CH_4),
- nitrous oxide (N_2O),
- a variety of fluorinated gases (F-gases).

Measurements are displayed in parts per million (ppm) for CO_2, parts per billion (ppb) for CH_4 and N_2O, and parts per trillion (ppt) for F-gases. These are units of air pollution mixing ratios commonly used to describe ambient air pollution concentrations (1 ppm = 1,000 ppb = 1,000,000 ppt).

Carbon dioxide (CO_2)

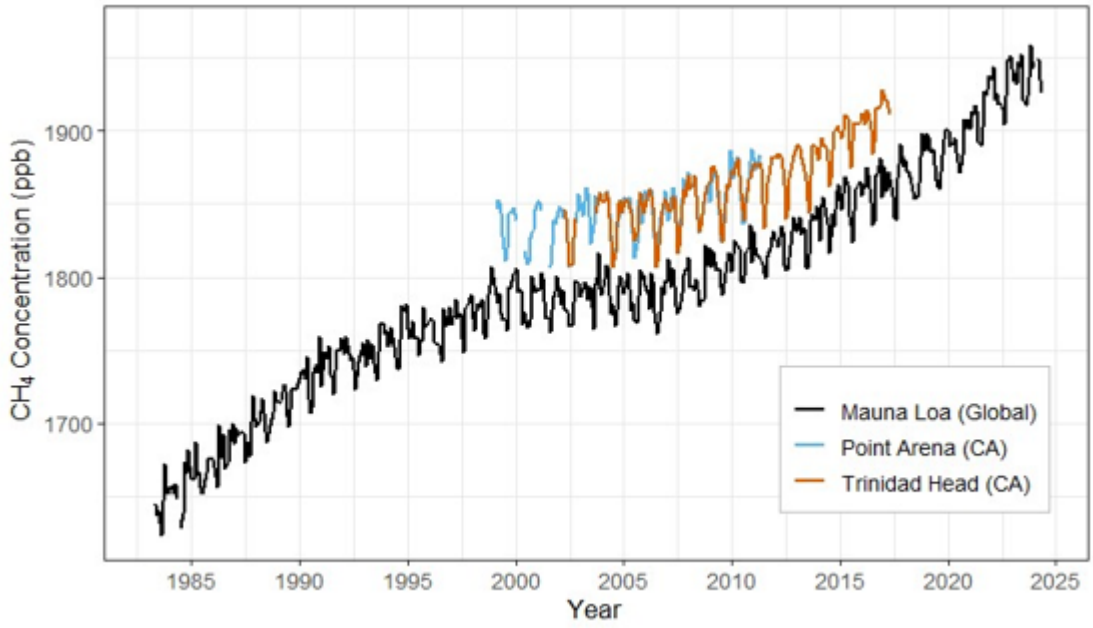
Annual average CO_2 concentrations measured at Mauna Loa have increased from 315 ppm in 1958 to 426 ppm in 2025, at an average rate of approximately 1.6 ppm per year over the past few decades, accelerating in the last five years to about 2.5 ppm per year. As shown in **Figure 1.2.1**, CO_2 exhibits a seasonal trend with increasing CO_2 levels observed from autumn through late winter and decreasing CO_2 levels from spring through late summer. This is due to seasonal biosphere-atmosphere interactions – that is, plants take up more CO_2 in spring and summer, then decay and release CO_2 in fall and winter along with subtle seasonal changes in anthropogenic fossil fuel use.

In the Northern Hemisphere, CO_2 concentrations tend to increase when moving north from the equator. This latitudinal gradient is largely a result of global population centers (and hence, sources of CO_2) being located at higher latitudes. As a result, CO_2 levels tend to be slightly higher at California sites than at Mauna Loa, and at northern California sites (Trinidad Head and Point Arena) than at La Jolla in southern California. California sites also tend to have higher variability than the Mauna Loa site, primarily due to their location on a major continent with large population centers and forested regions, which act as sources and sinks of CO_2, respectively.

Methane (CH_4)

Global CH_4 levels have increased since 1983, except for a brief period between 1999 and 2006 when they were relatively constant before increasing again starting in 2007. CH_4 concentrations in the pre-industrial era (i.e., pre-1750) were approximately 722 ppb (IPCC, 2013). By contrast, today's atmospheric CH_4 concentrations exceed 1900 ppb at Mauna Loa and the California sites – an increase of over 150% (**Figure 1.2.2**; NOAA, 2026b). Concentrations at the California sites are higher than those observed at Mauna Loa. As with CO_2, this is due to a strong latitudinal gradient that promotes elevated CH_4 concentrations in the northern latitudes, where more human activities lead to greater emissions (Frankenberg et al., 2005).

Figure 1.2.2. Monthly Average Atmospheric CH_4 Concentrations.



The graph shows CH_4 measurements at Mauna Loa (1983 to present), Point Arena (1999 to 2011), and Trinidad Head (2002 to 2017). Source: NOAA (2026b)

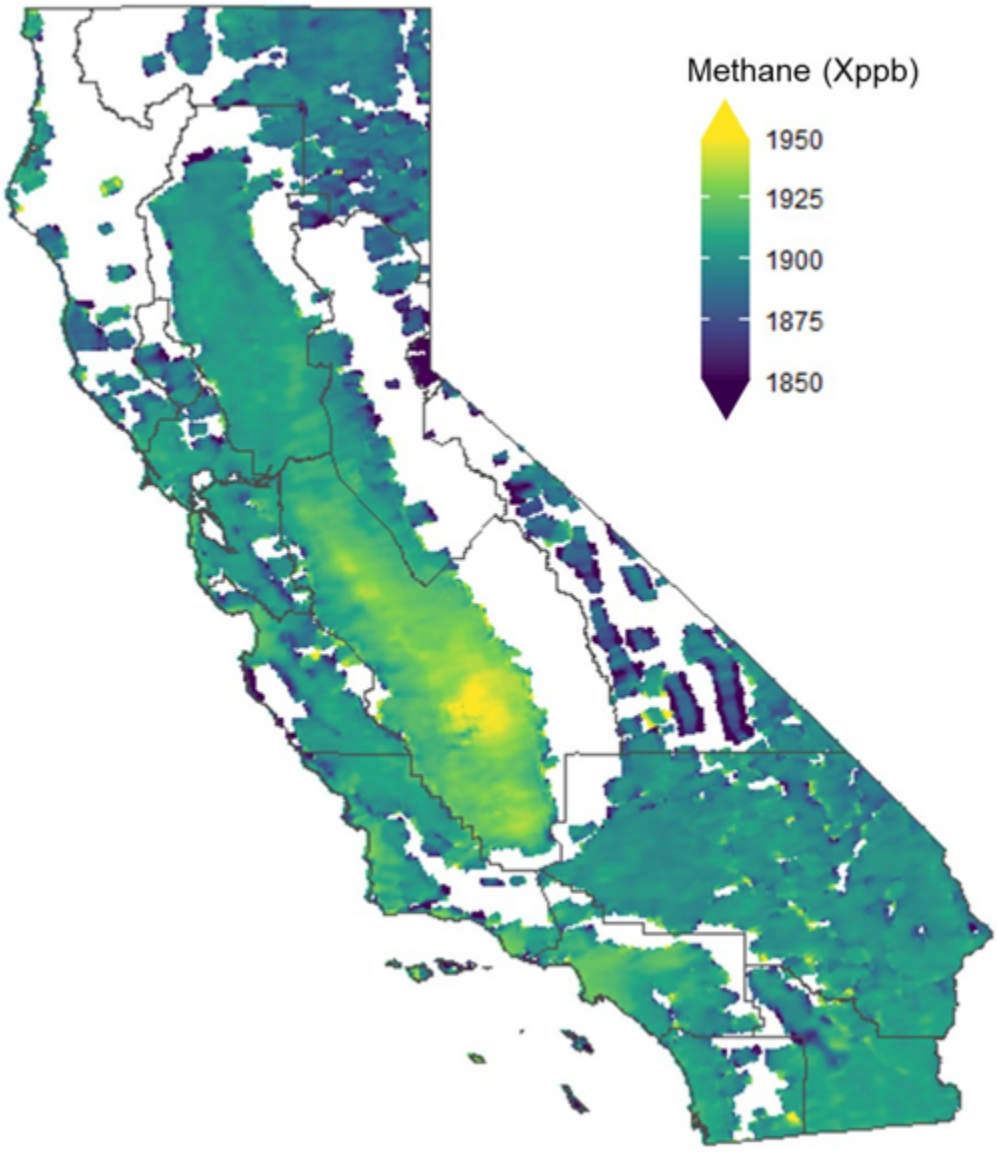
Regional sources of greenhouse gas emissions in California can lead to elevated concentrations above global background levels. Satellite data reveal significant subregional differences in CH_4 concentrations.

Figure 1.2.3 shows column-integrated CH_4 concentrations (Xppb) over California in 2023, measured by Tropospheric Monitoring Instrument (TROPOMI) (ESA, 2024). In addition to the monitoring and measurement efforts undertaken by various researchers, CARB has also funded several studies to utilize the atmospheric measurements from regional greenhouse gas monitoring sites to infer the most likely distribution and strength of regional CO_2, CH_4, and N_2O emission sources in California (Fischer and Jeong, 2016; Zhao et al., 2009; Cui et al., 2019). These top-down studies enhance understanding of California's methane emissions, supporting inventory findings that identify San Joaquin Valley as the largest regional contributor to the statewide methane emissions.

The following regions contribute the most to statewide CH_4 emissions (**Figure 1.2.4**; Jeong et al., 2016 and 2017; Cui et al., 2015 and 2019):

- San Joaquin Valley Air Basin: approximately 50% of total emissions, mainly from dairy farms and active oil and gas operations,
- South Coast Air Basin: about 20% of total emissions, primarily from oil and gas industries, landfills, and dairy farm operations,
- Sacramento Valley: about 10% of total emissions, primarily from agriculture and landfills
- San Francisco Bay Area: nearly 10% of the state's total CH_4 emissions, primarily from landfills, dairy livestock and fossil fuel sources.

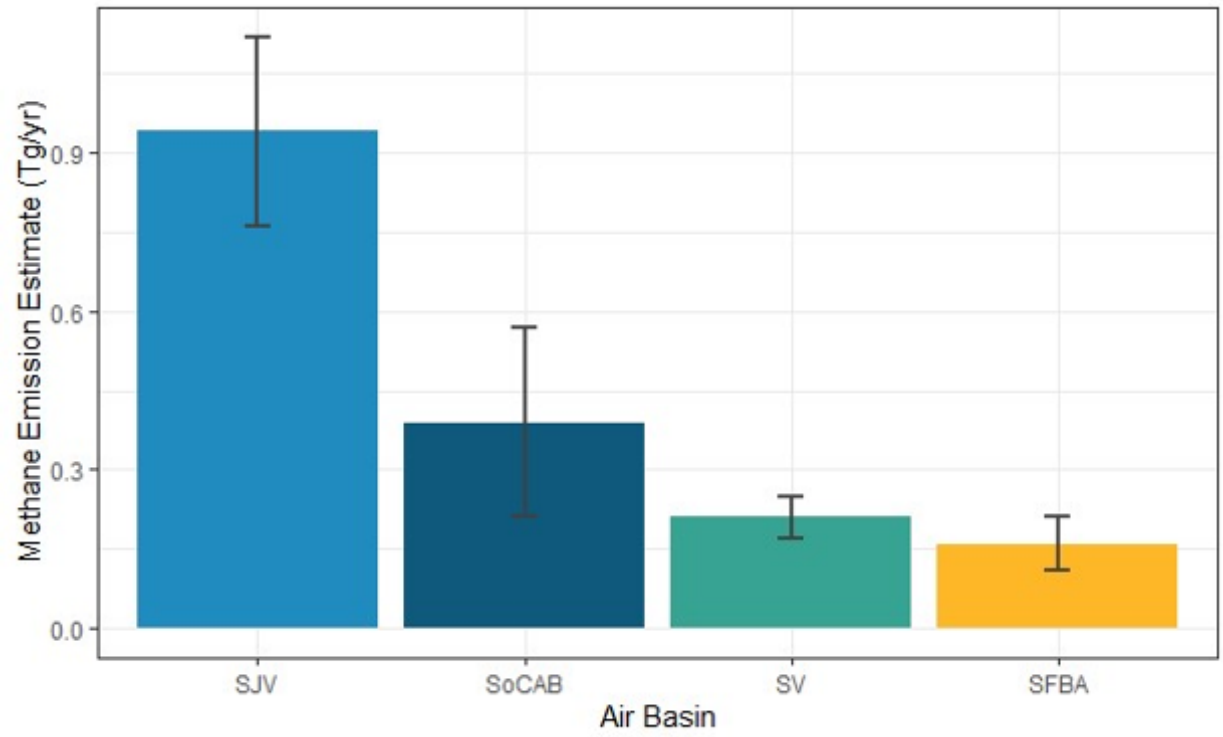
Figure 1.2.3. TROPOMI Satellite Observations of Methane over California in 2023*.



This figure shows TROPOMI satellite observations of methane over California in 2023. Methane is reported in Xppb, where “X” indicates a column-averaged mixing ratio rather than a surface value because the satellite measures the entire column of air from the sensor to the ground. Black lines designate air basin boundaries.

Source: ESA (2024)

Figure 1.2.4. Top-Down Regional Emission Estimates of Methane.

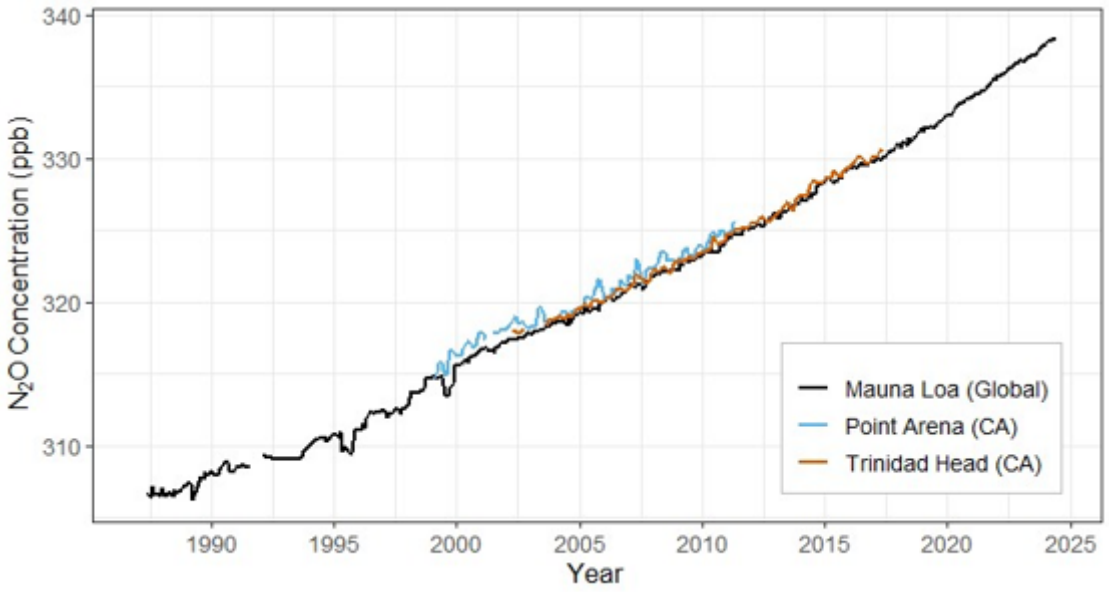


Methane emission estimates (Tg*/yr) for four major emission regions are presented below: San Joaquin Valley (SJV), Southern California Air Basin (SoCAB), Sacramento Valley (SV), and the San Francisco Bay Area (SFBA). *Teragram (Tg)=1 trillion grams=1 million metric tons; Source: Cui (2019)

Nitrous oxide (N_2O)

Global N_2O concentrations have been increasing at a rate of approximately 0.9 ppb per year over the past few decades (**Figure 1.2.5**). N_2O concentrations are now approximately 24% greater than the pre-industrial levels of 270 ppb (NOAA, 2026c). Global N_2O concentration trends do not display a strong seasonal cycle in the lower atmosphere.

Figure 1.2.5. Monthly Average N_2O Concentrations.



This graph shows the atmospheric concentrations of N_2O at Mauna Loa (1987 to present), Trinidad Head (2002 to 2017), and Point Arena (1999 to 2011). Source: NOAA (2026c)

Fluorinated gases (F-gases)

F-gases are potent greenhouse gases that can trap heat hundreds to thousands of times more effectively than CO_2 (i.e., they have a high global warming potential). They are entirely synthetic with no known natural sources. F-gases began to appear in the atmosphere in the 20th century, primarily because of their use as refrigerants, and in smaller amounts from aerosol propellants, foam blowing agents, fire suppressants, industrial solvents, and medical sterilants. Pre-industrial F-gas concentrations are assumed to be zero. Interest in atmospheric measurements of F-gases first began in the 1970s when they were linked to the destruction of stratospheric ozone (i.e., the "ozone hole") (Molina and Rowland, 1974).

Chlorofluorocarbons (CFCs): CFCs are strongly ozone-depleting, and their production and use were halted in 1996 under the Montreal Protocol (UNEP, 2012). Consequently, global ambient concentrations have been slowly decreasing since the mid-1990s. Although no new emissions are expected, CFCs remain in the atmosphere for decades after they are released. CFCs are now well-mixed throughout the atmosphere, and

there is no latitudinal gradient in atmospheric concentrations. Thus, Mauna Loa and Trinidad Head have nearly identical CFC levels.

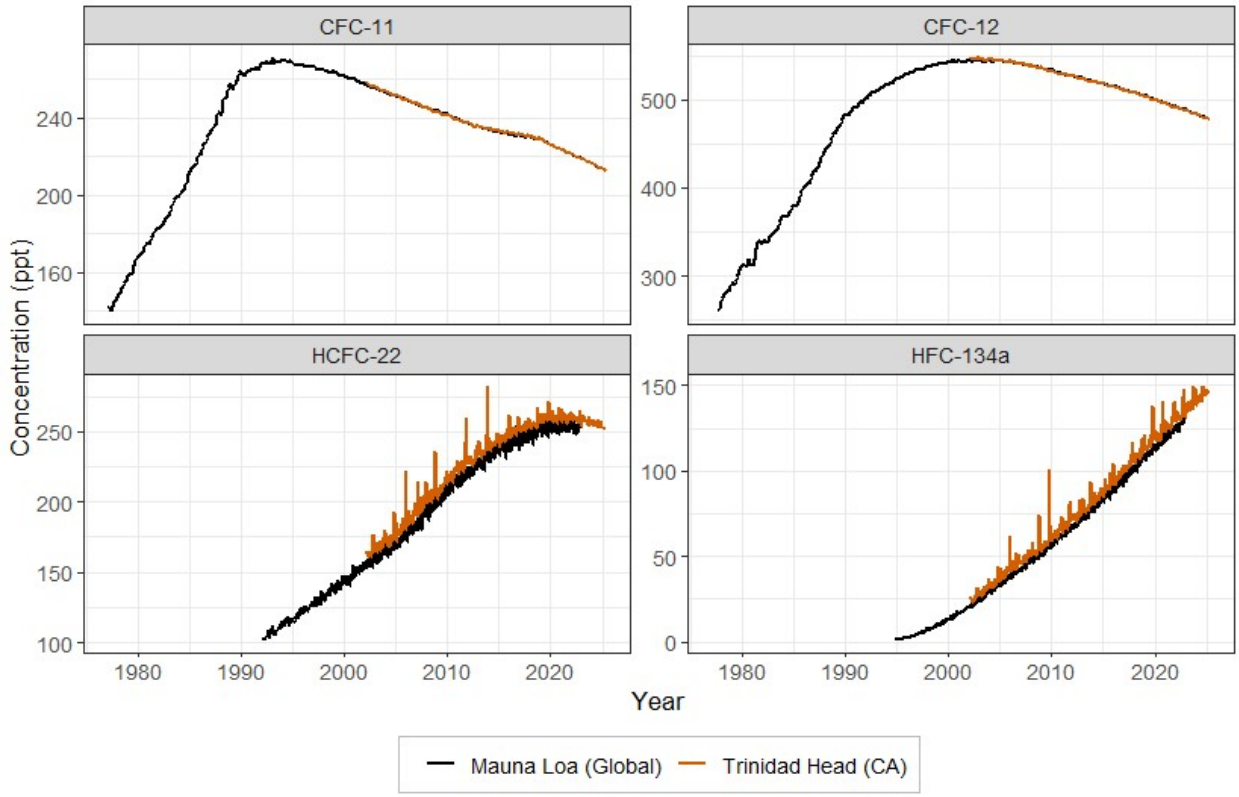
Hydrochlorofluorocarbons (HCFCs): HCFCs were an interim replacement for CFCs. While not as destructive towards stratospheric ozone as CFCs, HCFCs still have considerable ozone depletion potential and are also being phased out globally. Banned in the US and European Union, HCFC-22 still has limited use and production in developing countries. HCFC-22 has a latitudinal gradient that closely follows human population centers (i.e., higher levels in the mid-latitudes), thus levels are higher at Trinidad Head than at Mauna Loa. Ambient monitoring indicates an increasing HCFC-22 trend since the 1990s. Concentrations have begun to plateau in recent years as global phase-outs have ramped up.

Hydrofluorocarbons (HFCs): HFCs are refrigerants. They have negligible ozone depletion potential and thus have been widely used across the world since their introduction in the mid-1990s, despite their high global warming potential. First detected in the atmosphere in the 1990s, concentrations of one prevalent HFC (HFC-134a) have risen, but others have plateaued or decreased. HFC-134a concentrations have grown at approximately 5 ppt per year since 2005. Like HCFCs, HFC-134a levels follow population centers and display a latitudinal trend, whereby Trinidad Head typically experiences higher levels than Mauna Loa.

Figure 1.2.6 shows the atmospheric concentrations at Mauna Loa and Trinidad Head of the four most prevalent F-gases:

- trichlorofluoromethane (CFC-11),
- dichlorodifluoromethane (CFC-12),
- chlorodifluoromethane (HCFC-22),
- 1,1,1,2-tetrafluoroethane (HFC-134a)

Figure 1.2.6. Monthly Average F-gas Concentrations.



The graphs show monthly average concentrations with individually scaled y-axes chosen to best highlight the unique trends and patterns of each gas. Source: NOAA (2026d)

Why is this indicator important?

Global temperatures are directly linked to greenhouse gas levels in the atmosphere (IPCC, 2021). Greenhouse gas emissions reduction targets have been established to prevent atmospheric concentrations from reaching levels that would result in irreversible, catastrophic impacts (see the *Greenhouse Gas Emissions* chapter*).*

The 2015 Paris Agreement aims to hold the increase in the global average temperature to below 3.6°F (2°C) above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 2.7°F (1.5°C) above pre-industrial levels (UNFCCC, 2016). Atmospheric greenhouse gas concentrations help track changes in the emissions of anthropogenic drivers of climate change and their accumulation in, and removal from, the atmosphere.

Though all Californians are affected by climate change, disadvantaged communities often lack the financial resources to adapt to its effects and may therefore experience stronger negative impacts from extreme heat (see the *Extreme Heat Events* chapter), wildfire smoke (see the *Wildfire Smoke* chapter), and flooding (see the *Coastal Flooding* chapter). Due to structural and historical inequities, these communities may also face compounding vulnerabilities, including proximity to emission sources and reduced access to health. These factors can amplify health concerns in a warming climate (Casey et al., 2021; Lieb et al., 2025; Morello-Frosch and Obasogie, 2023).

CO_2 is a long-lived GHG responsible for approximately 65% of the total warming effect caused by greenhouse gases globally. It contributes about 80% of the current greenhouse gas emission inventory in California on a 100-year timescale (CARB, 2025a; WMO, 2016). CO_2 remains in the atmosphere for many centuries, so atmospheric levels may remain elevated for some time even if emissions are significantly reduced.

Additional atmospheric greenhouse gases amplify the warming driven by CO_2. CH_4 accounts for 25% of this added warming, while N_2O and F-gases together contribute less than 10% (IPCC, 2021; CARB, 2022). CH_4 and certain F-gases have a much shorter lifetime than that of CO_2 and are called “short-lived climate pollutants” (SLCPs). Even so, they could play a more important role in climate change than CO_2 owing to their greater 100-year global warming potentials as compared to that of CO_2.

The 100-year global warming potential is a standardized metric that compares the amount of heat trapped by a greenhouse gas over a 100-year period to the amount trapped by the same mass of CO_2 (CARB, 2025b). It allows scientists and policymakers to express the climate impact of different gases using a single, comparable value. CH_4 has a 100-year global warming potential of approximately 28 (i.e., 1 ton of CH_4 traps 28 times more heat over 100 years than 1 ton of CO_2) and remains in the atmosphere for about 12 years before removal, whereas F-gases such as HCFC-22 and HFC-134a have global warming potentials of over 1,000 and can remain in the atmosphere for one to two decades. On the other hand, N_2O has a 100-year global warming potential of 273 and remains in the atmosphere for approximately 120 years (IPCC, 2021).



What factors influence this indicator?

The concentrations of CO_2, CH_4, N_2O, and F-gases in the atmosphere reflect the difference between their rates of emission and their rates of removal. Many of the changes observed in global and regional greenhouse gas trends are directly related to human activities, including fossil fuel combustion, biomass burning, industrial processes, agricultural practices, and deforestation (IPCC, 2013). Additional discussion of factors affecting the emission of these greenhouse gases in California is presented in the *Greenhouse Gas Emissions* chapter.

CO_2

CO_2 is continuously exchanged between land, oceans, and the atmosphere through physical, chemical, and biological processes (IPCC, 2021). Prior to 1750, the global background CO_2 concentration was estimated to be less than 280 ppm (WMO, 2016). During this period, the amount of CO_2 released by natural processes (e.g., respiration and decomposition) was almost exactly in balance with the amount absorbed by plants during photosynthesis and other removal processes (WMO, 2016).

The increase in CO_2 concentration today primarily derives from emissions related to fossil fuel combustion and biomass burning. It is also directly related to changes in agricultural practices and deforestation (IPCC, 2021). While more than half of the emitted CO_2 is removed through natural processes within a century, approximately 20% remains in the atmosphere for many millennia (Archer et al., 2009). Consequently, atmospheric CO_2 concentrations may remain high for some time even if annual CO_2 emissions are substantially reduced from present levels.

While increasing levels of atmospheric CO_2 are affecting climate, changes in climate are likewise affecting the processes that lead to CO_2 uptake from, and release into, the atmosphere (IPCC, 2021). For example, warming temperatures increase plant photosynthesis, thereby enhancing CO_2 removal from the atmosphere, while wildfires release carbon that plants have stored back into the atmosphere (WMO, 2016).

Inter-annual variations have been attributed to El Niño and La Niña climate conditions; generally, higher-than-average increases in CO_2 correspond to El Niño conditions, and lower-than-average increases correspond to La Niña conditions (IPCC, 2021).

CH_4

Atmospheric CH_4 originates from both natural and anthropogenic sources. CH_4 is emitted naturally from the following:

- wetlands,
- oceans,
- termites,
- geological sources.

Anthropogenic sources of methane include:

- rice agriculture,
- livestock,
- landfills,
- waste treatment,
- biomass burning,
- fossil fuel and natural gas exploitation (i.e., extraction, transmission, distribution, and use).

The production of CH_4 by many of these sources is influenced by anaerobic fermentation processes and climate variables (notably temperature and moisture). Atmospheric removal of CH_4, on the other hand, is driven by oxidation processes, a process likewise affected by climate variables.

N_2O

Atmospheric N_2O is naturally present in the atmosphere as part of the Earth's nitrogen cycle. Its primary driver is the breakdown of nitrogen by microorganisms that live in soil and water (Anderson et al., 2010). N_2O is removed from the atmosphere through bacterial activities and through photochemical reactions (US EPA, 2024).

Human activities, including agriculture, fossil fuel combustion, wastewater management, and industrial processes, account for approximately 40% of total N_2O emissions globally (US EPA, 2024). In California, agricultural activities such as soil and manure management contributed approximately 55% of statewide N_2O emissions in 2023, with the remaining 45% primarily from transportation, industrial, commercial, and residential

sectors (CARB, 2025a). Synthetic fertilizers are a significant source of N_2O, as are tailpipe emissions from motor vehicles with inefficient engines and catalytic converters.

F-gases

As previously mentioned, F-gases do not exist in the natural environment; they are only emitted from anthropogenic sources and are only removed through photochemical reactions in the upper atmosphere. F-gases have been used primarily as refrigerants in a variety of applications, including:

- stationary refrigeration and air conditioning,
- industrial production and manufacturing processes,
- transmission and distribution of electricity, and
- vehicle air conditioning systems

CFC-11, CFC-12, HCFC-22, and HFC-134a emissions derive largely from the following sources (Gallagher et al., 2014):

- fugitive leaks,
- venting during the maintenance and servicing of equipment,
- leaks from improperly maintained or damaged equipment, and
- improper disposal of equipment

International, national, and state regulations affect the use, emission, and eventual atmospheric concentrations of F-gases. As noted above, pursuant to the Montreal Protocol of 1987, CFCs were phased out and banned in the United States in 1996. Most HCFCs were phased out of new production and consumption as of January 1, 2020.

Driven by the phase-out of ozone-depleting substances and by increased demand for refrigeration and air conditioning, HFCs became the fastest-growing source of greenhouse gas emissions in California and globally. Most HFC emissions in California come from refrigerants (CARB, 2025a). Prior to ratification of the Kigali Amendment, the U.S. Congress enacted the American Innovation and Manufacturing (AIM) Act of 2020, which directs the U.S. Environmental Protection Agency (US EPA) to:

- phase down the production and consumption of listed HFCs and their substitutes,
- facilitate the transition to next-generation technologies.

The U.S. EPA has adopted several rules to achieve the goals of the AIM Act. The following measures are already in place in California:

- California Senate Bill 1383 (Statutes of 2016): requires statewide reduction of HFC emissions to 40% below 2013 levels by 2030 (CARB, 2017).
- California Senate Bill 1013 and CARB regulation: Prohibits HFCs with high global warming potential in certain stationary refrigeration and foam end uses and establishes the F-gas Reduction Incentive Program to increase adoption of climate-friendly refrigerant technologies

Several other states followed California by adopting similar rules in their respective jurisdictions, including Connecticut, Delaware, Maryland, and New York. In December 2020, CARB approved additional HFC measures (previously identified in CARB's Short-Lived Climate Pollutant Strategy), including:

- Global warming potential limits on new and existing refrigeration and air-conditioning equipment,
- Company-wide reduction targets for retail food refrigeration facilities,
- Refrigerant Recovery Reclaim and Reuse or the R4 Program: a first of its kind program requiring the use of reclaimed refrigerant in air conditioning equipment.

More recently, California adopted SB 1206, which mandates the following:

- Prohibits the sale of newly produced HFCs with high global warming potentials on a phased-in timeline, ending with HFCs that have a GWP greater than 750 in 2033.
- Requires the use of reclaimed HFCs instead of high-GWP HFCs to promote recovery and better management of HFCs from existing equipment and prevent their release into the environment.
- Release of an assessment report (expected to be published on July 1, 2025) by CARB in collaboration with the California Energy Commission on how to transition the state's economy, by sector, away from HFCs and to ultra-low-GWP (GWP < 10) or no-GWP alternatives no later than 2035 and how to maximize recovery and reclamation of HFCs.

California continues to evaluate further HFC reduction measures that will be needed to meet the SB 1383 target and long-term carbon neutrality goals.

Technical considerations

Data characteristics

The CO_2 data in **Figure 1.2.1** combines measurements from the Scripps Institution of Oceanography (SIO) and the National Oceanic and Atmospheric Administration's Earth System Research Laboratory (NOAA-ESRL). NOAA-ESRL leads the Carbon Cycle Cooperative Global Air Sampling Network, which collects discrete air samples from observatories, cooperative fixed sites, and commercial ships (NOAA, 2026e). Weekly glass flask samples are analyzed using non-dispersive infrared absorption (Keeling et al., 2001), while at SIO's La Jolla Pier, monthly samples are collected. Ambient CH_4, N_2O, and F-gas concentrations (**Figure 1.2.2**, **Figure 1.2.5**, and **Figure 1.2.6**) were also obtained from the NOAA-ESRL networks. NOAA-ESRL collected samples in evacuated flasks and detected CH_4 using a flame ionization detector integrated with a gas chromatograph system, *in situ* systems to measure N_2O, and an electron-capture detector and a mass spectrometer to measure F-gases.

Satellite data of atmospheric CH_4 is presented in **Figure 1.2.3** as column-average concentrations from the surface to the top of the atmosphere. Atmospheric inverse modeling, presented in **Figure 1.2.4**, used computer models to trace CH_4 emissions to their sources, providing valuable insights into when and where emissions occurred. The inverse modeling was driven by data collected from the CARB Statewide GHG Monitoring Network, the Megacities Carbon Project's tower sites in the Los Angeles area, and NASA's Alpha Jet Atmospheric eXperiment, which flew missions over the San Francisco Bay Area and northern San Joaquin Valley (Cui et al., 2019).

Strengths and limitations of the data

Long-term, high-precision measurements presented in this chapter are essential for understanding greenhouse gas emissions from various sources – including human activities, atmospheric processes, plants, soils, and oceans. Tracking the life cycles of these greenhouse gases provides crucial information for formulating effective mitigation strategies. Data on atmospheric greenhouse gas levels are needed to project future

climate change associated with various emission scenarios, and to establish and revise emission reduction targets (IPCC, 2013).

Measurement data from NOAA-ESRL undergo critical evaluation for quality control (NOAA, 2026f). The long-term record at La Jolla, particularly when compared with the longer-term data at Mauna Loa, presents valuable time-series information for tracking greenhouse gas trends over the past half century (SIO, 2025). These data are useful for characterizing seasonal variations and provide information about the coastal air that travels into California. Although the La Jolla Pier at SIO extends considerably into the ocean, the site can receive some air currents polluted with urban greenhouse gas emissions from the Los Angeles area that mix with the oceanic and San Diego atmosphere. Likewise, the Point Arena location, although coastal, occasionally captures onshore GHG emissions. The Trinidad Head monitor sits on a peninsula extending into the ocean with a tower, however, the air coming from the Pacific Ocean can back up on the nearby coastal range mountains and backflow to the site, thus impacting the measurements of GHG in the onshore air.

Inverse modeling provides atmospheric-based estimates that offer a high-level statewide emission assessment, track greenhouse gas trends over time as regulations are implemented and guide further research. Satellites may enhance these capabilities in the future. This approach relies on atmospheric concentration measurements from a limited number of sites across the state, covering key areas with major anthropogenic emissions. However, inverse studies have inherent uncertainties due to measurement limitations, inventory estimates, and gridding processes. Additionally, models introduce uncertainties when converting concentration data into emission estimates. The method also depends on a statewide inventory that must be disaggregated using additional assumptions.

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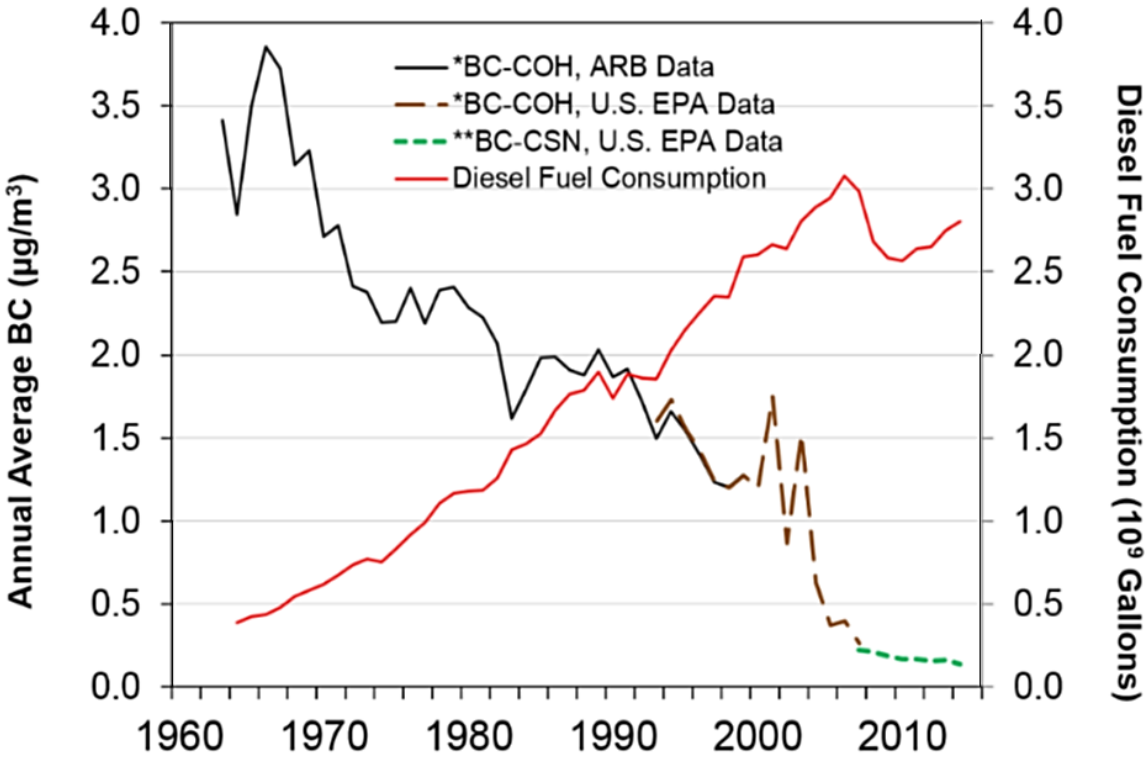
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1.3 Atmospheric Black Carbon Concentrations (No Update)

Atmospheric levels of black carbon, a major short-lived climate pollutant, have decreased dramatically in California since the 1960s.

About this indicator: This chapter was originally published in the 2018 Indicators of Climate Change in California Report and has not been updated for this edition. Data and references reflect conditions as of 2018.

Figure 1.3.1. Statewide Annual Average Concentrations of Black Carbon and Diesel Fuel Consumption.



* BC-COH – black carbon, coefficient of haze

**BC-CSN – black carbon, chemical speciation network

Note: Data after 2000 are based on a small number of monitors and may not be representative of statewide concentrations.

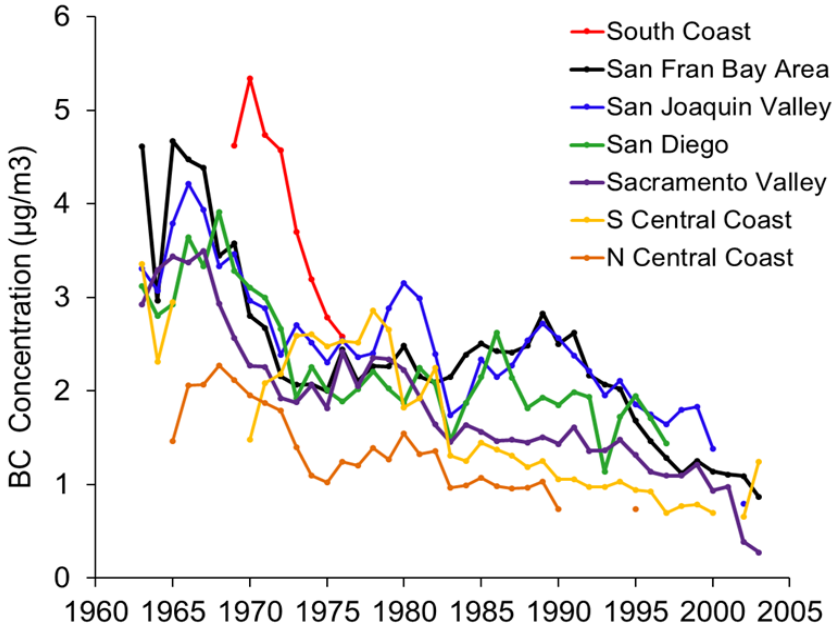
Source: CARB (2015a)

What does the indicator show?

Long-term data show that ambient black carbon (BC) concentrations in California have declined steadily (**Figure 1.3.1**). Annual average BC concentrations have dropped by more than 90% over the past 50 years, from an average of 3.4 micrograms per cubic meter ($\mu g/m^3$) in the 1960s to 0.14 $\mu g/m^3$ since 2010. This dramatic decline in BC concentrations in the last five decades occurred despite a seven-fold increase in statewide diesel fuel consumption — the largest anthropogenic source of BC emissions in California. New emission standards and restrictions on diesel engines and biomass burning have significantly reduced atmospheric BC concentrations across the state (Kirchstetter et al., 2017).

Archived records of coefficient of haze (COH) were used to reconstruct historical BC concentrations. COH was one of the first measures of particulate matter (PM) pollution used by regulatory agencies and was determined to be a strong proxy for BC (see *Technical considerations* section).

Figure 1.3.2. Estimated Annual Average Black Carbon Concentrations by Air Basin.



Source: Ramanathan et al. (2013)

Although there is considerable variation, BC concentrations by air basin generally followed the decreasing statewide average trend. As shown in **Figure 1.3.2**, downward trends occur across all of the state's major air basins from the mid-1960s to the early 2000s. BC concentrations were considerably higher in the South Coast Air Basin than in the rest of California, at least until the mid-1970s; the lowest BC concentrations were in the North Central Coast Air Basin.

Why is this indicator important?

Black carbon is a light-absorbing particle in the air, commonly known as soot. Scientists recently determined that BC may be the second most important contributor to global warming after carbon dioxide (CO_2) (Bond et al., 2013). However, it behaves very differently than long-lived greenhouse gases such as CO_2 do. While greenhouse gases trap heat from the Earth's surface, BC contributes to climate warming by absorbing sunlight directly and releasing heat energy in the atmosphere. CO_2 remains in the

atmosphere for hundreds of years, while BC particles are removed from the atmosphere by rain and by deposition after a few days or weeks. However, although BC has a shorter lifespan, it is a much more powerful warming agent than CO_2. For example, one ton of BC has a warming effect equal to 900 tons of CO_2 over a 100-year period. Over 20 years, one ton of BC has the warming impact of 3,200 tons of CO_2 (Bond et al., 2013). Hence, it is considered a critical short-lived climate pollutant.

Black carbon influences the climate in several complex ways. In addition to its direct warming effects, BC particles can deposit on snow, glaciers, and sea ice. This darkens these light, frozen surfaces and reduces their reflectivity. Darker surfaces absorb more solar energy, causing snow and ice to melt more quickly (Hadley et al., 2010; Hadley and Kirchstetter, 2012). This early melting could significantly affect California's summer water supplies, which rely heavily on snowmelt runoff from the Sierra Nevada. Less snowmelt runoff during the spring months, combined with warmer temperatures over already dry areas, increases wildfire risks — which can in turn release more BC particles.

Black carbon can also change the reflectivity, stability, and duration of clouds. Its effects are different depending on how much of it is in the air and where it occurs in the atmosphere. Black carbon particles in a cloud layer can absorb solar radiation, heating the air in it, and leading to cloud evaporation and reduction. However, quantification of this indirect impact on the climate system is imprecise (Koch and Del Genio, 2010).

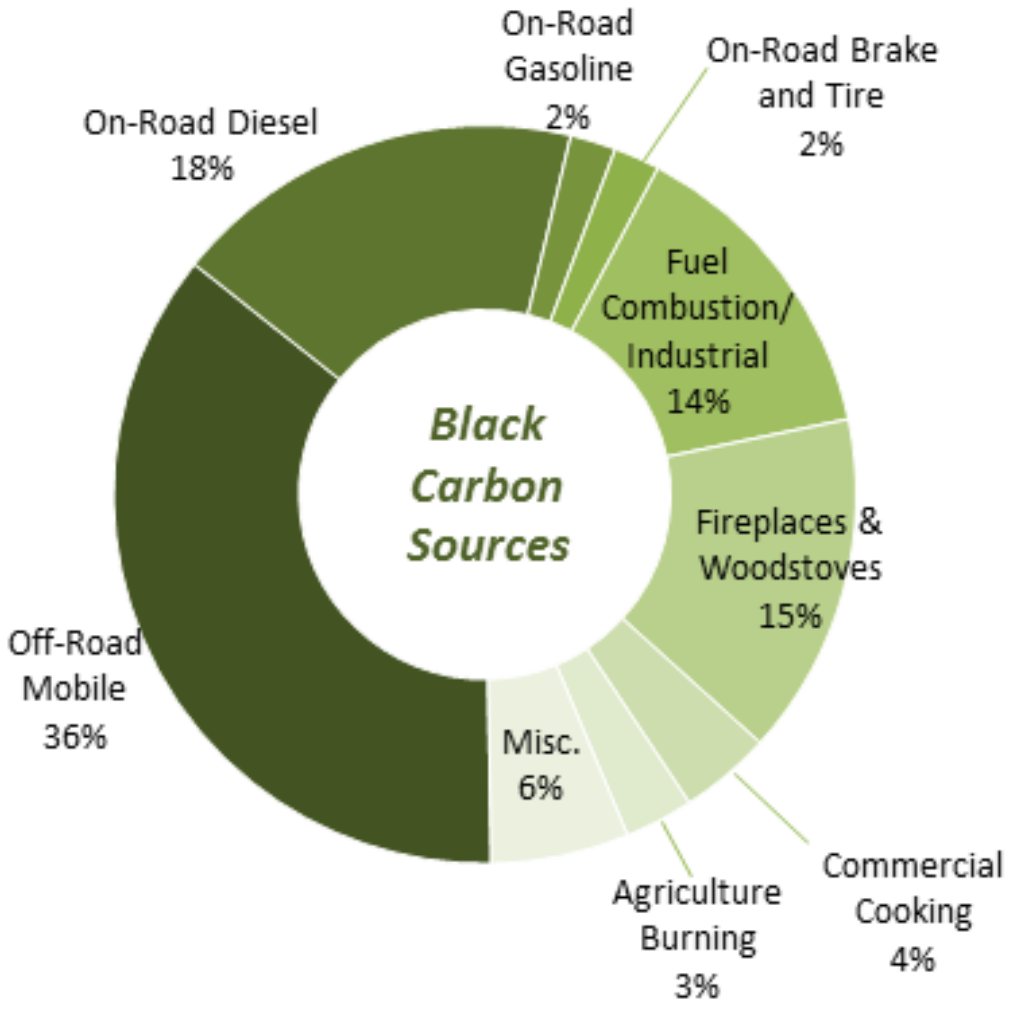
Reducing emissions of BC presents an opportunity to slow the rate of global warming in the near term. Black carbon is also a component of $PM_{2.5}$ air pollution (fine particulate matter that is 2.5 microns or less in diameter). $PM_{2.5}$ has been linked to respiratory and cardiovascular disease (US EPA, 2009). Therefore, reduced BC emissions also provide public health benefits. Control measures are projected to lead to substantial reductions in BC emissions from mobile sources, preventing an estimated 5,000 premature deaths in the state each year (CARB, 2016). These reductions are especially beneficial to disadvantaged communities. For example, diesel particulate matter concentrations are highest along freight corridors and near ports and rail yards where disadvantaged communities are often located. Regardless of net climate forcing or other climatic

effects, all BC mitigation options bring health benefits through reduced particulate matter exposure. A worldwide program along the lines of what is being done in California would avoid hundreds of thousands of premature deaths annually (Anenberg et al., 2011).

What factors influence this indicator?

In California, the major anthropogenic sources of BC in 2013 included diesel-fueled mobile sources, fuel combustion and industrial processes, and residential fireplaces and woodstoves. Off-road mobile emissions account for over a third of statewide BC emissions. On-road mobile sources account for nearly a quarter of emissions, primarily from on-road diesel combustion, which contributes approximately 18% to California's BC emissions. On-road gasoline, as well as brake wear and tire wear emissions of BC are relatively small. Residential fireplaces and woodstoves currently account for approximately 15% of BC emissions, with another 14% attributable to fuel combustion and industrial processes.

Figure 1.3.3. 2013 California Black Carbon Emissions.



Source: CARB (2015b)

Other anthropogenic sources include dust, waste disposal, residential natural gas combustion, and unplanned structure and car fires. These sources and the ambient concentrations of BC vary geographically and temporally. Emissions standards and restrictions implemented on diesel engines and biomass burning activities have had a significant effect on decreasing ambient air BC concentrations across the state. In 2013, total anthropogenic BC emissions were approximately 38 million metric tons of carbon

dioxide equivalent ($MMTCO_2e$), using the 20-year Global Warming Potential (GWP) value of 3,200 from the IPCC Fifth Assessment Report (IPCC, 2013).

Anthropogenic BC emissions do not include forest-related sources (i.e., wildfires and prescribed burning). Wildfire is the largest source of BC emissions in California, contributing an estimated 87 $MMTCO_2e$ annually (calculated as a ten-year annual average); prescribed fires, an important tool for forest managers, emit an estimated 4 $MMTCO_2e$. (To provide a more representative view of emissions without large year-to-year variability driven by natural forces, forestry emissions are calculated as a ten-year average) (CARB, 2017).

As shown in **Figure 1.3.1**, the largest decline in BC concentrations occurred in the years before 1975, coinciding with the adoption of state and federal air quality regulations. These include tailpipe emission limits established by California in the mid-1960s, federal emission standards for stationary sources and motor vehicles adopted in the mid-1960s, and diesel emission controls introduced nationally in 1970. Between 1975 and 1990, BC levels declined more gradually, likely due to the replacement of older, more polluting diesel vehicles as a result of on-road heavy-duty diesel particulate matter emission standards adopted in 1973 by California. BC concentrations decreased more rapidly after 1990, despite intermittent increases in the early 2000s (Kirchstetter et al., 2008). Retrofitting of urban transit buses with oxidation catalysts, limits on sulfur content in diesel fuel, changes in diesel engine technology, and restrictions on agricultural burning and residential wood combustion, among other measures, contributed to the reductions.

Existing regulatory programs, including ongoing efforts to reduce tailpipe emissions from trucks and buses, will continue to reduce BC emissions. For example, further reductions are expected from stricter diesel engine emission standards implemented by the state in 2007 and the complementary low-sulfur fuel introduced nationally in 2006. To comply with federal air quality standards, control measures that reduce $PM_{2.5}$ pollution (including BC and other constituents) are projected to decrease BC emissions from mobile sources in California by 75% between 2000 and 2020 (CARB, 2016).

Senate Bill 1383 (Chapter 395, Statutes of 2016) sets a target to reduce BC emissions by 50% below 2013 levels by 2030, with a focus on disadvantaged communities.

Technical considerations

Data characteristics

Because of their short residence time in the atmosphere and their strong dependence on local sources, particles exhibit high spatial and temporal variation, requiring frequent measurements at numerous sites to reliably track trends. However, few extensive records of particle concentrations are available. One of the first measures of PM pollution used by regulatory agencies, the coefficient of haze (COH), was determined to be a strong proxy for BC, based on co-located field measurements of BC and COH. Archived records of COH, a now-retired measure of light-absorbing PM, were used to reconstruct historical BC concentrations. BC concentrations were inferred from COH data based on a relationship determined from statistical analyses (Ramanathan et al., 2013). Statewide average BC concentrations were computed separately using data from CARB (1963 to 2000), and US EPA (1993 to 2007).

Where the US EPA and CARB datasets overlap, agreement is very good. The location and number of COH monitors operating in California has varied over time. From the mid-1970s to 2000, 30 or more COH monitors were in operation for most of the year, but these dropped to 15 by mid-2000 (mainly in the US EPA dataset). Hence, the data after 2000 are based on a smaller number of monitors and may not be as representative of statewide concentrations.

Data from 2007 to 2017 are from the US EPA's Chemical Speciation Network (CSN). Since early 2000, approximately 17 CSN sites have been providing information on $PM_{2.5}$ concentrations in California's ambient air. Samplers operate on a 24-hour schedule from midnight to midnight, generally sampling every third day or every sixth day. CSN must meet all federal and state requirements for monitoring methodology and quality assurance. CSN is designed to track the progress of $PM_{2.5}$ emission reduction strategies through the characterization of trends of individual $PM_{2.5}$ species, including BC. Although the CSN network has been collecting BC data since 2000, the collection and analysis methods were different during the first few years of the program (Chow et

al., 2007). The differences were significant enough to affect the trends, therefore data from the CSN network prior to 2007 are not presented in **Figure 1.3.1**.

Strengths and limitations of the data

For the purposes of climate change study, BC is defined as the carbon component of PM that absorbs light. A significant advantage of monitoring BC by an optical method is that it delivers results in real time with a high time resolution (in minutes). However, BC as a component of PM is difficult to measure. Methods that measure light absorption in PM assume that BC is the only light-absorbing component present. However, some components of organic carbon can also be light-absorbing. The impact of BC on climate forcing is well established, but the magnitude and wavelength dependence of absorption by organic carbon (often called brown carbon, a by-product of the biomass burning) is poorly constrained. Existing methods, such as using an enhanced thermal/optical carbon analyzer with multi-wavelength capabilities, can add value to current PM monitoring programs by providing a complete identification and quantitation of the carbonaceous component of ambient aerosols in near-real time.

Emissions inventories for climate change studies have focused primarily on greenhouse gases. Most of the important sources of greenhouse gases are also important sources of health-related pollutants. Likewise, BC is emitted primarily from combustion sources which are also important sources of health-related pollutants. California's BC inventory relies on PM inventories coupled with speciation profiles that define the fraction of PM that is BC. However, it is a challenge to estimate statewide BC emissions, and to define speciation profiles for all sources. Hence, improved emissions inventory methodologies and tools developed for health-related pollutants can also provide opportunities for improving climate change emission inventories (and vice versa).

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Introduction

Earth's climate is shifting at an unprecedented pace in recorded human history. Greenhouse gas emissions from fossil fuel combustion, industrial processes, and land use have driven global temperatures to levels not seen for millennia, intensifying extreme weather events worldwide (IPCC, 2023). More observational data, new statistical techniques, and improved models have strengthened the evidence that human-driven climate change is altering the frequency and intensity of these events globally (National Research Council, 2026).

Consistent with global trends, California continues to see higher air temperatures, greater precipitation variability, and more frequent droughts and extreme heat events. The increased risk of co-occurring climate hazards also creates cascading impacts across ecosystems and the built environment. For example, the convergence of record-breaking temperatures and drought drive "hot droughts" that are longer lasting and harder to recover from. Low-income communities, communities of color, and tribal nations often experience cumulative exposure to extreme heat, drought, and flooding, with less capacity to prepare for or recover from their impacts due to structural inequities such as limited access to air conditioning, stable water supply, and reliable healthcare. For many tribes, climate-driven disruptions to lands, waters, and natural resources deepen longstanding inequities, threatening cultural and subsistence practices tied to California's ecosystems.

The following chapters – Air Temperature, Precipitation, Drought, Extreme Heat Events, and Cooling and Heating Degree Days – document clear, measurable trends attributed to climate change and provide an updated look of how climatic conditions are shifting in California.

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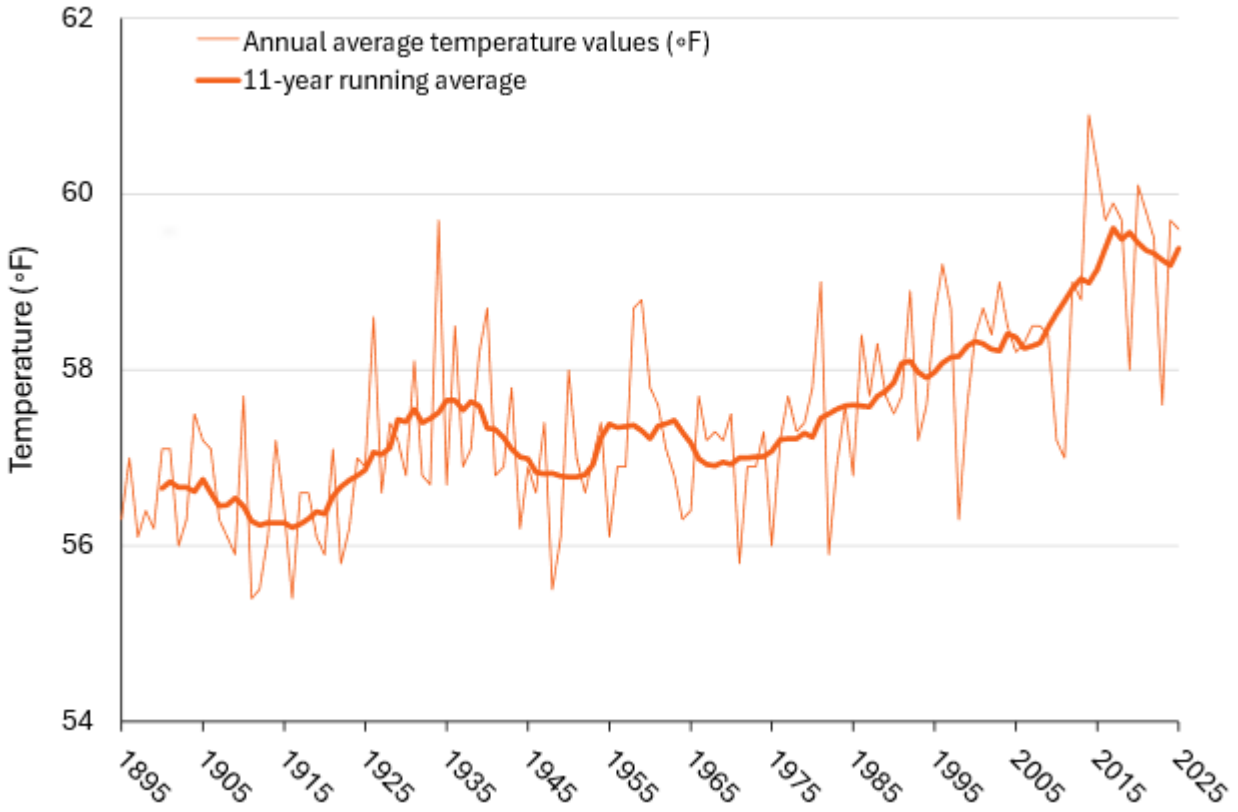
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2.1 Air Temperature

Air temperatures have increased over the past century, especially at night during the summer and fall seasons, driven mainly by greenhouse gas emissions from the burning of fossil fuels. Warming has accelerated in recent decades. Southern California is warming faster than Northern California.

Figure 2.1.1. Statewide Annual Average Temperatures.



The graph shows annual average temperatures from 1895 to 2025 (using calendar years) and the 11-year running average. Source: WRCC (2026)

What does the indicator show?

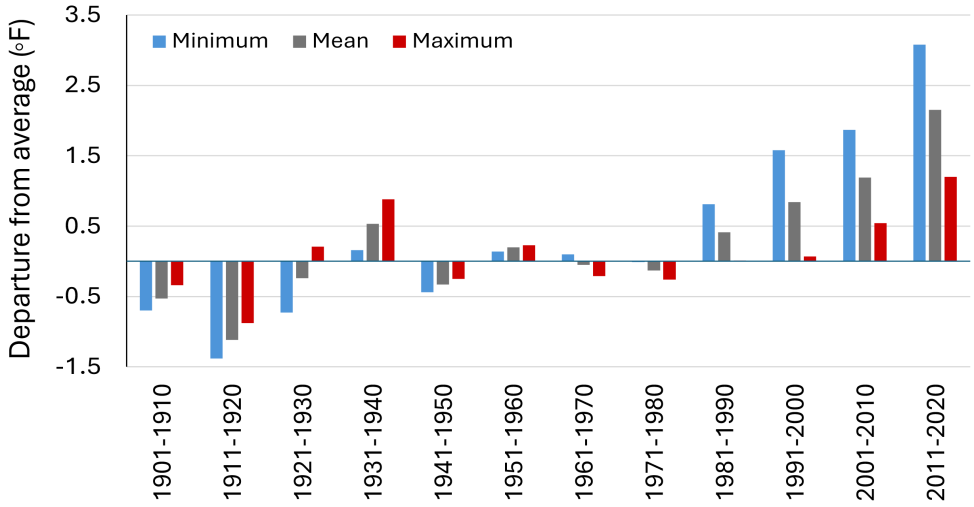
Statewide air temperatures show a warming trend consistent with that found globally (IPCC, 2023; also see the Global Warming Index). **Figure 2.1.1** presents annual average temperatures statewide. California has warmed by about 2.6 degrees Fahrenheit (°F) (1.4 degrees Celsius (°C)) (about 2°F or 1.1°C per century) since

records began in 1895. Recent years have been notably warm, with 2014 being the warmest on record, followed by 2015, 2020, 2017, 2021, 2024, 2025, and 2022. Some of the warmest years coincided with some of the driest years in the instrumental record and led to exacerbated drought conditions in response to more evaporation resulting from increased air temperatures.

Minimum temperatures (which reflect overnight low temperatures) have increased the fastest. **Figure 2.1.2** depicts "departures" by decade from a long-term average (base period of 1901 to 2000) for minimum, mean, and maximum temperatures. Departures are the difference between each decade's value and the long-term average.

Before the 1930s, temperatures were cooler than the long-term average, then hovered around the average between the 1940s and the 1970s. The last four decades have shown marked warming as temperatures increased faster. Minimum, mean, and maximum temperatures have increased overall. Minimum temperatures have risen by about 3.9°F (2.2°C) since 1895 (a rate of 3°F or 1.7°C per century), and maximum temperatures have risen by about 1.3°F (0.72°C) (a rate of 1.1°F or 0.61°C per century). Faster warming at night is also observed globally (Cox et al., 2020; Luo et al., 2024).

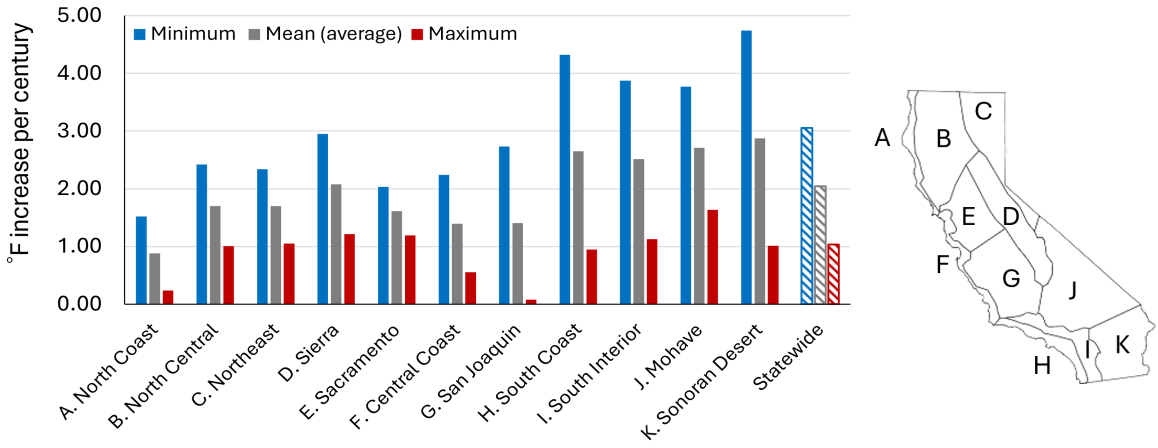
Figure 2.1.2. Statewide Temperatures, Decadal Departures.



Values shown for each decade are "departures" from the long-term average, 1901-2000— that is, the difference between the long-term average and the average for the decade.
Source: WRCC (2025)

Warming trends vary by region and county. **Figure 2.1.3** shows that all of California's 11 climate regions have experienced warming trends over the last century at varying rates. The greatest increases are observed in the Sonoran Desert region (about 3.7°F or 2.1°C since 1895, or about 2.9°F or 1.6°C per century) and South Coast (3.4°F or 1.9°C since 1895, or about 2.6°F or 1.4°C per century). Minimum temperatures are warming faster than maximum temperatures in all the regions, consistent with statewide trends.

Figure 2.1.3. Regional and Statewide Temperature Trends (1895-2024).



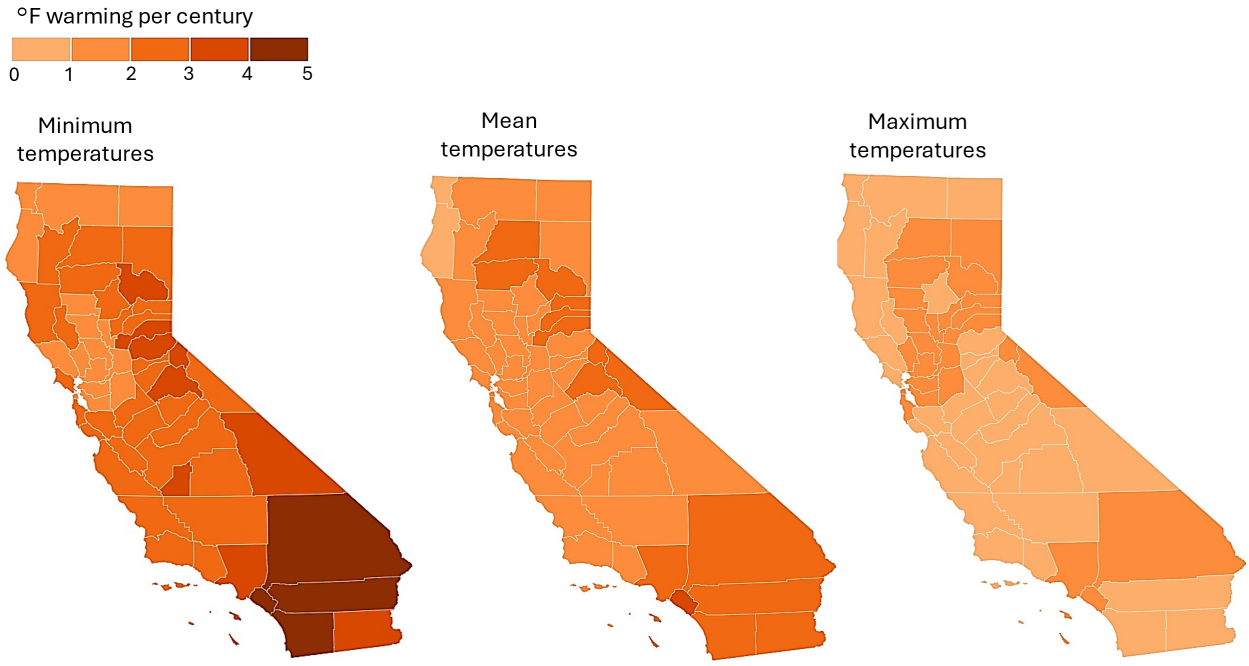
The graph shows long-term regional (solid colors) and statewide (hatched colors) warming trends in California. Source: WRCC (2025)

Similarly, **Figure 2.1.4** shows statewide warming trends over the past century that vary by county (county-level analyses identify more localized trends and patterns that are averaged out in larger regional scales). At the county-level, the greatest warming trends are observed in:

- Orange County (warmed by about 3.9°F or about 2.2°C since 1895, or about 3°F or about 1.7°C per century),
- San Diego (warmed by 3.7°F or 2.1°C since 1895, or about 2.9°F or about 1.6°C per century),
- San Bernardino County (warmed by 3.6°F or 2°C since 1895, or about 2.8°F or about 1.6°C per century).

Minimum temperatures are warming faster than maximum temperatures for all counties, consistent with regional and statewide trends.

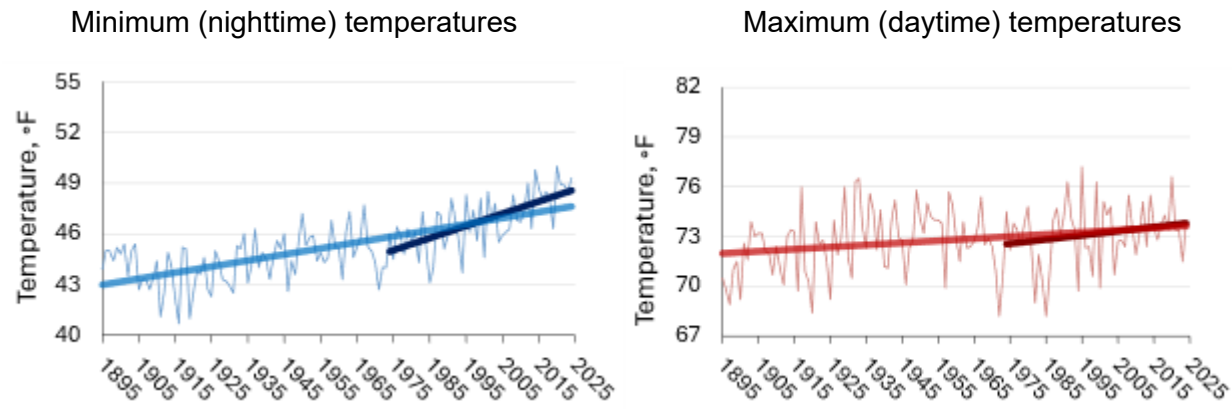
Figure 2.1.4. County Temperature Trends (1895–2024).



Source: WRCC (2025)

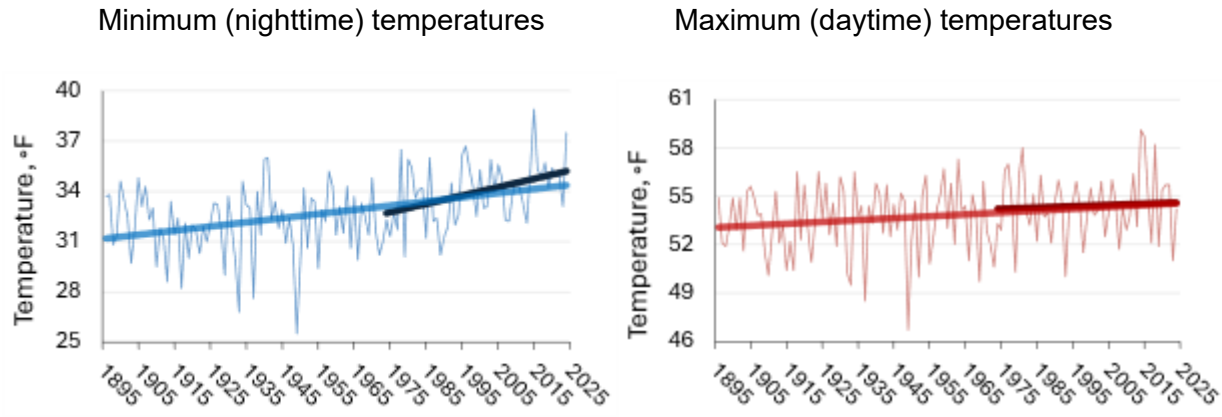
Figure 2.1.5 through **Figure 2.1.8** present statewide seasonal trends in calendar years. For all seasons, minimum temperatures are increasing faster than maximum temperatures. Trends for the more recent period (from 1974 to 2024, darker lines) are greater than trends since 1895 (lighter lines). The greatest increases in minimum temperatures occurred in the summer and fall over both time periods. For maximum temperatures, the greatest increases over the entire period of record occurred in the fall and winter; since 1974, the greatest increases occurred in the fall and summer.

Figure 2.1.5. Fall Air Temperature Trends in California.



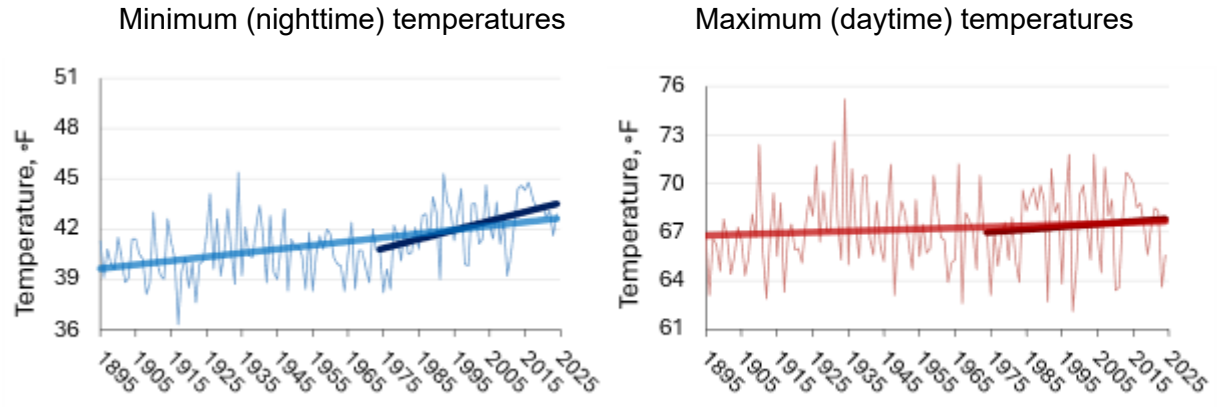
The graphs show annual average minimum (or nighttime) and maximum (or daytime) fall temperatures (September–November) between 1895–2024. Lighter colored lines show linear trend lines for the entire period (1895–2024), and darker colored lines show linear trend lines for the more recent period (1974–2024). Source: WRCC (2025)

Figure 2.1.6. Winter Air Temperature Trends in California.



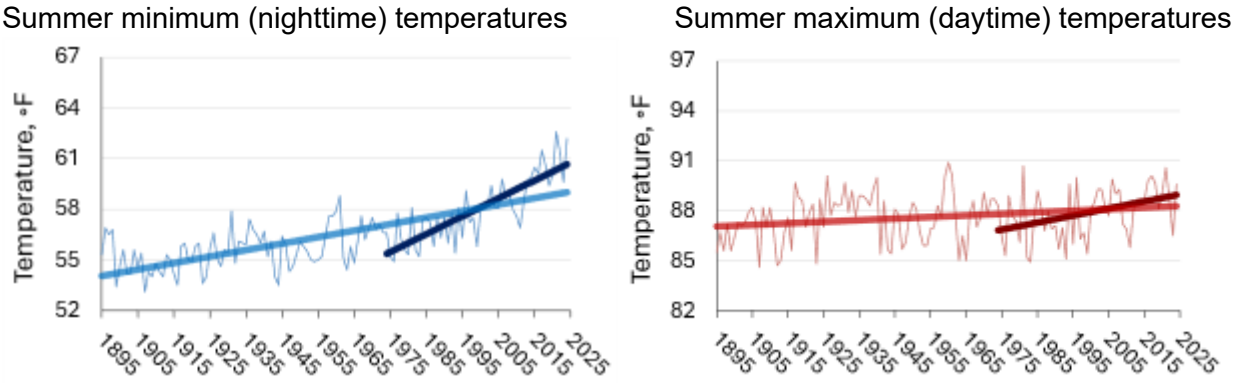
The graphs show annual average minimum (or nighttime) and maximum (or daytime) winter temperatures (December–February) between 1895–2024. Lighter colored lines show linear trend lines for the entire period (1895–2024), and darker colored lines show linear trend lines for the recent period (1974–2024). Source: WRCC (2025)

Figure 2.1.7. Spring Air Temperature Trends in California.



The graphs show annual average minimum (or nighttime) and maximum (or daytime) spring temperatures (March–May) between 1895–2024. Lighter colored lines show linear trend lines for the entire period (1895–2024), and darker colored lines show linear trend lines for the recent period (1974–2024). Source: WRCC (2025)

Figure 2.1.8. Summer Air Temperature Trends in California.



The graphs show annual average minimum (or nighttime) and maximum (or daytime) summer temperatures (June–August) between 1895–2024. Lighter colored lines show linear trend lines for the entire period (1895–2024), and darker colored lines show linear trend lines for the recent period (1974–2024). Source: WRCC (2025)

Why is this indicator important?

Temperature is a basic physical factor that affects many natural processes and human activities. Warmer air temperatures alter precipitation and runoff patterns, influencing the availability of freshwater supplies. Increases in minimum and maximum daily and

seasonal temperatures lead to a wide range of impacts on ecosystems — including changes in species' geographic distribution, the timing of life cycle events, and species abundance. Along with health impacts through heat-related illnesses, warming temperatures are also linked to the spread of diseases like West Nile Virus and Valley Fever. Warming temperatures affect energy needed for cooling and heating, which in turn influences the types of energy generation, infrastructure, and management policies needed to meet these demands. Temperature changes also increase the risk of extreme weather events such as heatwaves and intense storms. Understanding observed temperature trends is important for refining future climate projections for the state's climate-sensitive sectors and natural resources (Beadling et al., 2026). Observational data provides the foundational base for predictions, establishing current trends and patterns, and indicating when climate projections are aligned with real-world changes or need to be refined.

Environmental justice communities face heightened vulnerability to rising air temperatures, driven by a confluence of systemic and structural inequities. These communities often experience greater exposure to extreme heat (see the *Extreme Heat Events* chapter) due to a lack of green space and urbanization, while also having limited access to air conditioning, cooling centers, and reliable healthcare. As discussed below, materials like concrete and asphalt absorb and retain heat, intensifying local temperatures, a phenomenon known as the urban heat island effect. Historically redlined neighborhoods, which were denied investments in parks, trees, and infrastructure, tend to have more pavement, less shade, and lower-quality housing. This results in heightened exposure to extreme heat, coupled with overlapping challenges such as higher energy costs, limited cooling options, poorer health outcomes, and restricted access to care. Socioeconomic barriers, disinvestment, and a legacy of marginalization further limit these communities' ability to adapt—amplifying both the health and economic risks of a warming climate (Morello-Frosch and Obasogie, 2023).

What factors influence this indicator?

Carbon dioxide and other greenhouse gas emissions into the atmosphere since the Industrial Revolution in the mid-1700s have driven rapid warming worldwide (IPCC,

2021). Emissions of these greenhouse gases intensify the natural greenhouse effect, causing surface temperatures to rise. Greenhouse gases absorb heat radiated from the Earth's surface and lower atmosphere and re-emit much of the energy back toward the surface.

Additional factors affecting air temperatures include clouds, water vapor, solar radiation (sunlight), and small airborne particles from aerosols, dust, and soot.

Clouds

Clouds have a cooling effect during the day and a warming effect at night. Faster long-term warming at night is observed globally and has primarily been attributed to the nighttime impacts of cloud cover (Cox et al., 2020; Luo et al., 2024). During the day, clouds reflect heat from sunlight back into space, creating a cooling effect. At night, clouds trap heat by absorbing it from the ground and re-emitting it back down, amplifying warming trends at night.

As part of a water vapor feedback loop, warming increases evaporation. A warmer atmosphere can hold more of this evaporated moisture. More moisture at night leads to higher humidity and more cloud cover, which means greater warming at night (Cox et al., 2020; Luo et al., 2024).

Solar radiation

The sun has an 11-year sunspot cycle, which causes a very small variation in the amount of heat from solar radiation reaching the Earth (Burch and Harris, 2021).

Aerosols, dust, and soot

Very small airborne particles from human and natural sources can have various effects on climate. Sulfate aerosols, which result from burning coal, biomass, and volcanic eruptions, tend to cool Earth. Other kinds of particles, such as black carbon, have a warming effect. The net effect of aerosols, dust, smoke, and soot is cooling (NASA, 2023).

Local temperatures are influenced by topography, elevation, proximity to the ocean, and global and regional atmospheric and oceanic circulations.

Climate patterns can vary widely from year to year and from decade to decade, in accordance with large-scale circulation changes around the Earth. The Pacific Ocean

has a major effect on California temperatures all year along the coast, especially in summer, and farther inland in winter (see "Climate of California" by WRCC for more information).

In addition to topography, local influences on temperature include changes in land surface and land use. For example, urbanization is generally known to have a warming effect, due in large part to the heat-absorbing concrete and asphalt in building materials and roadways. Climate change and urbanization are the most significant drivers of warming in cities. Expansion of irrigation has a cooling effect on summertime temperatures (Bonfils and Lobell, 2007). Over the past century, more urbanization in Southern California and greater irrigation in Northern California have likely contributed to differences in their warming trends.

Technical considerations

Data characteristics

The Western Regional Climate Center (WRCC)'s California Climate Tracker provides monthly temperature values in California from 1895 to the present using the PRISM Climate Mapping Program from Oregon State University. PRISM is an analytical modeling tool that generates fine-scale grid-based estimates of monthly precipitation and temperature. The "About the California Climate Tracker" page provides more information.

PRISM-modeled outputs can change slightly over time due to ongoing data refinement, including the addition of new reporting stations, quality control measures, and the application of new or updated methodologies, especially for data within the last six (6) months.

Strengths and limitations of the data

The PRISM dataset uses modeling extrapolations to offer complete coverage across the state for every month of the record.

The datasets used are subject to separate quality control procedures. Limitations include the bias of station data toward populated areas and the limited ability of quality control processes in remote or high-terrain areas. The dataset is constantly updated to

map climate in the most difficult situations, including high mountains, rain shadows, temperature inversions, coastal regions, and associated complex climate processes.

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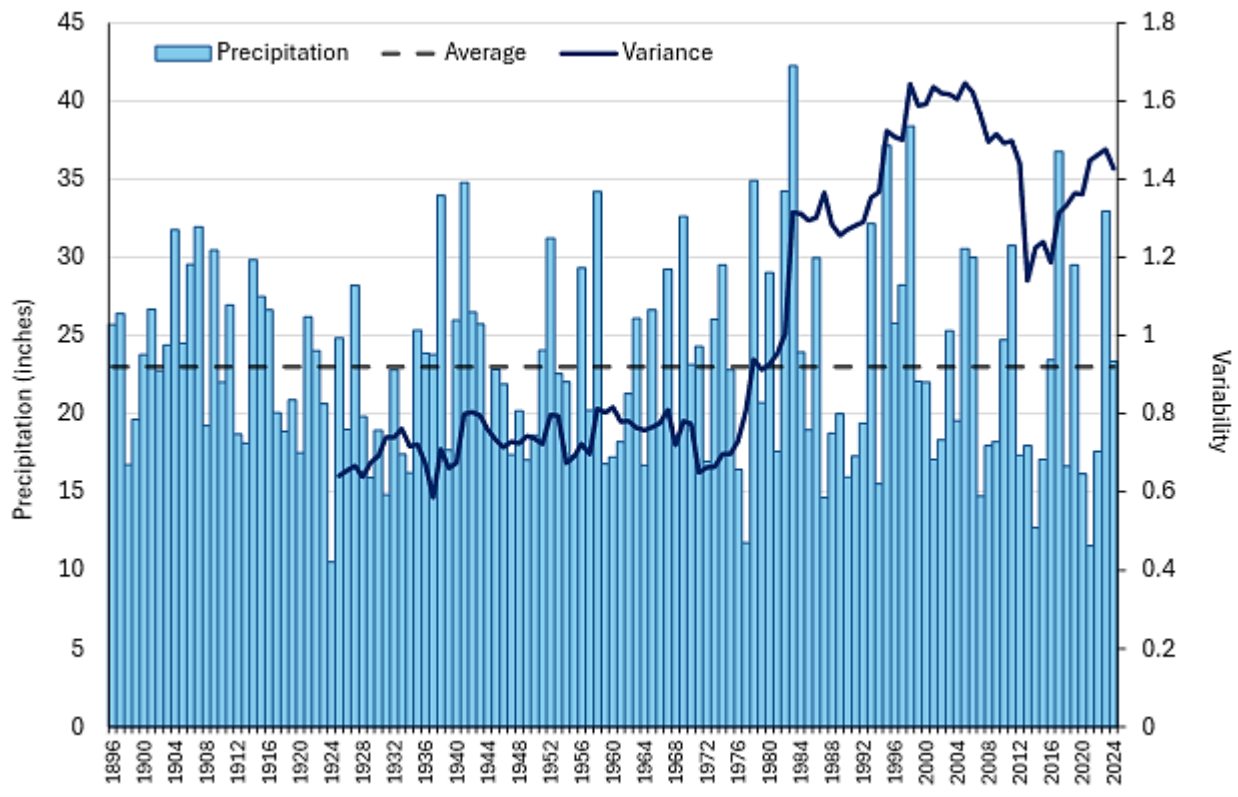
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2.2 Precipitation

Although total annual precipitation does not show a consistent statewide trend, California's year-to-year variability has increased since the 1980s. In recent years, the fraction of precipitation that falls as rain instead of snow has increased in the Sierra Nevada and Southern Cascades, reducing the water stored in the snowpack that provides most of California's water supply.

Figure 2.2.1. Statewide Total Annual Precipitation (1895–2024).



Blue bars show total statewide precipitation by water year (October–September). The dotted grey line is the long-term average of annual totals (23.02 inches). The dark blue line shows variability: each value (from 1925) is the annual ratio of 30-year variance to total variance (1895–2024), as a measure of how variable each year is relative to long-term historical patterns. Values above 1 indicate more variability; below 1, less. Source: WRCC (2025)

What does the indicator show?

California's total annual precipitation is characterized by high year-to-year variability (**Figure 2.2.1,** also see Dettinger, 2011). Since records began in 1895, statewide annual precipitation has ranged from a low of 10.52 inches in 1924 to a high of 42.26 inches in 1983. No clear trend is evident in the amount of total annual precipitation (**Figure 2.2.1**, blue bars).

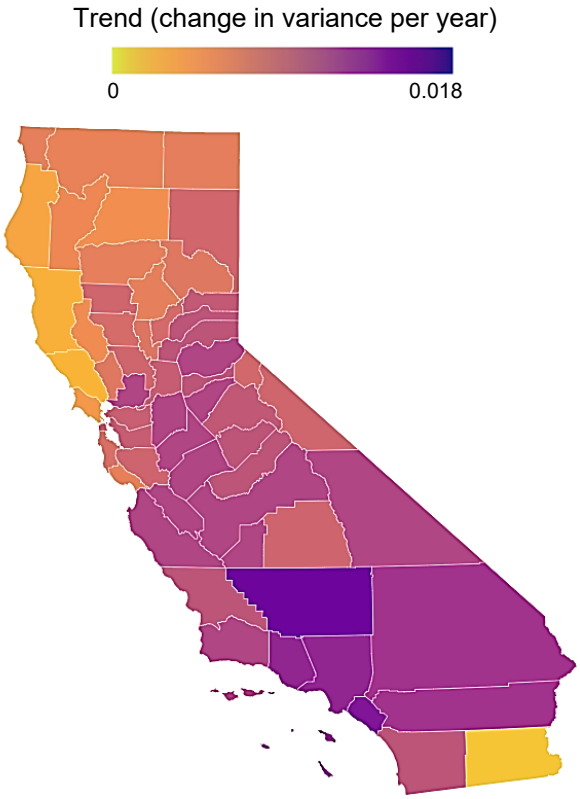
Tribal Connection 2.2.1

Some areas have seen a reduction in precipitation: the Pala Band of Mission Indians in San Diego County are receiving less annual rainfall over time, since 1895. However, "*When the rains come, these rain events are becoming more intense, causing flooding that rises and falls quickly (Prosper Sustainably, 2018). The Pala Environmental Department tracks rainfall, water flows, stream levels, storm damage, and flooding at multiple locations on the Reservation. Flooding has become a regular occurrence at Pala. Between 1917 and 1997 there were two major flood events. Since 1997 there have been 23 major floods that covered roads, damaged property, and trapped residents*" (Pala Band of Mission Indians, 2026).

Since the early 1980s, year-to-year precipitation has become increasingly variable (**Figure 2.2.1**, solid dark blue line), with notable regional differences (**Figure 2.2.2**) across the state (note: **Figure 2.2.2** shows long-term trends in variability, i.e. the estimated change in variance each year, whereas **Figure 2.2.1** shows annual values). This increasing variability —often referred to as hydroclimatic "whiplash"— reflects more frequent and abrupt shifts between extremely wet and dry years.

Recent decades illustrate this pattern. The past decade included both the fourth wettest year on record (2017) and the second driest (2021). The period from 2012 to 2015 set a record for the driest consecutive four-year historical record, followed shortly after one of the wettest three-year periods (2017 to 2019). Similarly, 2020 to 2022 were the driest consecutive three-year period of statewide precipitation, followed by a wet year for 2023.

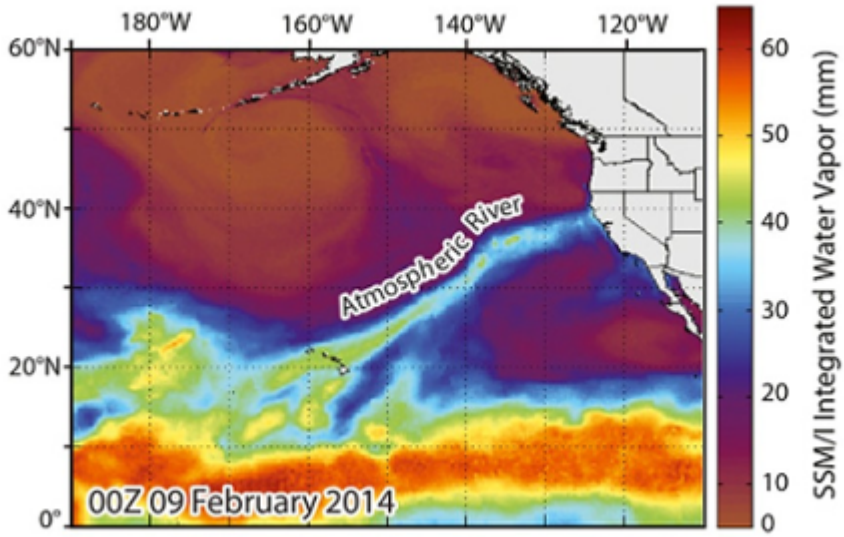
Figure 2.2.2. Interannual Precipitation Whiplash by County.



The map shows trends in interannual variability, as measured by the ratio of 30-year variance to total variance (1895–2024) for each county. Trends are the slopes of the trendlines, where higher values indicate greater rates of change. Statewide, variance is increasing at an average rate of 0.01 each year. Source: WRCC (2025)

Approximately 30 to 50% of California's annual precipitation and about 40% of the Sierra Nevada snowpack comes from long, narrow bands of water vapor (greater than 1,000 miles long and typically about 250 to 370 miles wide), known as atmospheric rivers (**Figure 2.2.3**; Dettinger, 2013; Guan et al., 2010). A natural part of the global water cycle, they transport most of the water vapor outside of the tropics. Some atmospheric rivers originate from the Pacific Ocean near Hawaii and make landfall in California, where they can release water vapor in the form of heavy rain or snow (NASA, 2021; NOAA, 2025).

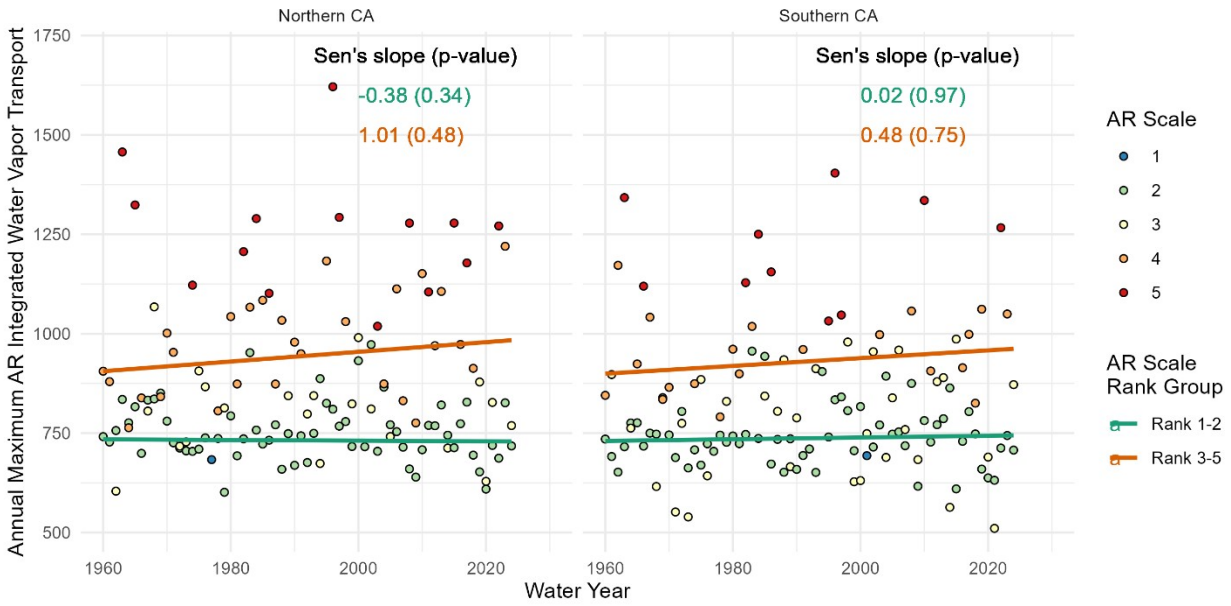
Figure 2.2.3. Satellite-Derived Image of an Atmospheric River.



Satellite-derived image showing an atmospheric river along the western United States, depicted as a long, narrow band of high integrated water vapor (colors represent atmospheric moisture content). Source: Hatchett et al. (2017a)

Atmospheric rivers are categorized by intensity and duration (ranked on a scale of 1 to 5, with 1 being the least amount of water vapor and shortest duration). The intensity of these events along the California coast is expected to increase as the climate warms and the atmosphere can hold more water (Payne et al., 2020), and precipitation extremes are expected to be driven by the largest events (Gershunov et al., 2019; Warner et al., 2014). Since the 1960s, the strongest atmospheric rivers (Categories 3 to 5) have increased in frequency, large interannual variability, thus no significant change has yet been detected (Gershunov et al., 2025 and **Figure 2.2.4**).

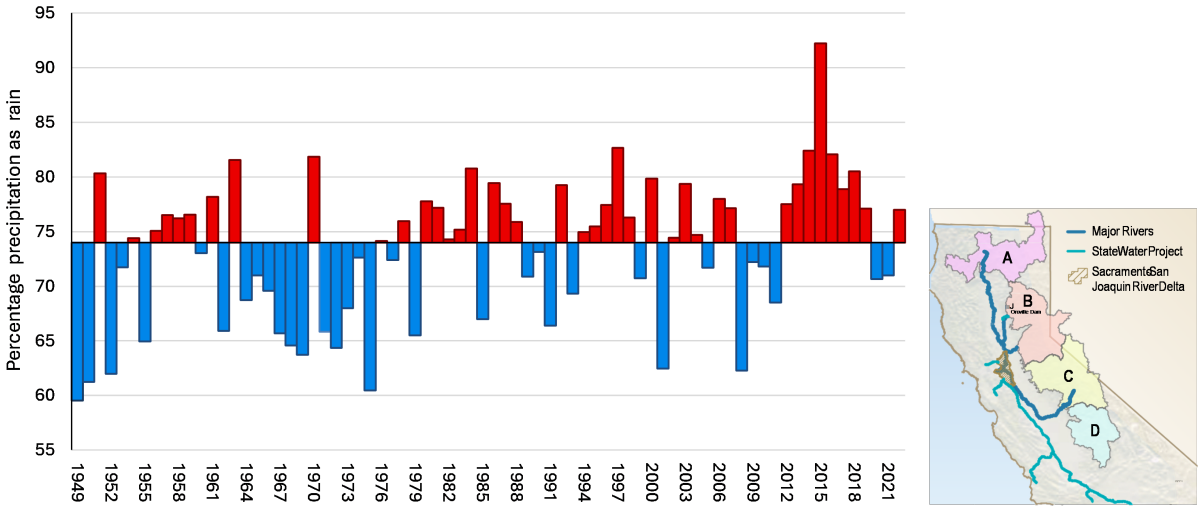
Figure 2.2.4. Atmospheric Rivers in California.



Annual maximum integrated water vapor transport (IVT) in Northern and Southern California for weak (Rank 1–2) and strong (Rank 3–5) groupings of atmospheric rivers. Points show yearly values and are colored according to the rank of the largest AR in the group and lines show trends for weak and strong, which are small and not statistically significant. Source: Center for Western Weather and Water Extremes, Scripps Institution of Oceanography (2025)

Figure 2.2.5 shows the percentage of yearly precipitation falling as rain over the 33 watersheds that provide most of the state's water supply. Values represent whether each year has precipitation falling as rain than the historical average. Each value is calculated as the difference between that year's percentage of rain compared to the long-term average (74%, black line) for the entire period (1949 to 2022). Red bars show years with more rain than average (and thus less snow), and blue bars show years with less rain than average. Despite high year-to-year variability, recent years clearly show a trend toward more precipitation falling as rain. The percentage of precipitation falling as rain for eight of the last 10 years was higher than average. The 2015 water year, which had the lowest snowpack on record, also had the highest percentage of rain, at about 92%.

Figure 2.2.5. Rain as a Percentage of Total Precipitation (1949–2022).



Annual percentage of precipitation falls as rain in major California water-supply watersheds. Red bars indicate years above the long-term mean (74%), and blue bars indicate years below the mean. The map shows the watershed zones included in the analysis. Source: DWR (2024)

Why is this indicator important?

Precipitation, in the form of rain and snow, provides most of California's supply of water. The fraction of precipitation falling as rain significantly affects how much water is stored as snow. During warmer months, the state relies on Sierra Nevada snowmelt to meet a large fraction of its water demand. Tracking changes in the amount and physical state of precipitation, and in the patterns of storm events gives critical information for balancing the multiple water management objectives of reservoir operations, including storage and flood protection.

Historical trends help inform short- and long-term water management planning and provide the basis for future projections (Siirila-Woodburn et al., 2021; Sterle et al., 2019). The availability of water has significant implications for California's people, environment, and economy (see the *Drought* and *Coastal Flooding* chapters). People who are historically marginalized, often low-income and people of color, are disproportionately impacted by lack of water (in the form of droughts) or extreme

precipitation (such as with floods) and have limited ability to prepare for or adapt to such events that will become increasingly common with climate change.

Changes in the timing of precipitation are also important to track. A comparison of historical and current precipitation (1960–1989 vs 1990–2019) averaged across the state shows a change in the monthly distribution of precipitation (Luković et al., 2021). This study found a later onset of the rainy season, with less precipitation early in the wet season, and greater concentration of precipitation during the winter months, resulting in a shorter, more intense rainy season in California. These observed changes are consistent with climate change projections (Oakley et al., 2019; Polade et al., 2014; Swain et al., 2018).

Tribal Connection 2.2.2

Variable precipitation, larger atmospheric rivers, and increased flooding in low-lying areas are impacting the lifeways of the Wiyot Tribe around Humboldt Bay or Wigi. "*Wiyot basketweavers and berry pickers must gather plant material and fruit at particular times of year. Gathering camps have traditionally been established around August and September when plants are in the best condition for harvest and traditional uses. […]. Early precipitation can cause less or incomplete ripening of berries, a process which is dependent on there being sunnier days in the period before the cold season arrives. Losses of material and food due to weather are compounded by the fact that the majority of the Wiyot's historically and culturally important gathering sites were incorporated into National and State Parks. Tribal members are no longer permitted to gather in those areas and may face consequences for trying to access ancestral gathering grounds. This makes it even more important that the sites that Tribal members can still access are productive*" (Wiyot Tribe, 2026).

Along with providing water to people in California, precipitation also nourishes the natural environment. Changes to precipitation or water availability can manifest in ecosystems in various ways. The record droughts of 2012–2016 and 2020–2022 contributed to significant tree mortality, wildfires, fish die-offs, and harmful algal blooms, while also straining water systems (Sum, 2024; Hartman et al., 2025).

Sharp shifts from extremely dry to extremely wet years can have major impacts. For example, California's recent rapid shift from severe drought (2012–2016) to heavy precipitation and flooding (2016–2017 winter) exemplifies what this precipitation whiplash looks like and what its impact can be: hundreds of roads and other infrastructure throughout California were damaged by floods and mass movements such as landslides. Heavy runoff in the Feather River watershed contributed to the failure of the Oroville Dam spillway, forcing the evacuation of almost a quarter of a million people (Swain et al., 2018). A wet-to-dry whiplash promotes the growth of vegetation that later dries and serves as fuel for wildfires (Williams et al., 2019). Altogether, projections of climate change suggest that California will spend most of the year in a perennial drought, interrupted periodically by large storms that produce heavy precipitation (Allen and Luptowitz, 2017; Gershunov et al., 2019; Huang et al., 2020; Pottinger, 2020). Both droughts and floods have major consequences for the people, environment, and economy of California (discussed in the *Drought* and *Coastal Flooding* chapters).

Tribal Connection 2.2.3

Prolonged droughts followed by heavy floods threaten cultural resources of many California Native American tribes, including the Big Pine Paiute Tribe. "*In addition to wildfire and drought, the region has also faced climate extremes in the form of heavy snowmelt and runoff. In 2023, a season of significant snowfall in the Sierra Nevada was followed by a rapid and intense melt, forcing the community to prepare for possible flooding. […]. Historically, water flowing off the mountains during the spring melt was absorbed by the valley's meadows, wetlands, and creeks, but with shifts in precipitation timing, land development, and soil health, the ability of the land to buffer these events has weakened. Much of the land where one of our Tribal groups traditionally lived lies directly in a floodplain, placing areas of cultural and ancestral importance at continued risk. These patterns further underscore how the challenges we now face are not isolated or seasonal—they are cumulative, intersecting, and deeply tied to both climate and the long-term legacy of altered land management*" (Big Pine Paiute Tribe, 2026).

As previously mentioned, atmospheric rivers are the source of most of California's water supply. They also cause most of the state's flood damage. Approximately 80% of levee breaches in California's Central Valley are associated with atmospheric rivers in the Categories 3 to 5 magnitude range (Florsheim and Dettinger, 2015; DWR, 2019). Weaker atmospheric rivers are generally beneficial because they can enhance water supply and snowpack, while stronger atmospheric rivers, especially those occurring after a prolonged duration, can become mostly hazardous because of flooding and associated impacts like landslides (DWR, 2019).

Floods, landslides, avalanches, and post-fire debris following heavy rainfall pose serious risks to human life, infrastructure, and communities (Collins et al., 2020; Hatchett et al., 2017a and 2020). Intense rainfall after a wildfire can produce fast-moving, highly destructive debris flows (USGS, 2021). For example, in January 2018, heavy rainfall over an area recently burned by the Thomas Fire triggered deadly landslides in southern California, causing loss of life and extensive damage (Lukashov et al., 2019). **Figure 2.2.6** shows shallow landslide and debris flow scars in the Tuolumne River Canyon on March 22, 2018, illustrating how extreme precipitation events can rapidly mobilize sediment and cause damage to infrastructure (Collins et al., 2020). More recently, from December 2022 through March 2023, fourteen atmospheric rivers caused flooding and hundreds of landslides, leading to condemned homes, severed lifelines, evacuated communities, and in early 2023 alone a series of storms resulted in 21 deaths and over $3 billion in losses (DOC, 2023; Castañón, 2024).

Figure 2.2.6. Heavy Rainfall Triggered over 500 Landslides at the Tuolumne River Canyon in 2018.



Source: Collins, et al. (2020), Photo credit: Wayne Hadley

Climate change is increasing both the frequency and magnitude of extremely severe storm sequences capable of causing megaflood events in California (Huang and Swain, 2022). The chances of an extreme 200-year flood event, last seen in the extraordinary "Great Flood" of 1861–1862, are more likely than not to occur within the next 40 years, and multiple occurrences are plausible by 2100 on a business-as-usual greenhouse gas emissions trajectory (Swain et al., 2018). During the Great Flood, flood waters remained throughout the state for months, transforming the land and making roads impassable (Jones, 2019). A storm of this magnitude today would probably lead to considerable loss of life and economic damages approaching a trillion dollars (Swain et al., 2018; USGS, 2011).

What factors influence this indicator?

High year-to-year variability in precipitation is a natural feature of California's climate. Climate change is intensifying these natural fluctuations, increasing both the frequency and severity of extreme wet and dry conditions. Greenhouse gases (GHGs) like carbon dioxide and methane, as well as solar forcing, contribute to increases in temperature. A warmer atmosphere's increased capacity to hold and release moisture—about 7% more water vapor for each degree Celsius of warming – leads to precipitation intensification (Swain et al., 2018 and 2025). In addition to GHGs, aerosols also influence precipitation patterns: sulfates tend to enhance winter precipitation, while black carbon can suppress it (Allen et al., 2020; Risser et al., 2024).

Along with interannual variability, California also has seasonal fluctuations. During the summer, California experiences a dry season as atmospheric moisture gets diverted away from the state by dense blobs of air parked over the north Pacific Ocean (also known as a "high pressure zone"). In the southeastern desert regions, however, some monsoonal activity in the summertime may bring thunderstorm precipitation (Corbosiero et al., 2009; WRCC, 2021). Precipitation deficits in winter during the recent drought have been associated with a prominent region of high pressure nicknamed the "ridiculously resilient ridge" that diverted storm tracks northward during California's rainy season from 2012 to 2015 (Swain, 2015). During winter, the Pacific high-pressure zone retreats southward, and much of California's annual precipitation falls during a few large

"atmospheric river" storms (Lamjiri et al., 2018; WRCC, 2021). Very heavy and rare rainfall events are expected to become larger and more frequent across the United States (Swain et al., 2020).

On average, rainfall from atmospheric rivers makes up 79%, 76%, and 68% of all extreme-rainfall accumulations in the North Coast, Northern Sierra, and Transverse Ranges of Southern California, respectively (Lamjiri et al., 2018). Windward slopes of hills or mountains provide the ideal location for atmospheric rivers to produce heavy precipitation in California through a phenomenon called orographic forcing: when air gets pushed up the slope of a mountain range, the water vapor cools and condenses if the air is moist enough, forming clouds and causing heavy precipitation to fall (Ralph, 2019). Precipitation from atmospheric rivers in western North America are expected to become more frequent, heavy, and extreme (Gershunov et al., 2019; Hagos et al., 2016; Polade et al., 2017) due to more moisture in the atmosphere. Although climate change will enhance the amount of precipitation delivered by landfalling atmospheric rivers along the West Coast, the overall frequency of precipitation will decrease as fewer storms not caused by atmospheric rivers are projected (Gershunov et al., 2019).

Most of the water vapor that provides the state's precipitation comes from the Pacific Ocean. Much of the variability in the state's precipitation is related to El Niño and La Niña in the tropical Pacific, which are the warm and cool phases of a recurring climate pattern called the El Niño-Southern Oscillation, or ENSO. Climate change may make extreme El Niño and La Niña events become more frequent and stronger by the end of the century (NOAA, 2020), although the specific impacts of ENSO on precipitation in California are highly variable and challenging to predict.

Regarding physical state, precipitation falls as rain or snow depending on the temperature of the air and the ground, the local geography, and the characteristics of the storm itself. Warming temperatures and their influence on a rising snowline (the altitude above which snow remains on the ground) make winter precipitation more likely to fall as rain instead of snow and run off into the ocean or be used by vegetation instead of being stored in reservoirs (Gonzales et al., 2019; Hatchett et al., 2017b;

Huang et al., 2020; Lynn et al., 2020). This higher runoff poses a greater flood risk (Huang et al., 2020).

Technical considerations

Data characteristics

Precipitation totals are tracked by “water year,” from the beginning of the rainy season defined as October 1 through September 30, the end of the dry season. This is more useful than a calendar year in California due to its typically dry summer and wet winter (“Mediterranean”) climate. On average, 75% of the state’s annual precipitation occurs from November through March, with 50% occurring from December through February.

Statewide precipitation is the area-weighted average of regional precipitation values. In other words, the regional precipitation values — computed as an area-weighted average of precipitation at the climate stations in the region — are weighted by the area covered by each region, and an average is calculated as the statewide value.

Annual precipitation data come from the California Climate Tracker, an operational database tracker for weather and climate monitoring information. This indicator tracks precipitation amount in a “water year”. This operational product, the California Climate Tracker, is updated periodically online at the Western Regional Climate Center (WRCC). Data, including historical data, is continuously monitored and updated. The data provided here is the data set available as of October 2025 from WRCC with the most up-to-date values for modeled historical data.

Precipitation data were obtained from the Western Regional Climate Center database, which obtains PRISM data using ACIS web services. The PRISM Climate Mapping Program (Oregon State University) is an ongoing effort to produce and disseminate the most detailed, highest-quality spatial climate datasets currently available. PRISM (Parameter-elevation Regressions on Independent Slopes Model) is an analytical tool that uses point data, a digital elevation model, and other spatial data sets to generate fine scale (4-kilometer, 2.5 arc-minutes) grid-based estimates of monthly precipitation and temperature from 1895-present. PRISM uses point measurements of climate data and a digital elevation model of terrain and is constantly updated to map climate in the

most difficult situations, including high mountains, rain shadows, temperature inversions, coastal regions, and associated complex meso-scale climate processes.

The methodology for determining the rain/snow trends combined fine-scale gridded precipitation data with coarse-scale freezing level and precipitation data from an atmospheric reanalysis. Snowfall was estimated as a fraction of total precipitation at a high spatial resolution, with output from WRCC's North American Freezing Level Tracker (NAFLT). For more information about the methods used, see Lynn et al. (2020).

The atmospheric river data were obtained from the Center for Western Weather and Water Extremes at Scripps Institution of Oceanography.

Strengths and limitations of the data

The datasets used in this work underwent their own separate quality control procedures, to account for potentially incorrect data reported by the observer, missing data, and to remove inconsistencies such as station relocation or instrument change. PRISM data offers complete coverage across the state for every month of the record. However, limitations include the bias of station data toward populated areas and quality control processes are more limited in remote or high terrain areas. The results cited here offer a hybrid using both gridded and station data, considered more robust than either data set used independently (Abatzoglou et al., 2009).

An advantage of the rain/snow approach used by Lynn et al. (2020) is that the NAFLT can be updated as higher resolution gridded data products become available. This type of analysis can play an important role in developing and implementing adaptive strategies for water management. However, the approach relies on interpolated observational data which are sparse in mountainous regions and may not fully reflect snowline variability in complex terrain.

OEHHA acknowledges the expert contribution of the following to this report:

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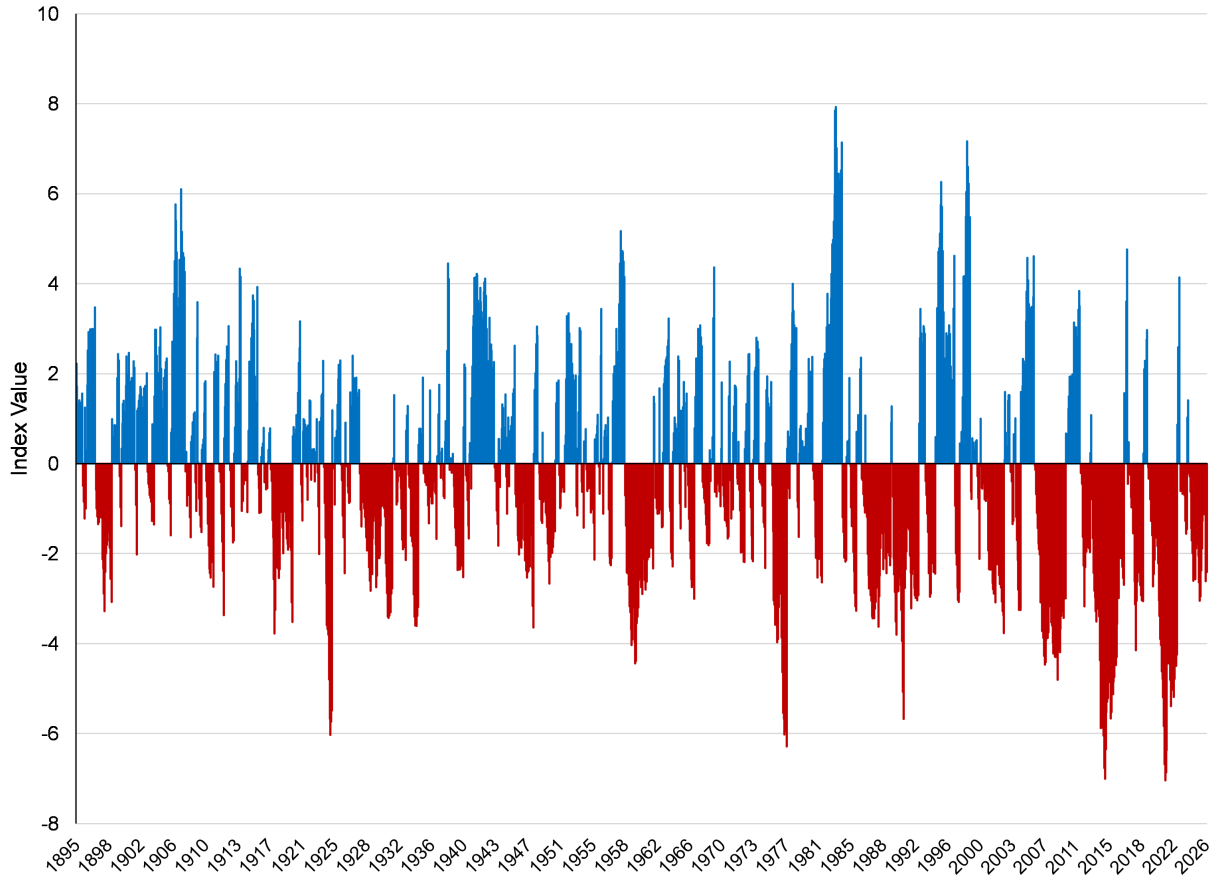
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2.3 Drought

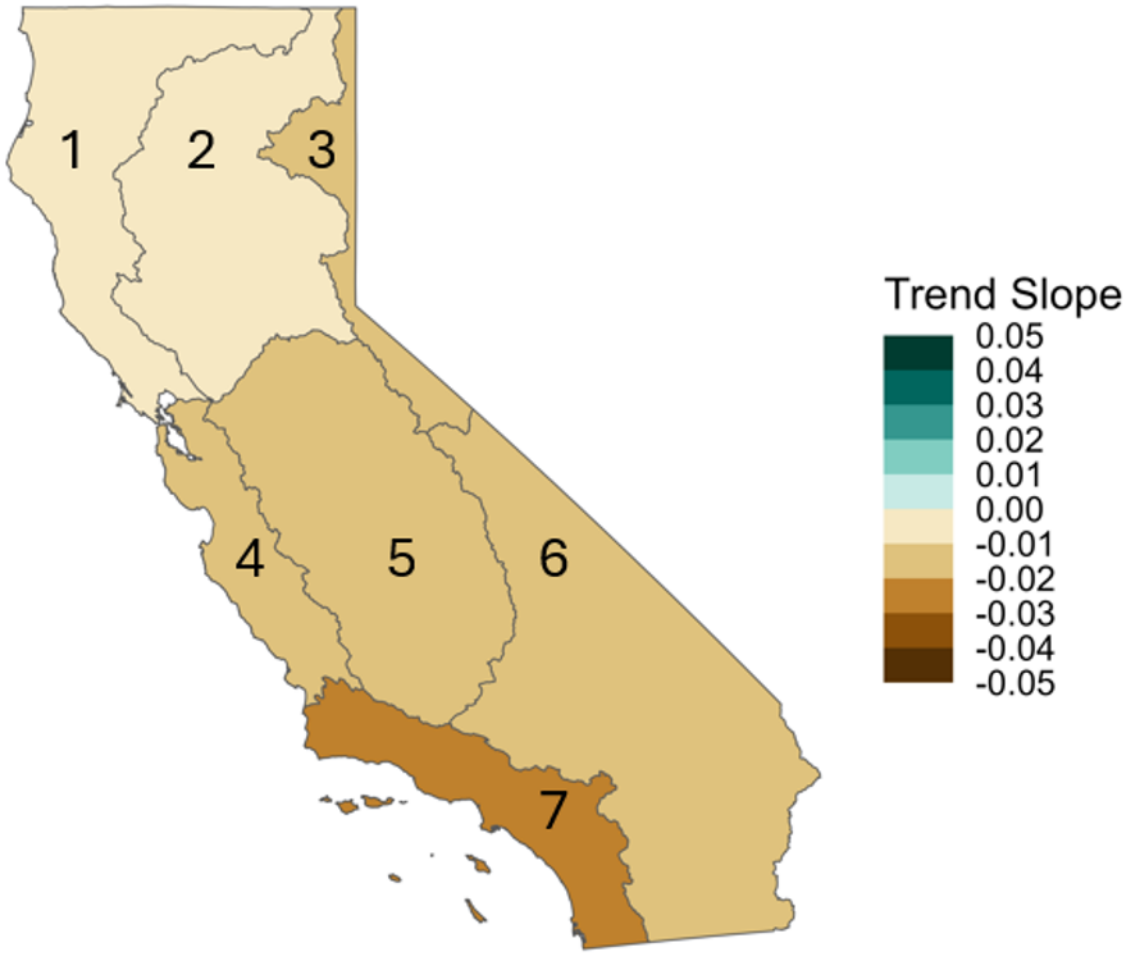
Droughts are prolonged periods of water shortage. In California, climate change has intensified droughts, making them hotter, longer, and more difficult to recover from. The multi-year, record-setting droughts of 2012–2016 and 2020–2022 created unique challenges for people, ecosystems, and the state's water security. Drought conditions abated in 2023 but returned in some parts of the state in 2024, 2025, and 2026.

Figure 2.3.1. California Palmer Drought Severity Index (PDSI).



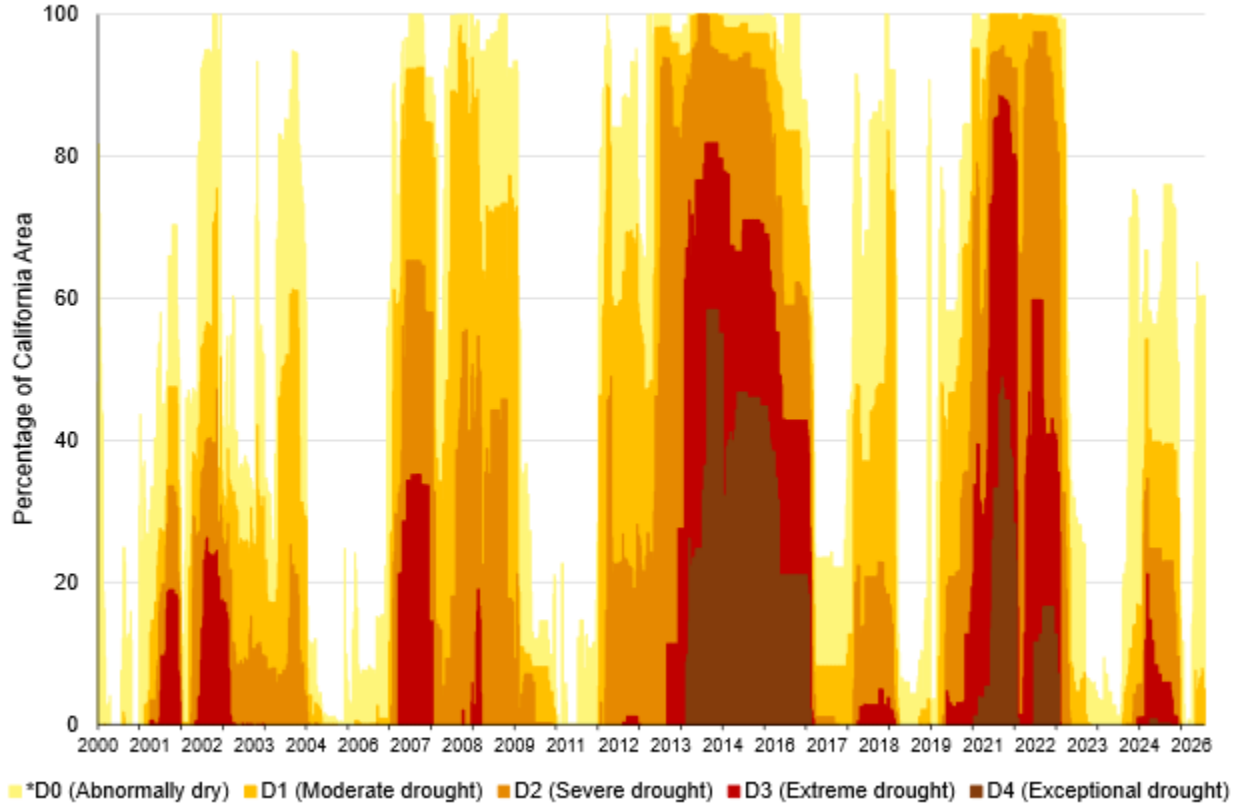
Monthly PDSI for California from January 1895 to May 2026 are presented in the graph below. Values greater than 0 (shown in blue) represent wet months. Values less than 0 (shown in red) represent dry months. Source: NOAA (2026)

Figure 2.3.2. California PDSI Trends.



The map shows trends in annual average PDSI for each California climate division from 1895 to 2024. Colors range from dark blue (a trend to wetter years) to dark brown (a trend to drier years), indicating a trend toward drier conditions. Climate divisions are geographical regions with consistent, long-term weather patterns of temperature and precipitation. The numbered climate divisions are as follows: 1) North Coast; 2) Sacramento; 3) Northeast Interior Basins; 4) Central Coast; 5) San Joaquin; 6) Southeast Desert; 7) South Coast. Source: NOAA (2026)

Figure 2.3.3. Percentage of California Land Area in Drought



This figure shows the percentage of California's land area impacted by different levels of drought severity from 2000–2026 according to the U.S. Drought Monitor. At each point in time, the colored bars represent a fraction of the total land area classified in each drought category, with darker colors indicating more severe drought conditions. Source: U.S. Drought Monitor (2026)

What does the indicator show?

Two key metrics, the Palmer Drought Severity Index (PDSI) (**Figure 2.3.1** and **Figure 2.3.2**) and the U.S. Drought Monitor, are commonly used to track drought conditions in California. The PDSI, developed in the 1960s, measures relative dryness based on precipitation and temperature (IDMP, 2023). Values at or below -4 reflect severe drought. The more recent U.S. Drought Monitor integrates a broader set of data – precipitation, streamflow, reservoir levels, temperature, soil moisture, vegetation health, snowpack, and expert input – and classifies drought severity using five categories, from

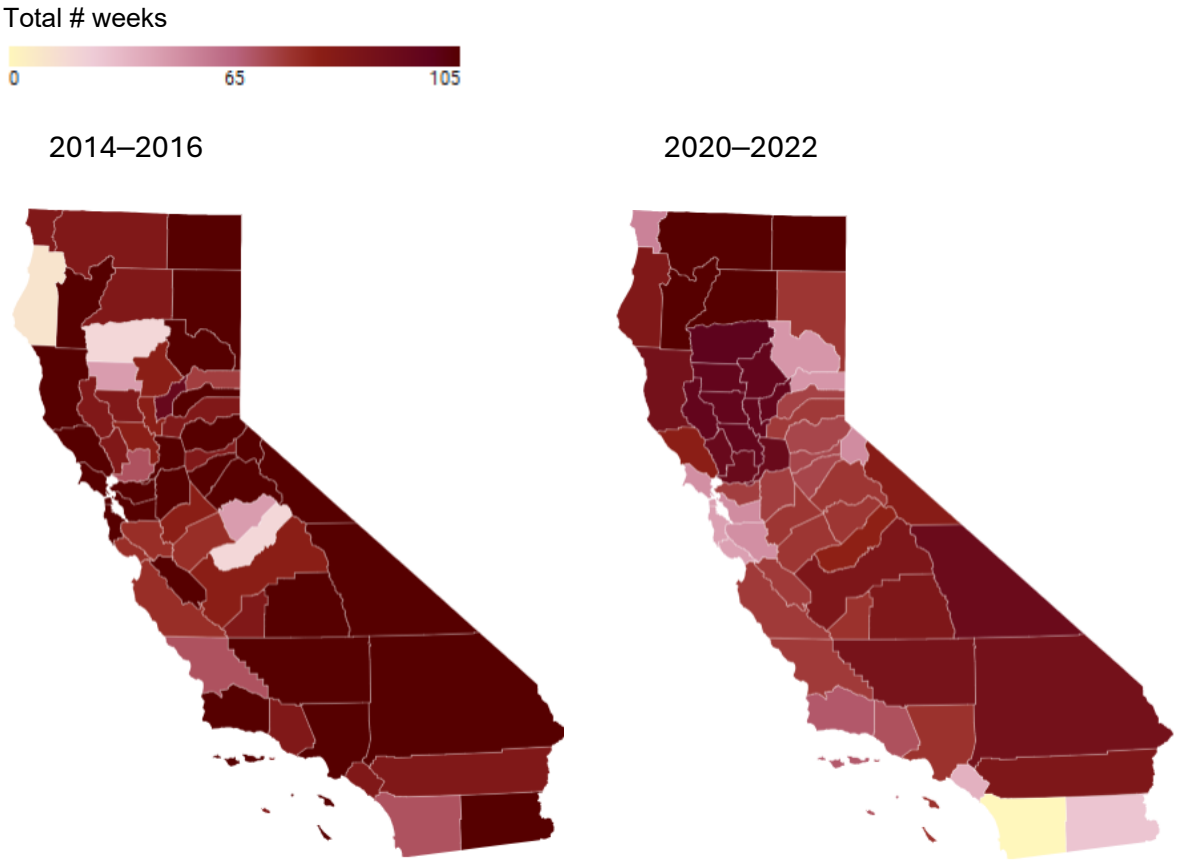
D0 (abnormally dry) to D4 (exceptional drought) (U.S. Drought Monitor, 2025). **Figure 2.3.3** shows the percentage of California's land area affected by each drought severity level since 2000. Both the PDSI and U.S. Drought Monitor track drought in natural water systems and are thus directly relevant to climate trends. In addition, they are applicable to activities that rely on unmanaged water systems like dryland farming and grazing.

California has undergone two unprecedented droughts in recent decades: the 2012–2016 drought and the 2020–2022 drought. As part of a long-term drying trend (**Figure 2.3.1**), California experienced its driest periods from 2014 to 2016 (during the 2012–2016 drought) and from 2020 to 2022 (the entirety of the 2020–2022 drought). The 2012–2016 drought in California ended with unusually high precipitation in 2017. Drought conditions began developing again in early 2020, persisted through the 2021 water year (October 2020 to September 2021), and continued into the 2022 water year, producing an extremely dry 3-year period. This coincided with a period of anomalously warm temperatures and low precipitation.

Characterized by unusually warm temperatures and low precipitation, these periods of "hot droughts" are becoming more common in western North America (King et al., 2024). All areas of California are experiencing a long-term drying trend, with the south coast drying the fastest.

In the 2022 water year, over 90% of the state experienced severe drought for most of the year (42 weeks). Conditions changed sharply in early 2023 after a series of nine atmospheric rivers delivered over 32 trillion gallons of rain and snow in just three weeks (NOAA, 2023). Drought conditions remained mild through 2024 but increased again in 2025, with 25% of the state under severe drought for 17 straight weeks by mid-May in 2025. Every drought has its own unique pattern of extent, duration, and intensity. The U.S. Drought Monitor shows that while many counties in California faced more weeks of severe drought in 2014–2016 than in 2020–2022, some counties, primarily those in the north, such as Siskiyou, Shasta, Humboldt, Glenn, and Tehama, endured more weeks of severe drought in 2020–2022.

Figure 2.3.4. Drought Conditions in 2014–2016 and 2020–2022.



The maps show the total number of weeks that counties in California experienced severe drought during the 2014–2016 and 2020–2022 water years based on the U.S. Drought Monitor. Source: U.S. Drought Monitor (2025)

Why is this indicator important?

Droughts have wide-ranging environmental, social, and economic impacts – disrupting water supplies for cities, agriculture, hydropower, and ecosystems. Snowpack (see the *Snow-Water Content* chapter), snowmelt runoff (see the *Snowmelt Runoff* chapter), freshwater (see the *Salmon River Water Temperature* chapter), and groundwater resources are all affected – disrupting ecosystems and impacting human health and well-being. Dry vegetation, for instance, provides more fuel for large and destructive wildfires (see the *Wildfires* chapter). Climate change impacts on dry vegetation have

contributed to larger wildfires in California and an earlier start to the wildfire season (Madakumbura et al., 2025).

The record droughts of 2012–2016 and 2020–2022 contributed to widespread tree mortality, wildfires, fish die-offs, and harmful algal blooms. They also strained water systems, exacerbated drinking water shortages, reduced farm deliveries, and increased groundwater use (Sum, 2024; Hartman et al., 2025).

Drought disproportionately affects communities that are low-income, rural, or comprised of people of color, as well as California tribes (SWRCB, 2021a). These marginalized groups face greater risks from impacts such as water contamination, job loss, loss of resources, and air pollution (Pacific Institute, 2026). In addition, climate change will increase the likelihood of drought and heatwaves occurring simultaneously (Tripathy et al., 2023).

Tribal Connection 2.3.1

The interconnected lifeways and homelands of the Pala Band of Mission Indians in San Diego County have been deeply impacted by drought. "*In the past 30 years, Pala has had 12 years during which they experienced severe drought conditions […]. Drought, combined with climate change-driven extreme heat, season shifts, and insect and pest outbreaks can weaken plants, trees, and forests or shift growth patterns […]. Pala Environmental Department staff note declining numbers of Englemann (Quercus engelmannii) and coast live oak (Quercus agrifolia) trees, which are considered culturally important (Pala, 2019). […]. The Pala reservation is home to endangered or threatened plant species including Parry's tetracoccus (Tetracoccus dioicus) and Rainbow manzanita (Arctostaphylos rainbowensis). Drought, along with increased temperature, stresses these plants and creates conditions for certain non-native, invasive species to thrive. […]. These species can degrade habitat quality for native wildlife and contribute to increased wildfire frequencies*" (Pala Band of Mission Indians, 2026).

Ecosystem and human interactions

Forests and aquatic ecosystems are especially vulnerable to ecological drought. During 2020 and 2021, low streamflows with high water temperatures and salinity threatened already declining salmon and steelhead populations (Shimabuku and Kammeyer, 2022; CNRA, 2021). Drought has also led to widespread tree mortality (see the *Tree Mortality* chapter), shifts in vegetation (see the *Vegetation Distribution Shifts* chapter), and increased wildfire risk, especially in northern California, where water-stressed trees have added to fuel loads. Drought further impacts bird species, reducing habitat, water, and food sources. In response, some bird species have shifted into human-managed landscapes, like Central Valley farmland (Goldstein et al., 2024).

Drought impacts of ecosystems disproportionately affect people who depend on these natural resources. People most reliant on annual rainfall usually experience the impacts of drought first. A single dry year can impair dryland farming or livestock grazing that depend on unmanaged water supplies (DWR, 2015). Drought impacts on local habitats place additional burdens on rural populations that depend on them for food, firewood, or their livelihood (Taylor et al., 2024; Roos, 2018). The loss of culturally significant animals and plants can have profound impacts on Tribes who rely on them for traditional foods, medicine, and cultural practices.

Managed water systems

Domestic water supply

During the 2012–2016 drought, large urban water districts with diverse supplies avoided major disruptions, while more than 100 small water systems and 2,000 domestic wells—mostly in low-income, rural, and often Latino/a communities of the Central Valley and Sierra Nevada foothills—ran dry (Lund et al., 2018; PPIC, 2016, 2021). Climate change and rising temperatures further strained domestic supplies by increasing evaporation from surface reservoirs and reducing available surface water (Friedrich et al., 2018). Drought also worsens water quality, further limiting access to safe, reliable, and affordable drinking water. It does so through saltwater intrusion and elevated levels of contaminants and pathogens, disproportionately affecting small systems and vulnerable communities. For example, in the San Joaquin Valley, droughts from 2007–2020 increased nitrate and arsenic concentrations in majority Latino/a water systems (Sum,

2024). Rising water costs compound these challenges: by late 2020, 1.6 million households carried water debt averaging $500, with low-income families and communities of color hit hardest during the COVID-19 recession (SWRCB, 2021b). Utilities also faced revenue losses and disaster damages, as evidenced by the destruction of Paradise's water system during the 2018 Camp Fire (Bohn et al., 2020; Chow et al., 2021).

Hydroelectric power generation

Drought reduces the generation of hydroelectricity, which depends on snowmelt runoff and rainfall. Under extreme drought, electricity generation from individual fossil fuel plants can increase up to 65% in the western United States, mainly due to the need to compensate for reduced hydropower (Qiu et al., 2023).

Agricultural water supply

During the 2012–2016 drought, reduced water deliveries forced farmers to leave more than 500,000 acres fallow, with major losses to orchards, vineyards, and farm jobs. The decreased water availability also drove an increased reliance on groundwater, the state's largest agricultural water source and a lifeline for communities and wetlands.

Increases in the crop water demand in the San Joaquin Valley over the past forty years caused half of the cumulative agricultural water balance deficits, exacerbating water reliance on groundwater supplies and variable surface water levels. This phenomenon of climate-induced increased crop water, or *invisible water surcharge,* has increased crop water demand in the San Joaquin Valley by 4.4% from 1980 to 2011 — the annual volume >800 gigalitres, the equivalent volume of a major local reservoir. San Joaquin Valley is a critical region for global fruit and nut production, and increased crop water demand adds a stressor to supply sustainability (Moyers et al., 2024).

Decades of groundwater overdraft have left 65% of wells statewide in decline, caused widespread subsidence in the San Joaquin Valley (where some areas sank up to 28 feet by 1970), and reduced aquifer capacity with every subsequent drought. As climate pressures intensify, meeting Sustainable Groundwater Management Act goals to halt overdraft and bring basins into balanced levels of pumping and recharge by the 2040s will be increasingly difficult, potentially requiring the permanent fallowing of half a million

acres. Concurrently, overpumping continues to degrade rivers, wetlands, infrastructure, and ecosystems.

Tribal Connection: Drought 2.3.2

The *Impacts of Climate Change on the Big Valley Band of Pomo Indians* report discusses the impact of increased groundwater pumping during drought on freshwater systems and species. They write: "*Water scarcity also impacts local agriculture, stressing crops such as pears, walnuts, and grapes. Increased reliance on groundwater to support agriculture in areas near the* [Big Valley] *Rancheria reduces the volume of surface water entering streams where Clear Lake Hitch, an endemic and culturally significant fish, spawn […]. Clear Lake Hitch have been forced to adapt to a very brief period of suitable stream conditions for their annual spawning run, as water diversions and a changing climate have caused streams to prematurely dry […]. Increased drought and rapid climate change due to warming temperatures will likely accelerate this trend, causing further spawning failures*" (Big Valley Band of Pomo Indians, 2026).

Human health

Droughts adversely impact human health in multiple ways, including reduced access to safe, reliable, and clean drinking water (Bell et al., 2018). Reduced water quantity during periods of drought can lead to:

- Decreased water flow
- Promotion of pathogens that favor warm, stagnant environments (Paz, 2015; see the *Vector-Borne Diseases* chapter)

Consumption or contact with water containing pathogens, such as *Vibrio* species, may result in ear, eye, wound infections, diarrheal illness, and death (Trtanj et al., 2016). Water conservation behaviors during the 2012–2016 drought, such as reduced handwashing and food washing, also increased the risk of communicable diseases (e.g., enteric disease and influenza) and exposure to pesticide residues (CDC, 2016a, 2016b, 2017).

Drought-related environmental changes also affect air quality and disease dynamics. Swings from extreme drought to extreme precipitation contribute to spikes in cases of Valley Fever in California (Camponuri et al., 2025; also see the *Valley Fever* chapter). In addition, drought increases air pollution from wildfires and dust storms (DWR, 2015). Under dry conditions, winds tend to transport inhalable soil particles, leading to unhealthy air quality.

Tribal Connection 2.3.3

Both the Bishop Paiute Tribe (Bishop Paiute Tribe, 2026) and the Big Pine Paiute Tribe who are in Payahuunadü, or the Owens Valley, have noted increases in airborne dust and harmful particulate matter during droughts which impact Tribal members' health. A Big Pine Paiute Tribal member writes, "*Droughts have become commonplace in the area. The dry soil leads to dust, which often affects the breathing of all community members; there are a number of elders with lung issues and a growing number of cases of children with asthma and other breathing issues. The soil is alkaline and causes clouds of dust that are very irritating to the eyes, throat and lungs*" (Big Pine Paiute Tribe, 2026).

Drought also affects surface water quality. A visible surface water quality impact during the 2012–2016 drought came in the form of more frequent harmful algal blooms. These blooms appeared in freshwater bodies throughout the state, from the Klamath River in the north to Lake Elsinore and the Salton Sea in the south (CNRA, 2021). Certain bloom-forming organisms, such as cyanobacteria, produce toxins that adversely impact people and their pets. In humans, exposure to these toxins can lead to a wide array of symptoms including skin rashes, blisters, vomiting, and abdominal pain (CWQMC, 2021; OEHHA, 2025). In pets, exposure can be lethal (CNRA, 2021).

Exposures to algal toxins can occur through ingesting contaminated water or food, or by direct contact to contaminated water. Communities that rely on freshwater for drinking water or recreational are disproportionately affected.

What factors influence this indicator?

Droughts are a naturally occurring feature of California's climate and are influenced by modes of global climate variability, such as the El Niño-Southern Oscillation, regional atmospheric pressure anomalies, and the frequency of landfalling "drought-busting" atmospheric rivers. A single wet year, composed of frequent atmospheric rivers that make landfall, can terminate a persistent drought (Dettinger, 2013, Williams et al., 2024; Gershunov et al., 2025). Historically, dry winters in California have been associated with a ridge of high atmospheric pressure off the west coast, while wet winters tend to occur with a trough off the west coast (Seager et al., 2015; Guirguis et al., 2024).

Droughts of the 21st century are hotter, longer lasting, and spatially larger than previous droughts (Crausbay et al., 2017). Human-caused warming – driven primarily by greenhouse gas emissions from fossil fuel combustion, land use change, and other anthropogenic sources – has increased the likelihood of extreme droughts in California and globally (Chen et al., 2025; Diffenbaugh et al., 2015; Zhuang et al., 2024). Rare atmospheric patterns driving extreme heat and dryness have become more frequent, contributing to events like the 2012–2016 drought. Starting from 2000, the record-setting drought in the southwestern U.S. includes the driest 22-year period since 800 CE with 19-42% of the dryness attributable to climate change (Williams et al., 2022). Continued warming is expected to worsen drought conditions through declining snowpack, more variable precipitation, and prolonged dry spells (Diffenbaugh et al., 2015; Gershunov et al., 2019; Swain et al., 2025).

Rising temperatures also increase "evaporative demand" intensifying drought by drawing more moisture from soils and vegetation. Since the 1980s, most of the western U.S. has seen higher evaporative demand, and in 2021, much of California experienced the highest levels in four decades (McEvoy et al., 2020; Pottinger, 2020; NIDIS, 2021). Since 2000, warming-driven evaporative demand has contributed more to droughts in the western U.S. than reduced precipitation (Fu and Zhuang, 2025).

A warmer atmosphere also fuels bigger storms, as more water is stored in the air. The likelihood of rapid transitions between extreme wet and dry conditions (such as those seen in 2022–2023 in the Pacific Southwest), sometimes known as "climate whiplash",

is expected to happen more often (Swain et al., 2025). By 2100, climate projections suggest California will experience longer and more persistent dry periods, punctuated by fewer but intense storms that produce heavy to extreme precipitation, rather than evenly distributed seasonal rainfall (Allen and Luptowitz, 2017; Gershunov et al., 2019; Huang et al., 2020; Pottinger, 2020).

Regional geography and local climate patterns also determine the severity of droughts. The 2012-2016 drought was most severe in southern California, which has displayed greater drying trends than northern California (Dong et al., 2019). Locally, soil moisture and vegetation may delay the onset of drought. Moist soil can delay the onset of soil droughts when precipitation is low, or when there is a lack of rainfall. In addition, drought-induced vegetation loss can slow the depletion of soil moisture due to reduced water loss through evapotranspiration (Jiang et al., 2025).

Technical considerations

Data characteristics

PDSI identifies droughts by incorporating data on temperature, precipitation, and the soil's water-holding capacity. The metric takes into consideration moisture received as precipitation and moisture stored in the soil, while also accounting for potential loss of water due to evaporation. It originally developed to identify drought affecting agriculture but has since been used to identify drought associated with broader impacts, including water supply, ecosystem stress, and wildfire risk (WMO and GWP, 2016). PDSI is used to assess long-term drought patterns (NOAA, 2017). The U.S. Drought Monitor provides a big-picture look at drought conditions in the United States. As previously mentioned, along with PDSI, metrics used in the U.S. Drought Monitor include soil moisture data, streamflow conditions, the standardized precipitation index, and blends of various drought indicators.

Strengths and limitations of the data

PDSI has been in use since the 1960s and is universally used to identify drought conditions. However, it assumes that all precipitation falls as rain (Williams et al., 2015), does not account for frozen precipitation or frozen soils (WMO and GWP, 2016), and does not account for drives of atmospheric water demand other than temperature, such

as wind speed, humidity, and solar radiation. PDSI also does not provide information on human water demand, streamflow, reservoir storage, or groundwater accessibility (Williams et al., 2015), and therefore represents drought conditions primarily in natural, unmanaged systems. The USDM integrates many types of data, including observations from local experts, as well as information about reservoir storage, and can be useful for identifying areas likely to experience drought impacts. However, it is not designed to infer specifics about local conditions.

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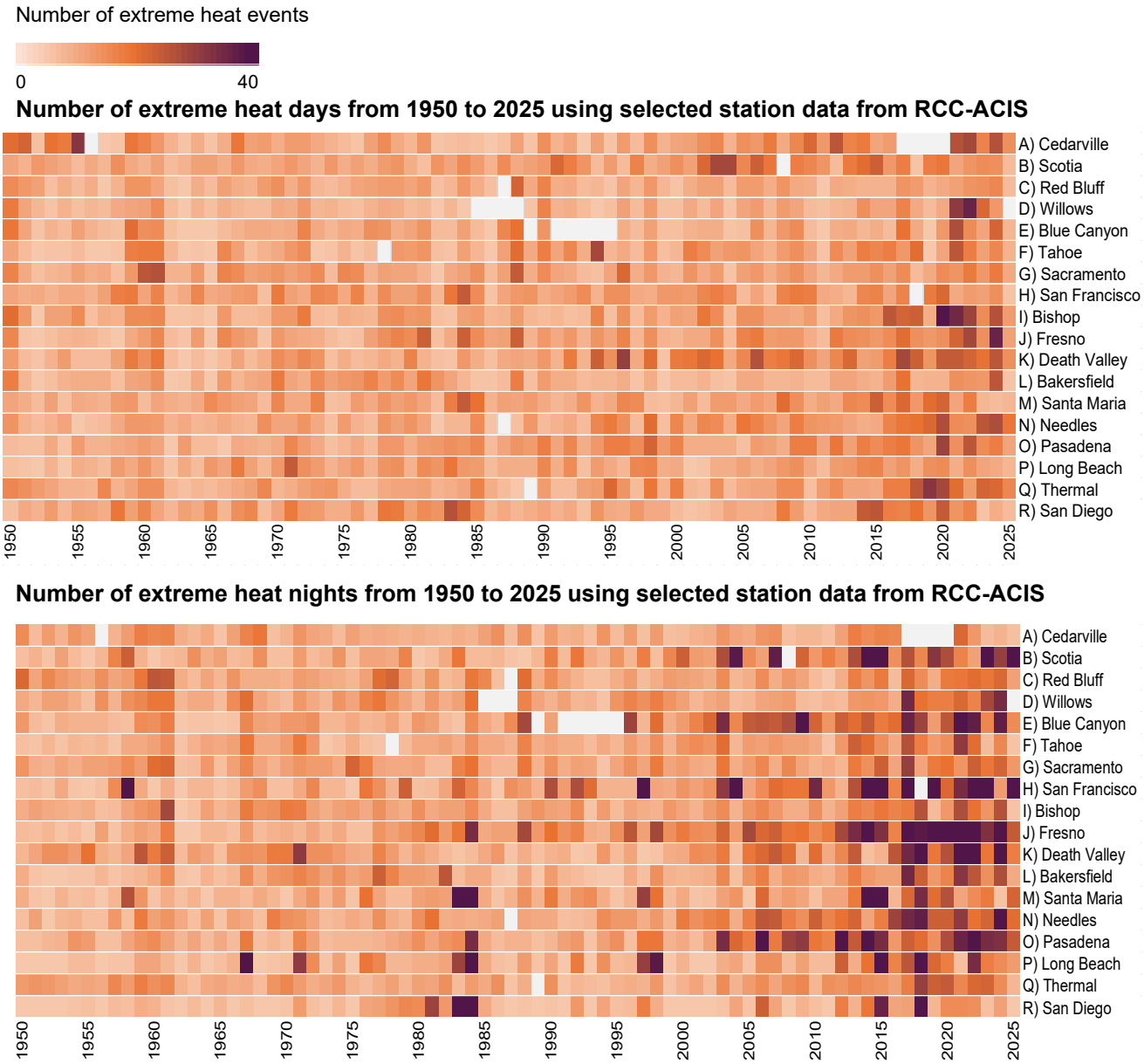
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2.4 Extreme Heat Events

Extreme heat events are days or nights when temperatures exceed a defined threshold. Since 1950, extreme heat days and nights have become more frequent at multiple locations in California, with the most widespread increases occurring at night. This has driven an increase in the number of heatwave days and nights, defined here as two or more consecutive extreme heat days or nights.

Figure 2.4.1. Frequency of Extreme Heat Events.



The charts show the annual sum of extreme heat days or nights from 1950 to 2025 for 18 weather stations in California, listed from north to south. Years for which not enough data was available are greyed out. For data to be included for the months of July and August, in a given year, there had to be fewer than seven days of data missing.

Source: NOAA Regional Climate Center's Applied Climate Information System (RCC-ACIS). Data retrieved April 2026.

Figure 2.4.2. Locations of Selected Weather Stations.



A) Cedarville
B) Scotia
C) Red Bluff
D) Willows
E) Blue Canyon
F) Tahoe
G) Sacramento
H) San Francisco
I) Bishop
J) Fresno
K) Death Valley
L) Bakersfield
M) Santa Maria
N) Needles
O) Pasadena
P) Long Beach
Q) Thermal
R) San Diego

The map shows the locations of the 18 weather stations used to calculate extreme heat days and nights.

Source: Map created with Datawrapper and OpenstreetMap contributors.

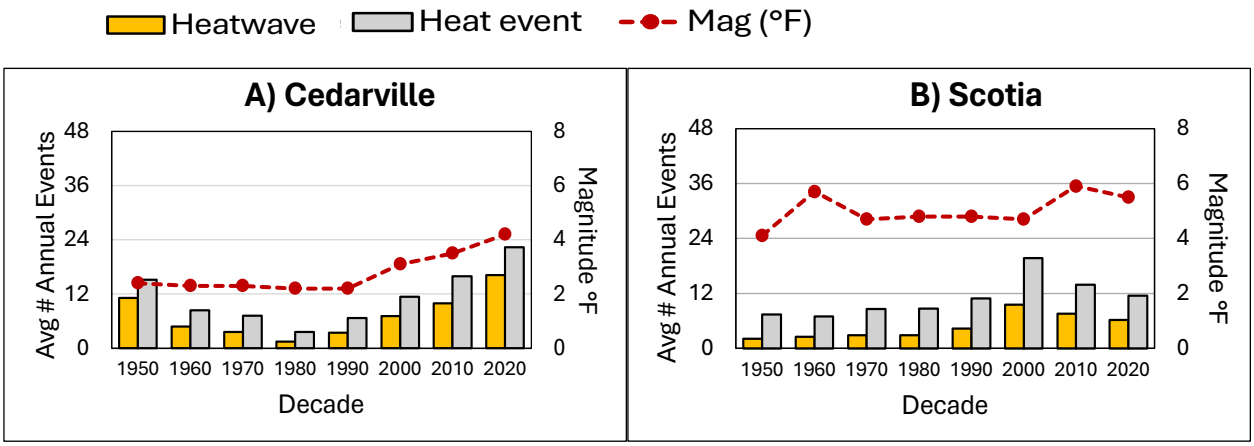
What does the indicator show?

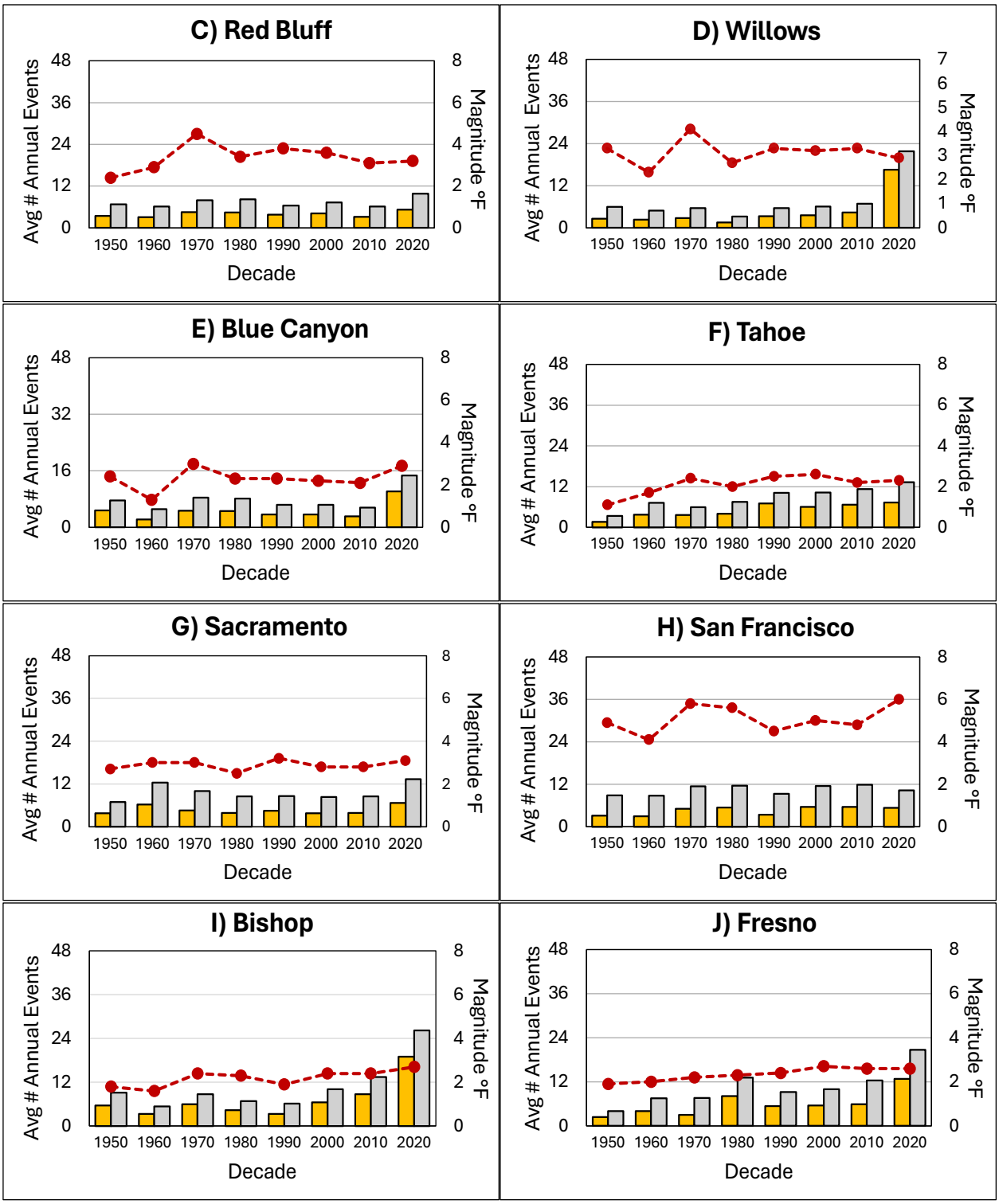
Extreme heat events broadly refer to individual days or nights or multiple days or nights when temperatures exceed a defined threshold for a designated length of time. While there is no standard definition for an extreme heat event, researchers often apply a percentile-based threshold from a set historical period to identify heat events. Here, extreme heat events are defined as days or nights from April to October where the air temperature is above the location-specific 95th percentile of either the daily maximum temperatures (for daytime events) or the daily minimum temperatures (for nighttime events) for the 1960–1990 reference period. Since 1950, the total number of extreme

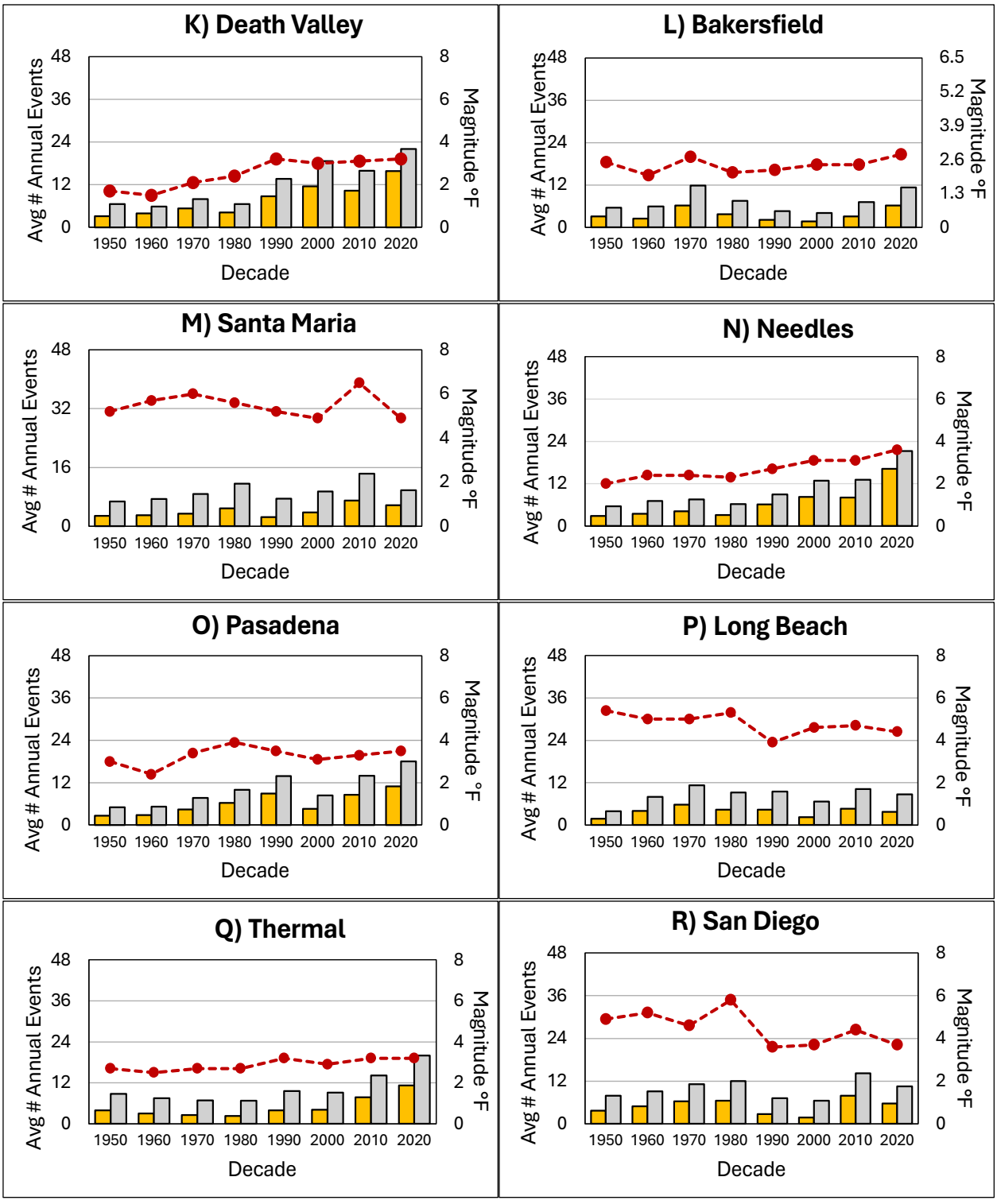
heat events at multiple locations in California has increased, especially at night (**Figure 2.4.1**; map of locations in **Figure 2.4.2**).

Heatwaves, which are multi-day heat events, are also important to consider as the short-term accumulation of heat can have greater impacts. Since there is no set definition for how many consecutive extreme heat days or nights make up a heatwave, this report defines a daytime or nighttime heatwave as two or more consecutive daytime or nighttime heat events, respectively. **Figures 2.4.3** and **2.4.4** present the decadal averages of the magnitudes (intensities of temperatures compared to historical averages) of daytime and nighttime extreme heat events, as well as the annual number of days and nights in a heatwave; values presented for the last decade ("2020") are for 2020 through 2025 only. For comparison, the frequency of extreme heat events is also presented. For most of the stations, the magnitude and frequency of extreme heat events and frequency of days and nights in heatwaves are higher in the second half of the time series (1988 to 2025) for both nighttime and daytime events.

Figure 2.4.3. Daytime Heatwaves and Heat Events by Decade.




C) Red Bluff
D) Willows
E) Blue Canyon
F) Tahoe
G) Sacramento
H) San Francisco
I) Bishop
J) Fresno
Avg # Annual Events
Magnitude °F
Decade
1950 1960 1970 1980 1990 2000 2010 2020



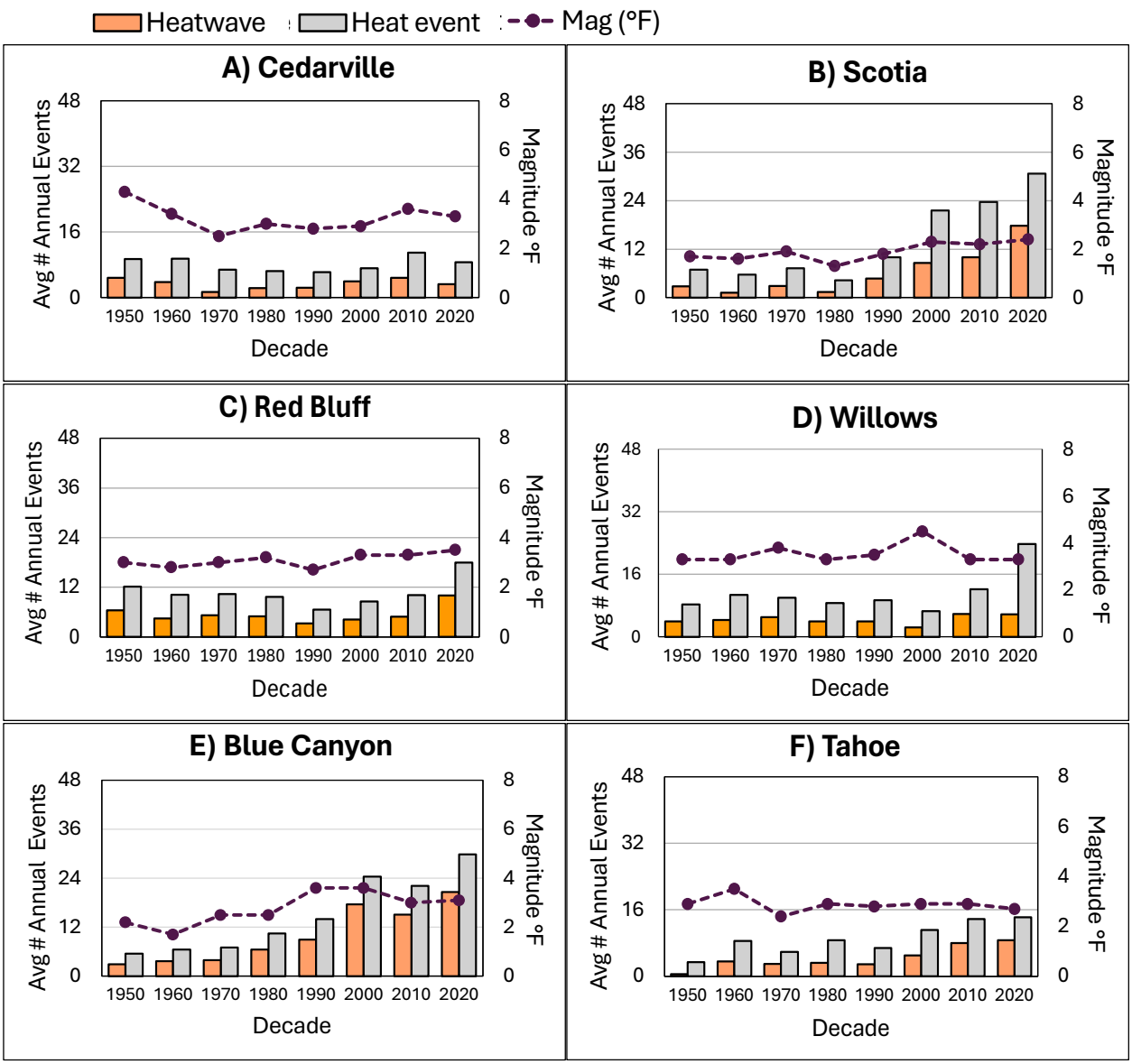
The average annual values by decade for the number of days in heatwaves and individual extreme heat events (yellow and grey bars) and the magnitude (the average of daily exceedances above the historical threshold, in degrees Fahrenheit (°F)) (dotted line) of individual extreme heat events are presented for each station. Yellow bars represent the average annual number of days in a heatwave, the grey bars represent the annual average

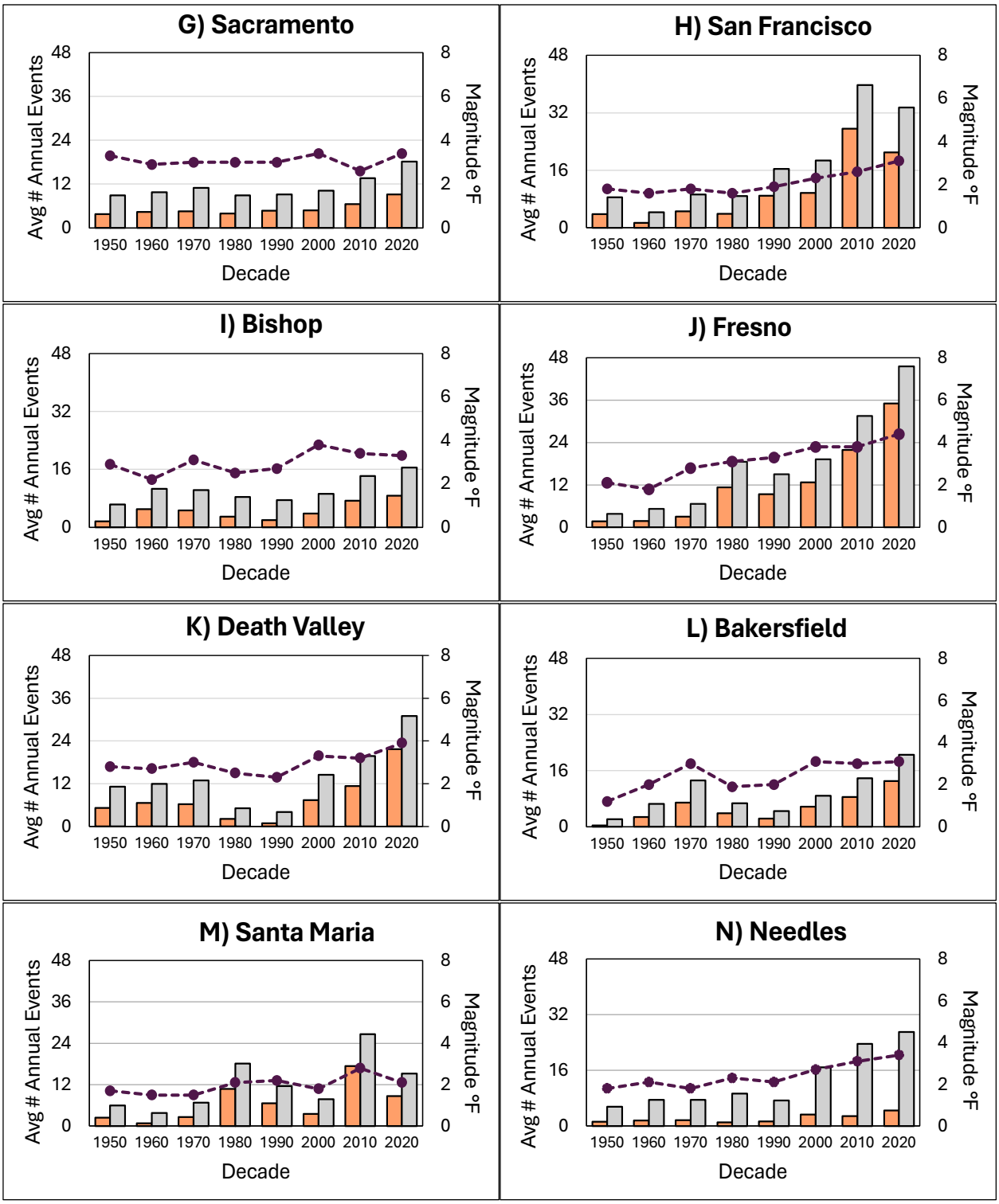
number of extreme heat days overall (irrespective of whether they were in a heatwave), and the red dotted line represents the average decadal magnitude of an extreme heat day for that year.

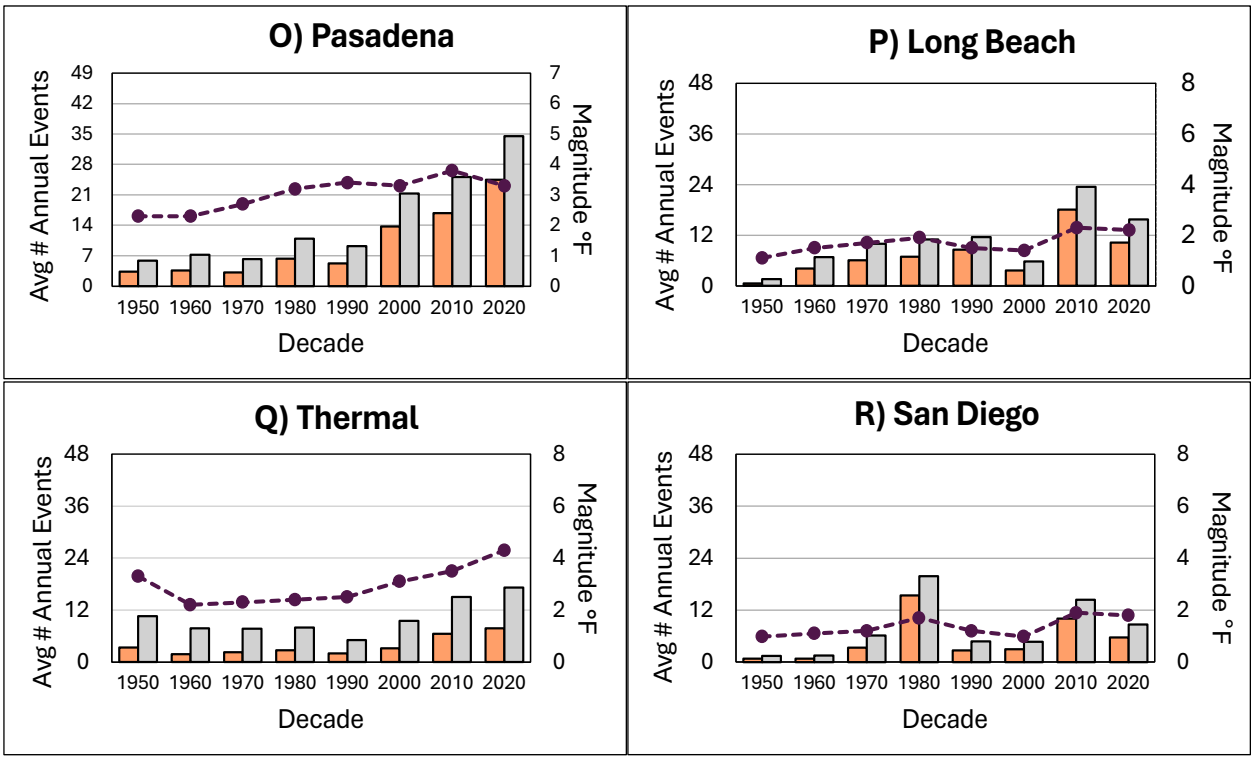
Note: The decadal average for 2020s represents the average values for the years 2020 to 2025 only.

Source: RCC-ACIS (2026)

Figure 2.4.4. Nighttime Heatwaves and Heat Events by Decade.




G) Sacramento
H) San Francisco
I) Bishop
J) Fresno
K) Death Valley
L) Bakersfield
M) Santa Maria
N) Needles
Avg # Annual Events
Magnitude °F
Decade
1950 1960 1970 1980 1990 2000 2010 2020



The average annual values by decade for the number of nights in heatwaves and individual extreme heat events (orange and grey bars) and the magnitude (the average of daily exceedances above the historical threshold, in degrees Fahrenheit (°F)) (dotted line) of individual extreme heat events are presented for each station. Orange bars represent the average annual number of nights in a heatwave, the grey bars represent the annual average number of extreme heat nights overall (irrespective of whether they were in a heatwave), and the purple dotted line represents the average magnitude of an extreme heat night for that year. The decadal average for 2020s represents the average values for the years 2020 to 2025 only. Source: RCC-ACIS (2026)

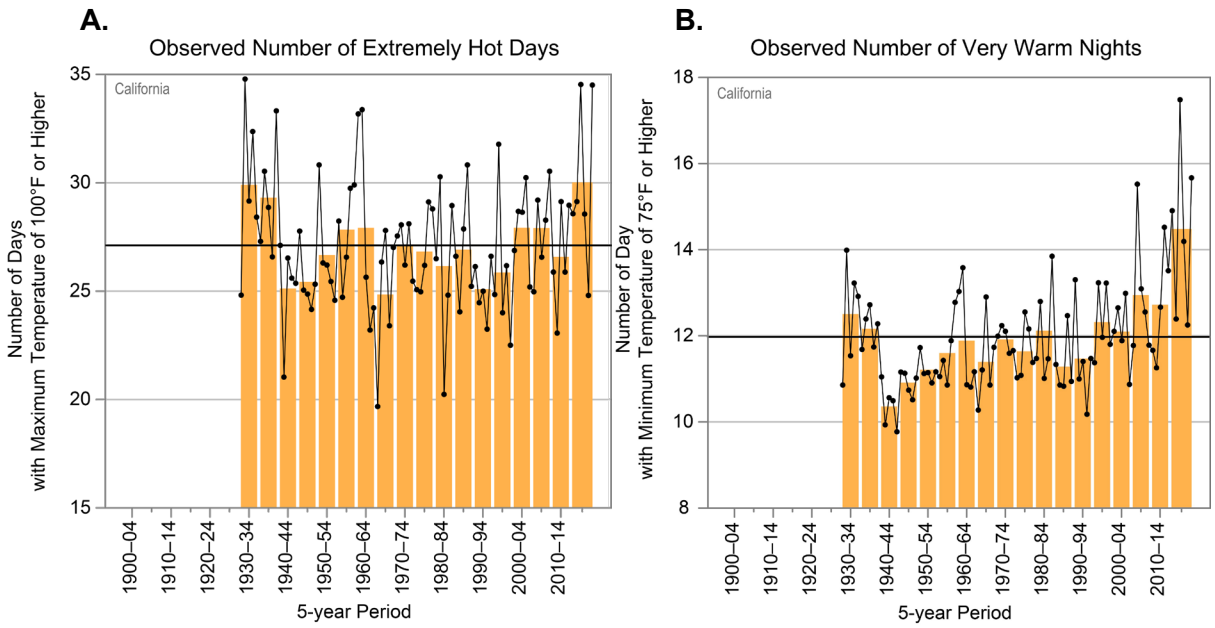
Tribal Connection 2.4.1

Tribal nations in Northern and Southern California alike have been experiencing more extreme heat events. The Big Valley Band of Pomo Indians, living around Clear Lake in Lake County, had a record-breaking heat event in July 2024, when they experienced 15 days of temperatures above 100ºF (37.8ºC) (Big Valley Band of Pomo Indians, 2026). The Pala Band of Mission Indians in San Diego County is also seeing higher temperatures during heat events. They write, "*Over the past 3 decades, there have been an average of 35.75 days per decade with temperatures over 100ºF (37.8ºC) at Pala. The number of days of the most*

> *extreme heat, above 105ºF (41ºC) and 110ºF (43.3ºC), are increasing over time*" (Pala Band of Mission Indians, 2026).

Similar to station-specific data, statewide averages show a variable but overall increasing trend in annual extreme heat days and nights. **Figure 2.4.5** is based on statewide analyses conducted by the National Oceanic and Atmospheric Administration's National Centers for Environmental Information. For this analysis, a state-average time series was created. First, California was divided into 1-degree grid boxes. Then, grid box time series were produced by averaging all stations within that grid box. Finally, a state-average time series was created by averaging the grid box time series (Frankson et al., 2022). Statewide, the number of extremely hot days (**Figure 2.4.5A**) (days on which the maximum temperature was at or above 100°F (37.8°C)) has been variable since 1930, both in terms of annual and five-year averages. The greatest number of hot days were observed during the 2015–2020 period, followed by 1930–1934 and 1935–1939 (the temperature spike during the "Dust Bowl" of the 1930s reflects large natural variability that can occur regionally; see Donat et al. (2016) for more information about anomalously high temperatures and severe drought conditions driven by abnormal sea surface temperatures during this time period). A more pronounced increase is evident in the number of very warm nights (**Figure 2.4.5B**), when minimum temperatures were at or above 75°F (23.9°C). As with extremely hot days, the 2015–2020 period had the greatest number of very warm nights; numbers have exceeded the long-term average on all five-year periods since 1995–1999.

Figure 2.4.5. Statewide Number of Extremely Hot Days and Very Warm Nights.



Left: Observed annual number of extremely hot days (maximum temperature of 100°F (37.8°C) or higher) 1930 to 2020. Right: Observed annual number of very warm nights (minimum temperature of 75°F (23.9°C) or higher). Dots show annual values. Bars show averages over 5-year periods (last bar is a 6-year average). The horizontal black lines show the long-term (entire period) averages: 27 days and 12 nights, respectively. Source: Frankson et al. (2022)

Why is this indicator important?

Periods of extremely high temperatures have significant public health, ecological and economic impacts. Heat causes the most weather-related deaths in the United States (NOAA, 2026). Heat waves accompanied by high humidity are especially dangerous to human health. Humidity prevents surfaces (both environmental and the human body) from cooling down at night, leading to higher nighttime temperatures (Brown, 2025; Joshi et al., 2024; Gershunov et al., 2009). People, wildlife, domesticated animals, and plants adapted to California's traditionally dry daytime heat and nighttime cooling are unable to recover from extreme heat, especially when humidity is high at night.

Heat can also accelerate the formation of ground-level ozone, trap ozone, particulate matter and other harmful air pollutants (Peel et al., 2013; Rahman et al., 2022).

Temperature is also a leading meteorological driver of ozone formation (Nolte et al., 2018). Air pollution may also work in synergy with extremely high temperatures to increase adverse cardiovascular, respiratory and other health effects (Anenberg et al., 2020; Rahman et al., 2022; see the *Heat-Related Deaths and Illnesses* chapter).

Although warmer temperatures are likely to impact a range of individuals and populations, certain subgroups are at greatest risk of health impacts from extreme heat due to intrinsic factors (such as age and health status), greater likelihood of exposures, or less capacity for adaptive measures (such as access to air conditioning). These include the elderly, children, pregnant individuals, people of color, those with lower socioeconomic status, those who have unequal access to green spaces, those who are socially, linguistically, or geographically isolated, or those who work in agriculture, construction, landscaping or other outdoor occupations (Berberian et al., 2022; Cheney et al., 2022; Jiao et al., 2023; Ma et al., 2026; Santodomingo et al., 2024; Syed et al., 2022; Ye et al., 2024; Yin et al., 2023) (see the *Heat-Related Deaths and Illnesses* and *Occupational Heat-Related Illnesses* chapters).

Tribal Connection 2.4.1

Elders of California Native American tribes are one at-risk group in extreme heat who may lack the cooling resources. The Wiyot Tribe writes, "*The temperature regime of Wiyot territory is relatively stable compared to other areas of California experiencing rapid warming, higher extreme heat, and higher variability. However, because Wiyot Tribal members are accustomed to low and consistent temperatures and most of them do not have air conditioning, even relative heat, such as extended temperatures in the high 70s or 80s ºF, can be dangerous for vulnerable Tribal members such as elders*." (Wiyot Tribe, 2026).

Extreme heat impacts infrastructure and economies (LCI, 2021). Urban infrastructure is especially threatened by cascading effects of extreme heat stress on interdependent water, power, and transportation systems. High heat can deteriorate pavement, buckle railway tracks, and restrict aircraft operations (Janatabadi et al., 2025; Sias et al., 2025; Yu and Shi, 2025). During hot weather, increased use of air conditioning and refrigeration increase electricity usage, thus straining the electrical grid (see the *Cooling*

and Heating Degree Days chapter). The strain on the electrical grid has caused blackouts during extreme heat events, eliminating many of the methods for coping with extreme heat such as air conditioning and manual ventilation leading to increased heat morbidity and mortality (Stone et al., 2023). Further, the increase in electricity generation to meet the demand for air conditioning during extreme heat events leads to increased emissions of highly reactive nitrogen oxides (NO_x) (Abel et al., 2017; Peel et al., 2013). NO_x and the ozone it can form through a sunlight-driven process in the troposphere (i.e., the atmospheric layer near the ground) can significantly impact human health, affecting respiratory and cardiovascular systems. NO_x also interacts with other air pollutants, amplifying their overall health impacts (Donzelli and Suarez-Varela, 2024; Taha et al., 2025).

Tribal Connection 2.4.2

Extreme heat can exacerbate pre-existing health disparities within California Native American tribes, and strain limited resources. For the Big Valley Band of Pomo Indians, "*Rising temperatures also strain energy demand and infrastructure, increasing the number and length of the Public Safety Power Shutoffs (PSPS) the Tribe has seen. To protect Elders during these PSPS events the Tribe has purchased generators. Increasing air temperatures promote ozone formation leading to adverse health effects such as lung irritation, inflammation, worsening of asthma, and increasing mortality (US EPA, 2021)*" (Big Valley Band of Pomo Indians, 2026).

Water resources are strained during heat events due to increased domestic, industrial and agricultural demand. Extreme heat conditions can also influence tourism, such as in California's Coachella Valley, where it is projected that hotter temperatures will deter visitors and pose a major financial impact to the local economy (Yañez et al., 2020).

Agricultural systems in California and across the globe are experiencing the impacts of heat stress and decreased water supplies. Extreme heat exposure stresses plants and stunts development of agricultural crops, resulting in reduced quality and lower yields. Scientists fear that current heat adaptation practices such as enhanced irrigation and crop breeding may not be sustainable under future climate conditions. Heat stress also

affects livestock by reducing weight gain or milk and egg production; in extreme cases, heat stress can lead to animal mortality (Parker et al., 2020; Walsh et al., 2020). Extreme heat exposure may also cause mismatches between the timing and duration of crucial life stages for flowering crops and their pollinators (Walters et al., 2022).

Droughts, heat waves, wildfires, and floods often result from interactions between various physical processes that in isolation might not be considered extreme but when combined result in significant impacts. A warming climate promotes co-occurrence of weather extremes, a higher risk of environmental disasters and greater reliance on emergency management and relief resources (AghaKouchak et al., 2020; Zscheischler et al., 2018). The western United States has experienced a larger frequency of simultaneously occurring dry and hot years in recent decades (see the *Drought* chapter). Multiple extreme events, also known as compound events, can amplify ecological and societal damage, as shown by the exceptionally dangerous wildfire seasons in recent years (AghaKouchak et al., 2020). For example, the Thomas fire in December 2017 and the Woolsey fire in November 2018, which caused tremendous devastation in four southern California counties, were both preceded by record-breaking heatwaves and extraordinarily dry autumn conditions (Hulley et al., 2020). Extreme rainfall over the burned area in January 2018 led to the deadliest debris flow event in California's history, killing 23 people, damaging more than 400 homes, and depositing large volumes of sediment, ash, and debris into the waterways, altering stream channels and degrading aquatic habitat (AghaKouchak et al., 2020). Severe wildfires also can disrupt aquatic ecosystems by altering streamflow, increasing sediment, and introducing pollutants like ash, fire retardants, and heavy metals—threatening species such as Chinook salmon (Alizadeh et al., 2021; Neary et al., 2008; see the *Wildfires* and *Chinook Salmon Population Abundance* chapters). Runoff from burned areas can carry such contaminants to the ocean, harming marine ecosystems for years (OPC, 2026).

Heat events are projected to become more intense, more frequent, and longer lasting, globally and in California (Cal-Adapt, 2026; IPCC, 2021). Taking action to mitigate and adapt to the impacts of extreme heat in California is critical, particularly given the largely preventable adverse effects on public health (LCI, 2021). Due to the need for a comprehensive statewide response, California developed an Extreme Heat Action Plan

that coordinates action across state agencies to improve public awareness and preparedness, strengthen community services and emergency response, increase the resilience of the environment, and expand solutions to reduce heat risk (CNRA, 2022).

What factors influence this indicator?

The increased frequency and intensity of temperature extremes since pre-industrial times is attributable to human-induced greenhouse gas emissions (IPCC, 2021). Some recent heatwaves would have been extremely unlikely without human influence on the climate system. For example, the duration, spatial extent, and amplitude of an unprecedented “Heat Dome” that formed in late June 2021 over western North America, and which contributed to large wildfires across the United States and Canada, was exacerbated by climate change: the event is estimated to have been 59% longer, 34% larger and 6% higher in maximum amplitude than the same event would have been without a warming climate (Jain et al., 2024). Similarly, record-breaking extreme heat events observed during an early spring heatwave that developed across the southwestern United States in March 2026 (with temperatures more typical of summer than late-March) were also driven by a “Heat Dome” and determined to have been virtually impossible without climate change (Clarke et al., 2026).

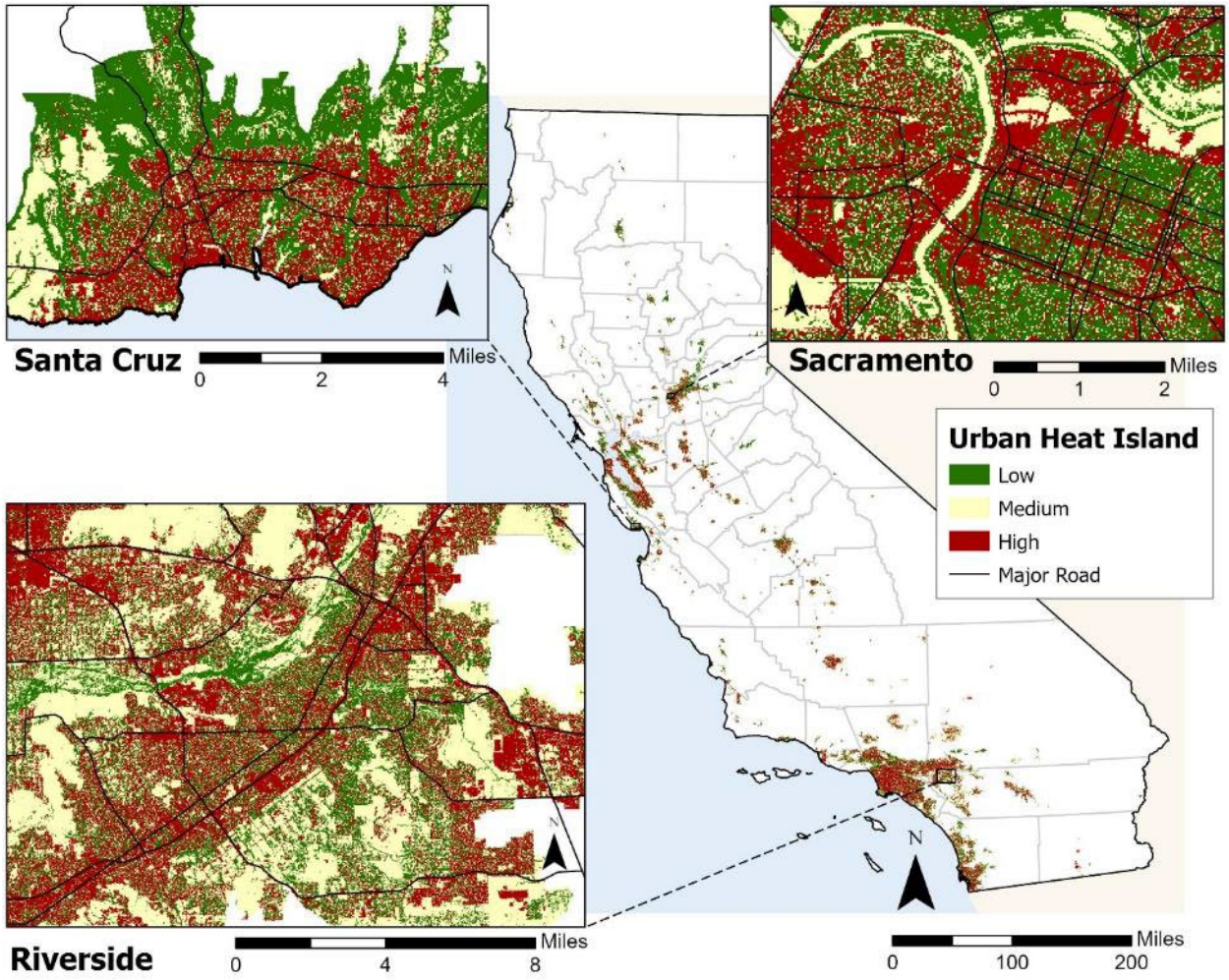
Regional heat extreme patterns are influenced by aerosol emissions, land use and land cover changes, feedback processes involving land-atmosphere interactions (for example, dry soils increasing temperatures due to reduced evaporation), and large-scale modes of natural climate variability (Hulley et al., 2020; Kornhuber et al., 2024). Local temperatures are influenced by topography, elevation, proximity to the ocean, and global and regional atmospheric and oceanic circulations. Clouds have a cooling effect during the day and a warming effect at night (Cox et al., 2020; Luo et al., 2024). Very small airborne particles from human and natural sources can have various effects on climate. Sulfate aerosols, which result from burning coal, biomass, and volcanic eruptions, tend to cool Earth. Other kinds of particles, such as black carbon, have a warming effect. The net effect on air temperatures of aerosols, dust, smoke, and soot is cooling (NASA, 2023). In addition, as air temperatures rise, the atmosphere can hold more water vapor, which traps heat and reduces nighttime cooling, providing less relief

from heat. Moreover, humid heat waves, as can occur in coastal areas, tend to last longer due to the stronger coupling of maximum and minimum temperatures during humid heat waves (Gershunov et al., 2009).

Urbanization is generally known to have a warming effect, due in large part to the heat-absorbing concrete and asphalt in building materials and roadways and can amplify the effects of extreme heat in cities (the urban heat island effect) (Lasky et al., 2024), while expansion of irrigation has a cooling effect on summertime temperatures (Bonfils and Lobell, 2007). Climate change and urbanization are the most significant drivers of warming in cities. A major factor in the urban heat island effect in California (**Figure 2.4.6**) is the scarcity of city trees (**Figure 2.4.7**), which provide shade and cooling, and can reduce energy needed to heat and cool buildings (McPherson et al., 2018). California's urban tree canopy currently covers just 14.5% of the state's urban areas (USFS and CAL FIRE, 2026).

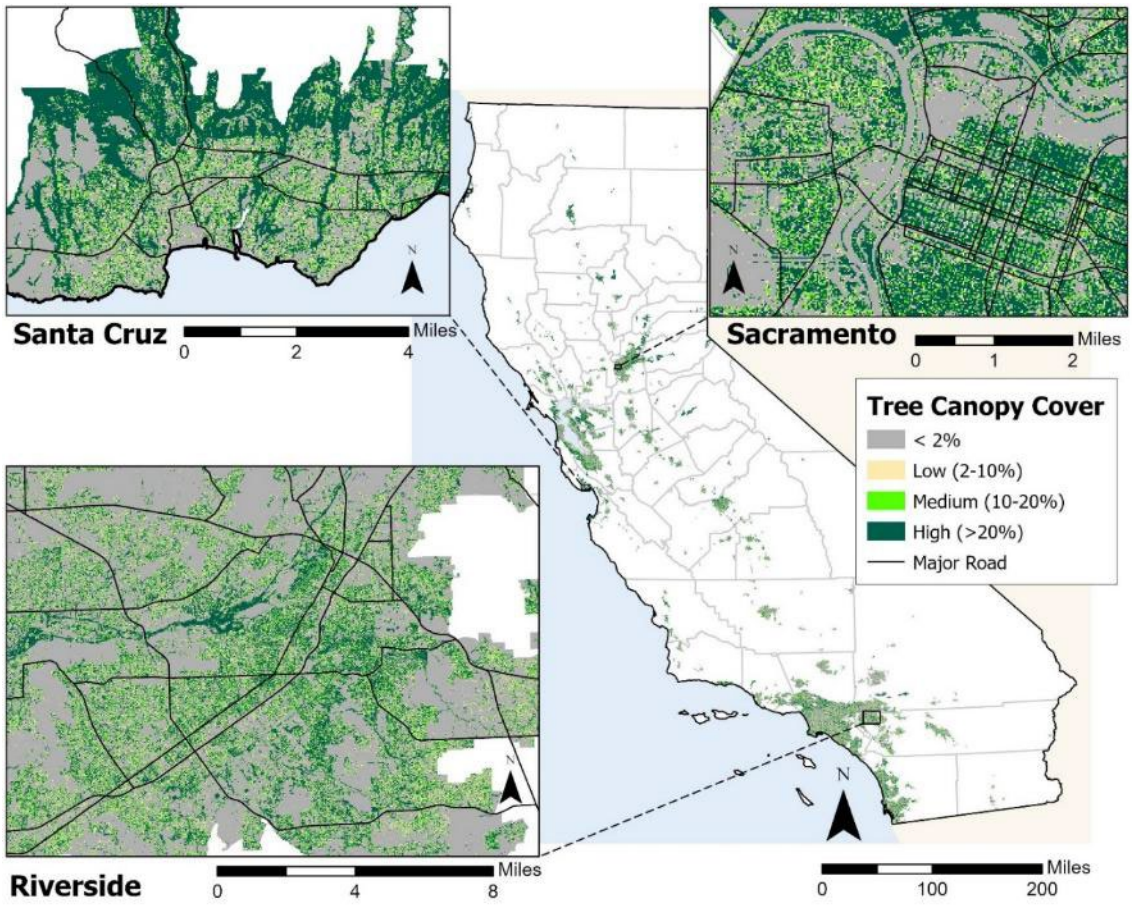
Research on urban tree cover shows that its distribution in the United States is unequal: In most U.S. cities, neighborhoods that are predominantly low-income or disproportionately people-of-color have less tree cover than high-income or non-Hispanic white neighborhoods and often experience higher summer surface temperatures (McDonald et al., 2024).

Figure 2.4.6. Statewide Urban Heat Islands.



Source: Bjorkman et al. (2015)

Figure 2.4.7. Percent of Urban Tree Canopy Cover.



Source: Bjorkman et al. (2015)

Technical considerations

Data characteristics

This indicator uses station data from the National Oceanic and Atmospheric Administration's (NOAA) Regional Climate Centers (RCCs) cooperative observation network acquired from the Applied Climate Information System (ACIS). The RCC Program partners with public and private partners, as well as other state, regional, and national climate services providers, to provide access to regional climate information and support the advancement of applied climate research (Umphlett et al., 2024).

Strengths and limitations of the data

The RCC-ACIS dataset is hosted online by the Southwest Climate and Environmental Information Collaborative and comprised of station data containing minimum and maximum daily temperature. RCC-ACIS station data pulls weather information from various networks such as the Cooperative Observer Program (COOP) and the Weather-Bureau-Army-Navy (WBAN). The network includes the National Weather Service (NWS) principal climatological stations. Observing equipment used at all the stations is calibrated and maintained by NWS field representatives, Cooperative Program Managers, and Hydro-Meteorological Technicians.

The station data have received a high measure of quality control through computer and manual edits, and are subjected to internal consistency checks, compared against climatological limits, checked serially, and evaluated against surrounding stations. Values calculated from RCC-ACIS may differ from those in other high-quality station datasets due to methodological differences. In addition, station coverage is not uniformly distributed geographically, and a limited number of stations were analyzed. Recorded temperatures in urban areas can also be affected by the urban heat island effect due to land surface modification and other human activities. Since most of California's population resides in urban areas, heat impacts from urban-induced warming on health are significant. Quantification of the specific magnitudes of station-based urban heat contributions are beyond the scope of the present study but are the subject of ongoing research.

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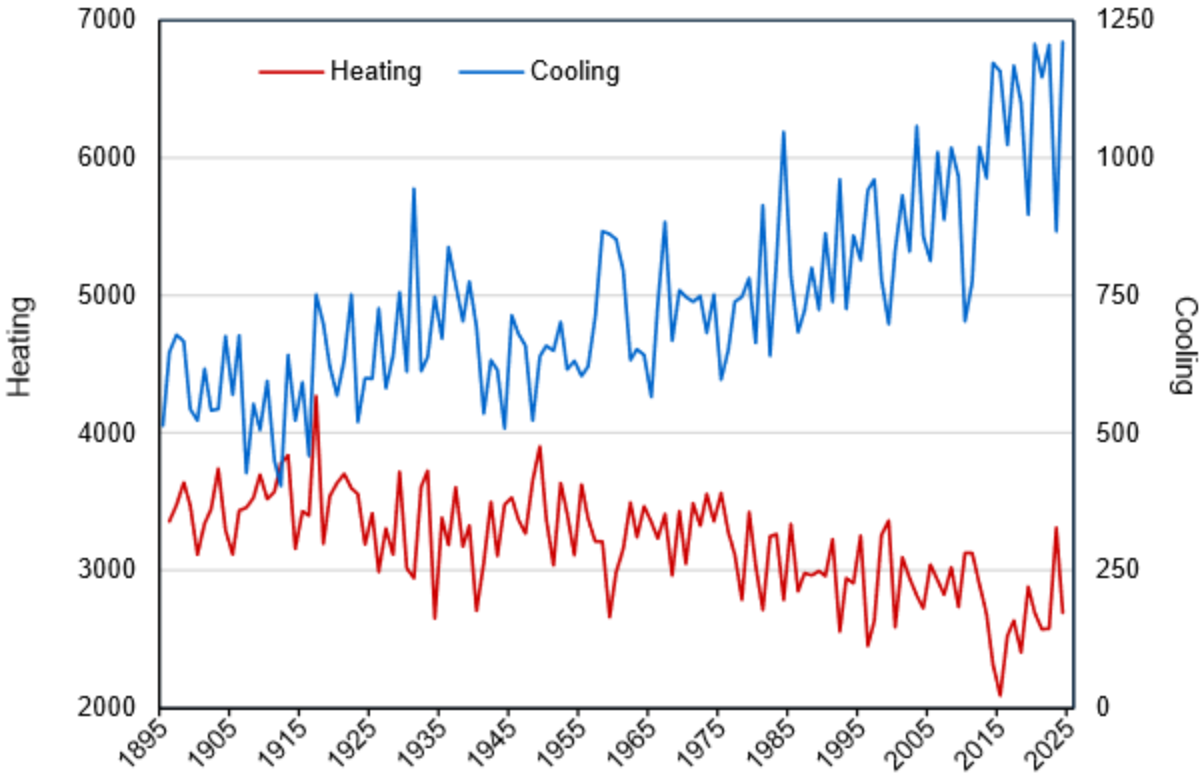
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2.5 Cooling and Heating Degree Days

Cooling degree days (CDDs) and heating degree days (HDDs) are temperature-based metrics used to help estimate cooling and heating needs. Other things being equal, the higher the CDDs over a period, the more energy required to cool a building to a given temperature. Similarly, the higher the HDDs, the more energy needed to heat a building. In California, CDDs have increased, and HDDs have decreased.

Figure 2.5.1. Statewide Cooling and Heating Degree Days.



Cooling degree days (CDDs) measure how much the average* daily temperature is higher than a reference temperature of 65°F (18°C); heating degree days (HDD) measure how much it is lower than 65°F (18°C). Each value shown in the graph is the sum of degree days for that year. The “cooling year” during which CDDs are calculated is defined as January 1st to December 31st of the calendar year. The "heating year" during which HDDs are accumulated is defined as July 1st to June 30th of the following calendar year.

*Average is defined as the midpoint of the hourly minimum and maximum temperature for the day. The values shown are a geographic average of temperature values across California.

Source: NOAA (2025)

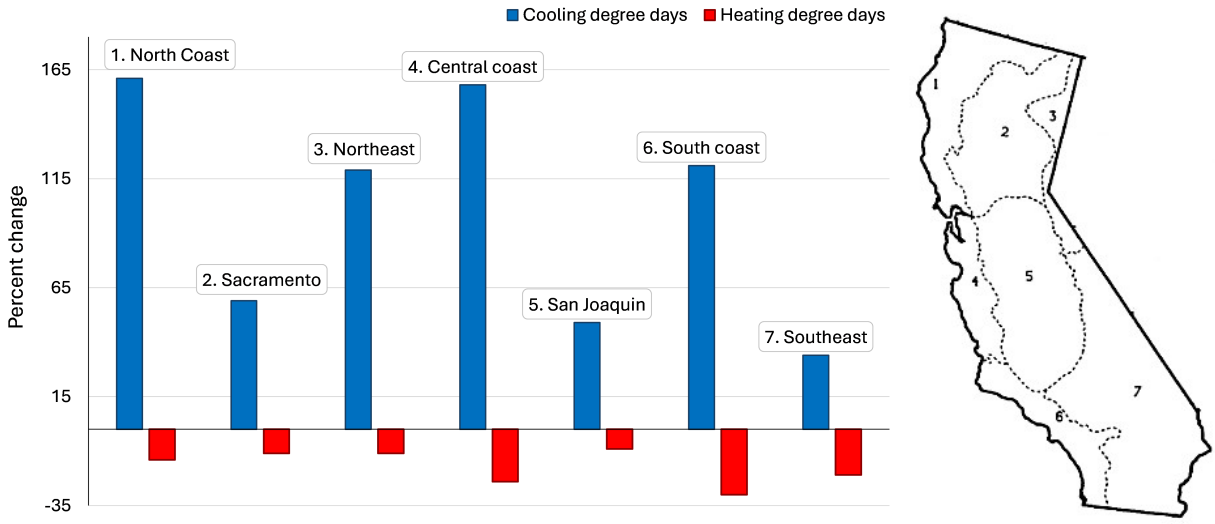
What does the indicator show?

Annual CDDs in California increased between 1895 and 2024, and HDDs decreased (**Figure 2.5.1**). Both trends are consistent with national patterns (NOAA, 2025). They have been especially pronounced in the past five decades: the rate of change for the most recent 50 years (1974-2024) is substantially higher than for the previous time period (1895-1974).

California's 100 million acres encompass diverse terrains and geographies with various climates. Long-term trends in degree days show local variations at the level of federally defined climate divisions (**Figure 2.5.2**, **Figure 2.5.3**, **Figure 2.5.4**, and **Table 2.5.1**) and county (**Figure 2.5.5**) level.

Coastal California shows greater percentage increases in CDDs over the last century compared to inland areas of the state, partly because it had low cooling degree days to begin with. The Central Coast and especially the South Coast had the largest percentage declines in HDDs.

Figure 2.5.2. Divisional Changes in Degree Days.



Source: NOAA (2025)

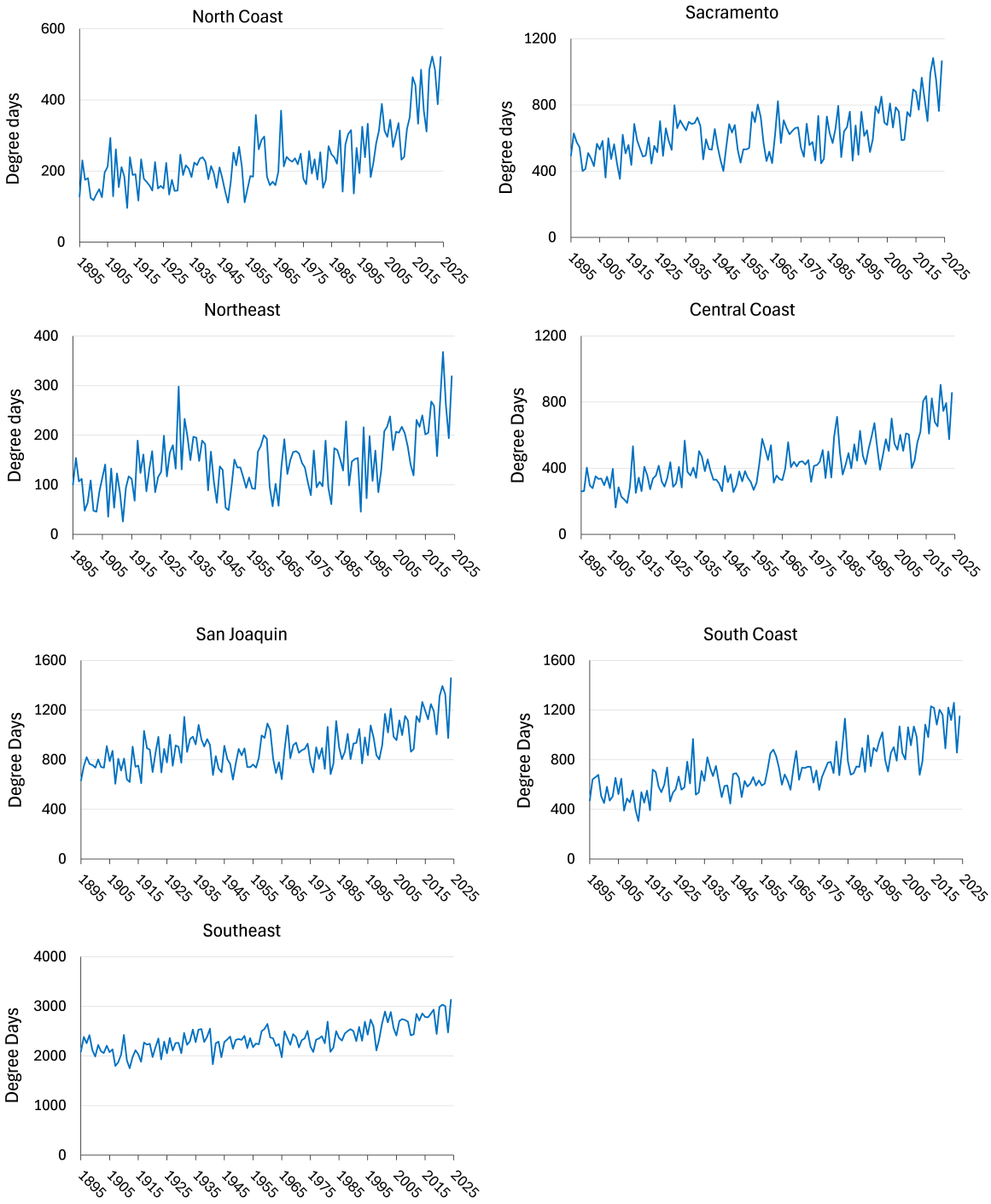
Table 2.5.1 summarizes these trends as changes in annual CDDs and HDDs for California's seven climate divisions, expressed as linear rates of change per decade. Trends are reported for two periods: 1895 to 1974 and 1975 to 2024. Across all regions and both periods, CDDs increased while HDDs decreased.

Table 2.5.1. Divisional Trends in Degree Days.

Climate Division	Trends, 1895-1974 (Degree Days per Decade)		Trends, 1975-2024 (Degree Days per Decade)	
	Cooling	Heating	Cooling	Heating
North Coast Drainage	+8	-27	+53	-111
Sacramento Drainage	+18	-12	+76	-95
Northeast Interior Basins	+6	-60	+32	-135
Central Coast Drainage	+16	-35	+69	-138
San Joaquin Drainage	+15	-12	+94	-135
South Coast Drainage	+26	-45	+86	-147
Southeast Desert Basins	+37	-19	+131	-66

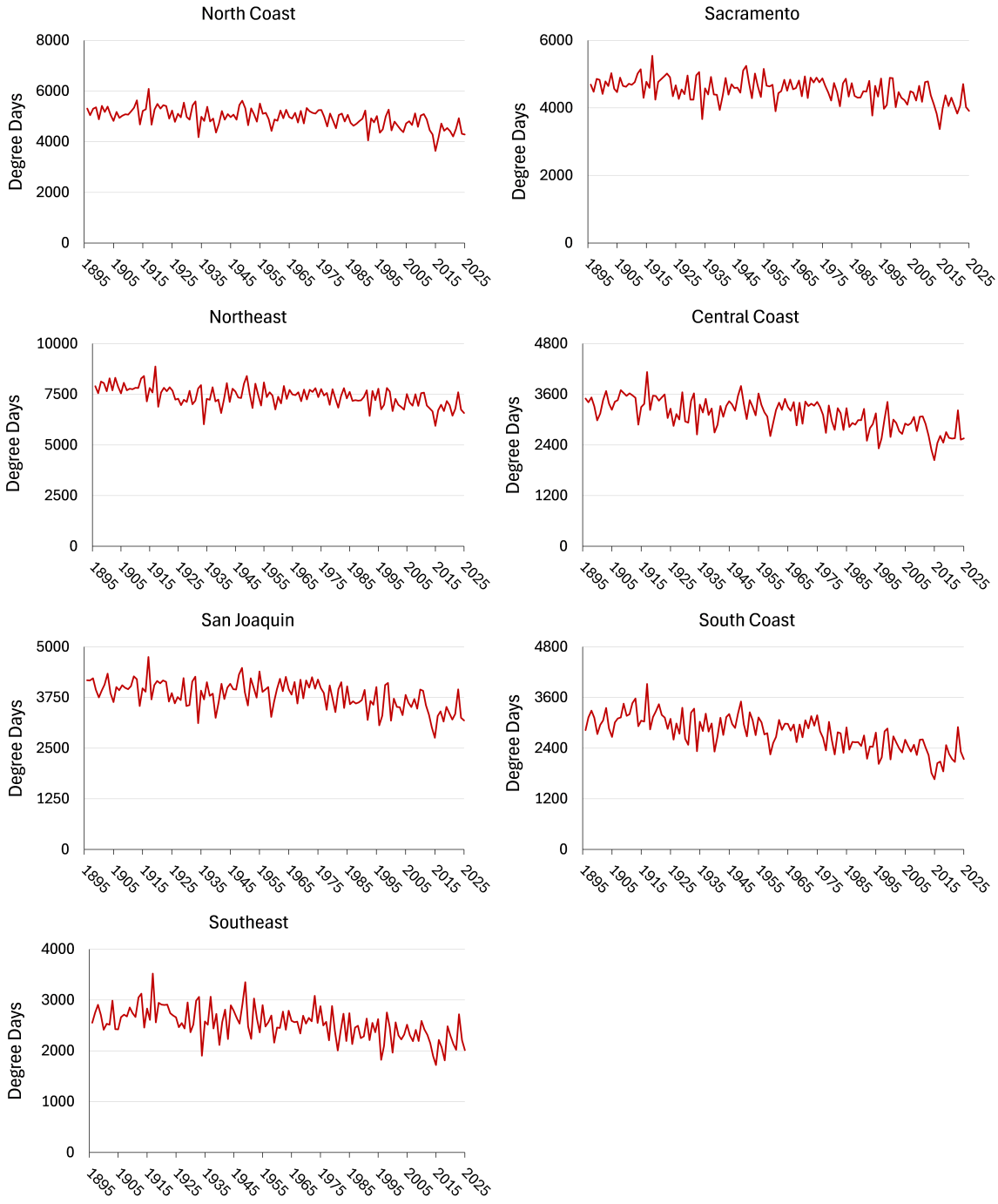
Trends are shown for each of California's climate divisions, with values corresponding to the slope of linear trends. These slopes represent the rate of change in cooling or heating degree days per year. Source: NOAA (2025)

Figure 2.5.3. Cooling Degree Days by Division.



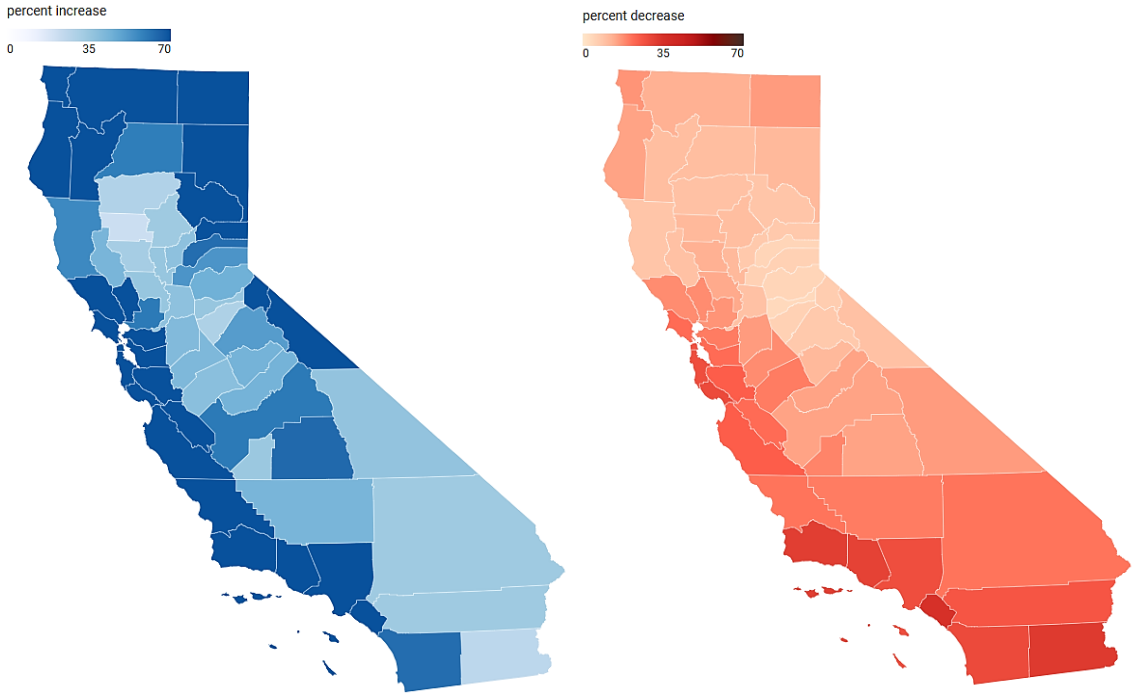
The graphs show annual cooling degree days for each climate division from 1895 to 2024. The y-axis scales differ so that the trends of each region are more visible. Source: NOAA (2025)

Figure 2.5.4. Heating Degree Days by Division.



The graphs show annual heating degree days for each climate division from 1895 to 2024. The y-axis scales differ so that the trends of each region are more visible. Source: NOAA (2025)

Figure 2.5.5. Change in Degree Days per Decade (1895 to 2024).



The maps show the county-level average per decade changes estimated from linear regression trendlines for CDDs (left) and HDDs (right).

Source: NOAA (2025)

Why is this indicator important?

Degree days provide a standardized temperature-based metric widely used in energy and climate modeling and forecasting. Since the 1930s, degree days have been used to estimate energy needed to cool or heat buildings, benchmark building performance, and support utility planning and construction decisions (Marston, 1935; Meng and Mourshed, 2017; NOAA, 2005).

As the climate continues to warm, heating needs will likely decline, and energy consumption is expected to shift from cooler months to warmer months (CEC, 2015) due to increased cooling energy use from expanded presence of air conditioning and higher levels of use. Meeting a growing demand for cooling creates challenges for new energy generation and distribution infrastructure (CEC, 2020). At the same time,

warming temperatures, sea level rise, and wildfires can negatively impact the operation or the efficiency of power plants, transmission networks, and natural gas facilities (CEC, 2009, 2012, 2020; Patrick and Fardo, 2009). Climate change can also affect renewable energy generation, given its dependence on natural resources like water, wind, biomass and available incoming solar radiation, which are all influenced by climate variations (CEC, 2009).

For lower-income households, heating and cooling costs often represent a bigger fraction of household income than for higher-income households (CalEPA, 2010). The impact of increased summer heat is disproportionate across households and communities. Lower-income households are less likely to own well-functioning efficient air conditioners or even any air conditioners at all (Chen et al., 2020; Fernandez-Bou et al., 2021).

What factors influence this indicator?

Since heating and cooling degree days reflect trends in temperature, factors that influence temperature affect this indicator. These factors are discussed in the A*ir Temperature* chapter.

The relationship between degree days and building heating and cooling energy use is approximate and is dependent on many factors that vary by building and over time. These include building construction and thermal characteristics (e.g., building size, ventilation, insulation, placement and energy efficiency rating of windows and doors); building type and function (single-family residential, multi-family residential and the myriad of commercial and industrial uses); the type and efficiency of cooling and heating technologies, and occupant practices (for example, based on occupancy, tolerance for heat or cold, and use of heat-generating appliances and equipment) (Meng and Mourshed, 2017). In addition, compressor-based air conditioning was not widely available in U.S. homes until the mid-20th century (Cooper, 1998). Prior to its widespread adoption, residential cooling relied primarily on passive and low-energy strategies (e.g., high ceilings, operable windows, cross-ventilation, building orientation, and the use of fans in some regions). As a result, household energy use for cooling was minimal. Other such changes in cooling practices and associated energy demand can

be expected as energy use patterns and technology evolve, such as more effective building design for energy conservation (Bal and Rani, 2025).

Technical considerations

Data characteristics

The values for degree days are downloaded from National Oceanic and Atmospheric Administration (NOAA's) Climate at a Glance website (NOAA, 2025). They are derived by NOAA using daily temperature observations at major weather stations in the United States with NOAA's Climate Divisional Database (nClimDiv). nClimDiv uses a 5 kilometer (km) gridded approach to compute temperature, precipitation, and drought values for the United States climate divisions. A mean daily temperature (average of daily maximum and minimum temperatures) of 65˚F (18°C) serves as the reference temperature for degree day calculations for this data set. Cooling degree days over a given period are calculated by summing the positive differences between the mean daily temperature and the 65˚F (18°C) reference temperature. Heating degree days for a period are calculated by summing the positive differences between 65˚F and the mean daily temperature.

Strengths and limitations of the data

The nClimDiv dataset is an improved version of an older climate dataset from NOAA, benefiting from additional quality assurance reviews and temperature bias adjustments and providing more robust values than its predecessor. New methodologies include a transition to a grid-based calculation and several thousand additional stations nationwide from before the 1930s (NOAA, 2021; Vose et al., 2014).

There are important limitations to consider when relating degree days to energy use. First, thermal comfort of building occupants does not depend on indoor temperatures alone (Kwok and Rajkovich, 2010). Heating and cooling energy use for a given set of degree days also depends on factors beyond the technical characteristics of structures and equipment, including occupant and social practices such as thermostat setpoints, hours of occupancy, use of supplemental heaters or fans, window-opening, and broader thermal comfort management regimes (Deumling et al., 2019; McGilligan et al., 2011).

Second, degree days do not fully capture the complexity of weather variability, spatial patterns, or how these changes may affect indoor conditions (Azevedo et al., 2015). For example, in much of California, especially since 2000, nighttime low temperatures have increased more rapidly than daytime high temperatures (Lindsey, 2018; see the *Air Temperature* chapter). This can reduce the contribution of nighttime temperatures to natural cooling but is captured only limitedly in degree days indicators. Also, though 65˚F is the standard base temperature used for computing degree days in U.S. energy applications, different base temperatures, such as a higher base temperature for CDDs (US EIA,1983), could give different results for energy predictions.

OEHHA acknowledges the expert contribution of the following to this report:

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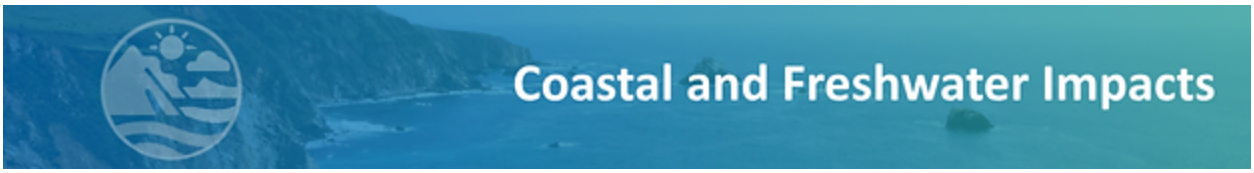


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Introduction

Climate change impacts on California's coastal and freshwater resources have become more visible in recent years.

California's iconic coast and ocean contribute $51.3 billion to California's GDP, support more than 500,000 jobs, and hold intrinsic value to the cultural identity, heritage, and overall quality of life for all Californians, and yet they remain on the front lines of climate change and biodiversity loss (Harris et al., 2026). Rising sea levels, coastal flooding, ocean acidification, increased ocean temperatures, and reduced oxygen in marine ecosystems are among a myriad of changing ocean conditions that ultimately alter ecosystems and affect people who depend on them. Several new indicators on coastal

impacts, namely coastal flooding and metrics tracking kelp populations, krill length and biomass, and Brandt's cormorant reproductive success, illustrate the extent of climate change impacts on the ocean and marine ecosystems. Changes to California's coastal waters are consistent with global trends (Volkov et al., 2026).

Further inland, freshwater resources are similarly important to the economy, cultural identity, and health of California and the people who depend on them (Mount et al., 2026), and yet a rapidly changing climate has led to rapid glacial retreat, a long-term decline in snowpack, earlier snowmelt, and rising water temperatures in the state's rivers and lakes. Chinook salmon populations have plummeted which impact the traditional lifeways and cultural practices of multiple California tribal nations.

The first ten chapters cover coastal systems: Ocean Acidification of California Waters, Dissolved Oxygen in Coastal Waters, Coastal Ocean Temperature, Sea Level Rise, Coastal Flooding, Marine Harmful Algal Blooms, Kelp Populations, Krill Length and Biomass, Brandt's Cormorant Reproductive Success, and California Sea Lion Pup Demography. The remaining six chapters cover freshwater systems: Glacier Change, Snow-Water Content, Snowmelt Runoff, Salmon River Water Temperature, Lake Water Temperature, and Chinook Salmon Abundance.

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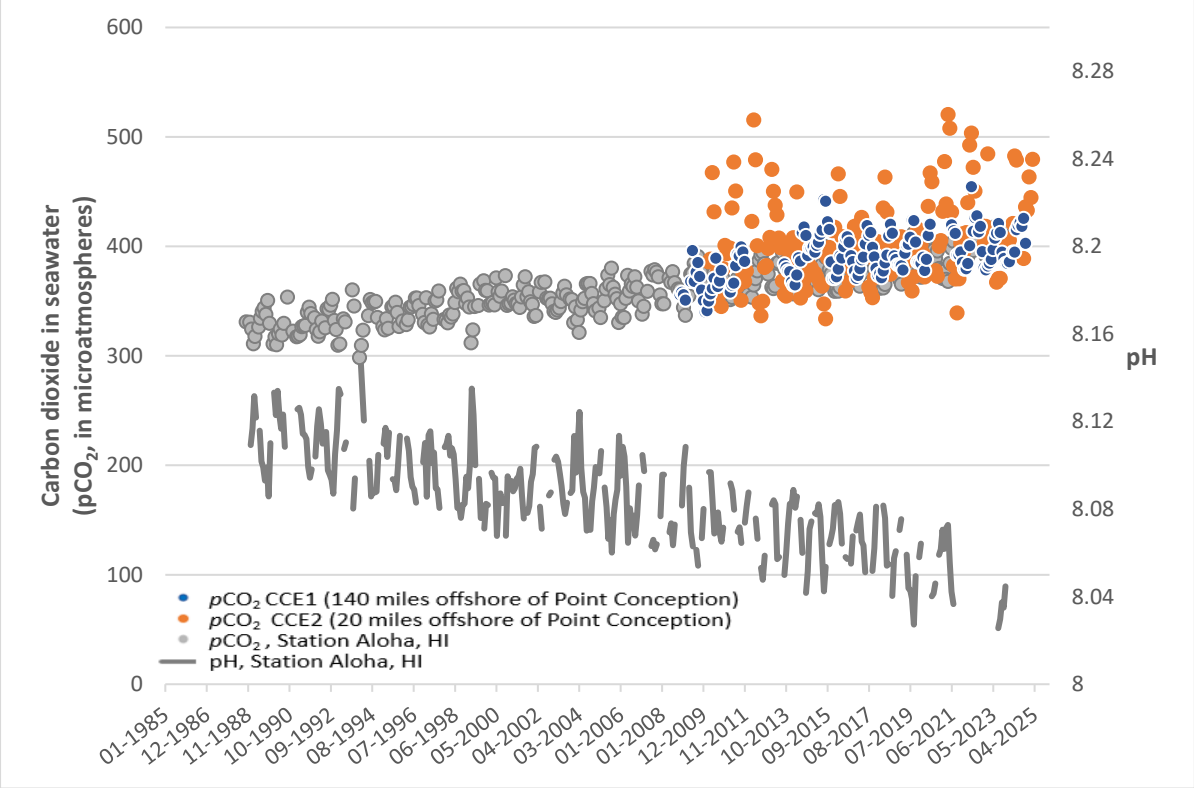
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3.1 Ocean Acidification of California Waters

As atmospheric concentrations of carbon dioxide (CO_2) increase, so do concentrations in the ocean, part of a process known as “ocean acidification.” While long-term data for California waters are limited, CO_2 measurements at one offshore location near Point Conception are similar to those from long-term monitoring in Hawaii. They show increases in seawater CO_2 concentrations accompanied by increasing acidity (measured as pH). This phenomenon has been observed at multiple sites throughout the global ocean.

Figure 3.1.1. Seawater CO_2 and pH off Hawaii and California.



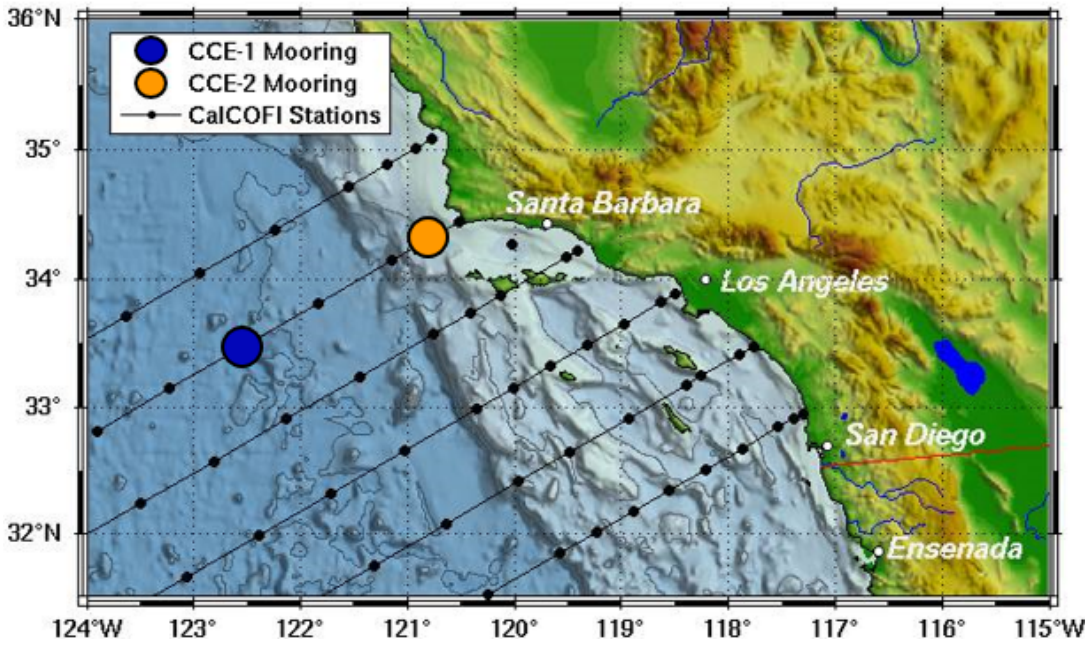
The figure shows CO_2 (measured as the partial pressure of CO_2 (pCO_2) in seawater) from two offshore California sites (CCE1 blue, and CCE2, orange). Data from the Hawaii Ocean Time-series (HOTS) are also shown in grey to provide a long-term reference record. Source: Hawaii Ocean Time-Series 2025, Dore et al. (2009); NOAA NCEI (2025); Sutton et al. (2012)

What does the indicator show?

The indicator shows increasing seawater CO_2 concentrations and decreasing pH concentrations measured offshore in California (**Figure 3.1.1**), consistent with ocean acidification observed globally. Concentrations of CO_2 are expressed as the partial pressure of carbon dioxide in seawater, or pCO_2. Off the coast of California, pCO_2 concentrations measured since 2008 at "CCE1" (see **Figure 3.1.2** for locations of monitoring sites) generally track those measured at Station Aloha where the Hawaii Ocean Time-series measurements are made, and consistent with increasing surface seawater pCO_2 concentrations observed at other open ocean time-series locations (**Figure 3.1.1**; Bates et al., 2015). At CCE2, a second mooring located approximately 20 miles from Point Conception, pCO_2 concentrations show greater variability, spanning 330–520 microatmospheres (µatm), reflecting the influence of seasonal upwelling at this more coastal location (Sutton et al., 2019; also see *Coastal Ocean Temperature* chapter). Upwelling is the wind-driven movement of deep, cool, carbon- and nutrient-rich ocean water to the surface, replacing the warmer, usually nutrient-depleted, lower CO_2 surface water.

Measurements at CCE1 began in September 2010 and provide the longest-running publicly available data on CO_2 concentrations in seawater offshore from California (there is a 21-month gap in measurements at CCE2). pCO_2 concentrations at CCE1 increased steadily from 2010 to 2024 at an average rate of approximately 2.6 µatm per year. At CCE2, pCO_2 increased at an average rate of approximately 2.0 µatm per year from 2010 to 2023 (not enough data for the year 2024 was available at the time of analysis).

Figure 3.1.2. Location of CO_2 Monitoring Sites.



Source: Modified from SIO (2026)

At Station Aloha, pCO_2 concentrations have increased steadily at the rate of approximately 1.8 µatm per year, and pH has decreased at the rate of 0.002 unit per year from 1985 to 2025. Global measurements show similar long-term changes (Bates et al., 2015; Bates and Johnson, 2023). Monitoring at Station Aloha off Hawaii provides the longest-running measurements of ocean acidity in the North Pacific Ocean.

Why is this indicator important?

CO_2 is the largest and most important anthropogenic driver of climate change. It is continuously exchanged between land, the atmosphere, and the ocean through physical, chemical, and biological processes. The global net uptake of CO_2 by the ocean is estimated at 29% of the total CO_2 emissions in the past decade (Friedlingstein et al., 2025), significantly reducing the accumulation of CO_2 in the atmosphere and some of the impacts of global warming (Rhein et al., 2013). As CO_2 concentrations in the ocean increase, carbonate ions (fundamental 'building blocks' for organisms that form shells or skeletons) decrease (Mekkes et al., 2021; Osborne et al., 2020; Rose et

al., 2020; Swezey et al., 2020). Economically and ecologically important West Coast species affected by ocean acidification include oysters, mussels and crabs (Chan et al., 2016). Marine species that are sensitive to ocean acidification include the California mussel (*Mytilus californianus*), krill, pelagic snails, and sea urchins (Bednaršek et al., 2022; Cooper et al., 2017; deVries et al., 2024; Gaylord et al., 2018; Harianto et al. 2021). Changes in species assemblages in southern California coastal waters and sediments suggest that the distributions of ichthyoplankton (fish eggs and larvae) and benthic invertebrate species have shifted – across water depths and north–south – due to warming and increasing acidification exposure since the 1970s–1980s (McClatchie et al., 2016; Gillett et al., 2023).

Tribal Connection 3.1.1

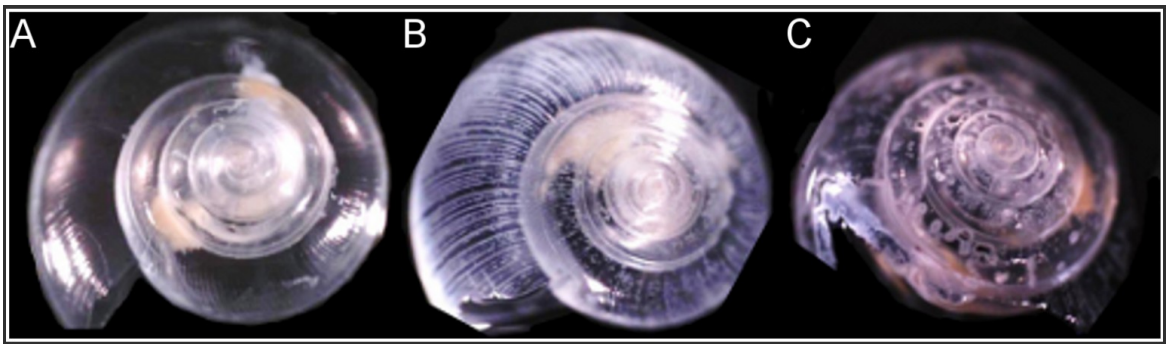
> "*Ocean acidification is also a concern for the Wiyot Tribe as it threatens low-lying cultural sites and many estuarine flora and fauna of great importance, including shellfish. While research is ongoing, there is some evidence that Wigi* [Humboldt Bay] *itself demonstrates a buffering effect against the otherwise rising acidity (lowering of pH) of the ocean. There are several hypotheses for this observation, one of which is that eelgrass plays a critical buffering role, underscoring its ecological importance (Barriquand et al, 2023)."* (Wiyot Tribe, 2026).

In Tribal listening sessions, several tribes, including the Coastal Band of the Chumash Nation and the Santa Ynez Band of Chumash Indians have reported that they have seen a decrease in abalone (a cultural keystone species), Pismo clams and Olivella shells due to ocean acidification (Pala Band of Mission Indians and Santa Ynez Band of Chumash Indians, 2021).

Other effects of acidification on coastal ecosystems include: indirect effects on marine food webs through sensitive calcifying prey species, such as sea snails (pteropods, also referred to as pelagic snails), and single-celled amoeboid organisms called foraminifera; degradation of the habitat provided by corals, mussels, oysters and other structure-forming calcifiers; and reduction of water filtration services provided by bivalves (Feely et al., 2016; Hollarsmith et al., 2020; Osborne et al., 2020; Mekkes et al., 2021).

Lower pH conditions can disrupt acid-base balance in marine organisms, affecting the physiology and behavior of marine species (Leung et al., 2022). Broader ecological consequences include trophic mismatch (Kroeker et al., 2021) and altered predator-prey and other species interactions, such as herbivory and competition (Ferrari et al., 2011; Kroeker et al., 2014; Sanford et al., 2014; Gaylord et al., 2018; Magel et al., 2020; Hodgson et al., 2018; Contolini et al., 2020; Lord et al., 2019).

Figure 3.1.3. Dissolution of Pelagic Snail Shells Exposed to Corrosive Seawater.



Images of *Limacina helicina*, a pelagic snail, after week-long incubation in Puget Sound waters at the following concentrations of aragonite (a form of calcium carbonate, Ω_a): [A] Ω_a ~ 1.59, corresponding to current summer surface conditions; [B] Ω_a ~0.56, current deep water or surface conditions during upwelling; and [C] Ω_a ~0.28, future deep water or surface conditions during upwelling. Corrosion is evident on the ribs of the shell in [B], and [C] shows shell perforations. Source: Busch et al. (2014)

What factors influence the indicator?

The Intergovernmental Panel on Climate Change (IPCC) concluded in its Sixth Assessment Report that the uptake of anthropogenic CO_2 emissions is the main driver for the global decline in ocean water pH over the last 40 years (Gulev et al., 2021). The air-sea exchange of CO_2 is largely determined by the difference in the partial pressure of CO_2 between the atmosphere and the ocean surface; as the partial pressure of CO_2 in the atmosphere increases with increasing emissions, the ocean absorbs more of it to reach equilibrium. Long-term measurements of ocean carbon content at seven monitoring sites around the globe collectively show consistent and coherent changes in

the uptake of CO_2 by the ocean. At decadal timescales, ocean acidification rates in open ocean surface waters generally track atmospheric CO_2 increase (Bates et al., 2015; Cooley et al., 2022).

The magnitude of the air-sea CO_2 difference is also influenced by biological processes. Photosynthesis and respiration remove and add CO_2 to seawater, respectively. In coastal habitats, kelp forests and seagrass meadows can locally reduce high CO_2 concentrations by removal of CO_2 via photosynthesis; these effects, however, are temporary (Hirsh et al., 2020; Ricart et al., 2020). Shell formation by marine calcifiers also affects the carbonate chemistry of surrounding seawater by reducing buffering capacity and increasing pCO_2, while shells dissolving in seawater decrease pCO_2.

While biological processes and climate variability (e.g., the El Niño and La Niña events) play important roles in determining short-term (daily to seasonal) to interannual variability in surface ocean pH and pCO_2, respectively (Hofmann et al., 2011; Nam et al., 2011), ocean uptake of anthropogenic CO_2 drives longer-term decadal trends.

California's coastal waters are experiencing more acidified and lower oxygen conditions earlier than many regions as ocean acidification adds to naturally high concentrations of carbon dioxide resulting from the combination of upwelling and global ocean circulation processes (Feely et al., 2008; Hauri et al., 2009; Gaylord et al., 2018; Hodgson et al., 2018; Osborne et al., 2020). Along the Central California coastline, the continental shelf is wider, leading to greater retention of seawater on the shelf, where respiration further enhances CO_2 and reduces oxygen, leading to longer, more intense exposure to ocean acidification and low oxygen conditions (Damien et al., 2024; Hickey and Banas, 2008; Siedlecki et al., 2015; Feely et al., 2024). The California Current System has experienced amplified acidification over the past century, driven by the interaction between the elevated natural CO_2 concentrations and anthropogenic CO_2 (Arroyo et al., 2022; Stoll et al., 2025), with significant variation in hypoxia and ocean acidification exposure across habitats due to variability of upwelling and other circulation processes along the coast and through seasons (Cheresh and Fiechter, 2020). On interannual–decadal timescales, large-scale climate oscillations such as the El Niño Southern Oscillation and the Pacific Decadal Oscillation can alter surface ocean CO_2

concentrations through basin-scale changes in oceanic and atmospheric circulation (Di Lorenzo et al., 2015), which in turn affect physical-biological processes and interactions among them (Chavez et al., 2007; Lilly et al., 2019).

The variability in pCO_2 concentrations in coastal waters (CCE2) compared to open ocean waters (CCE1) reflects the more complex acid-base chemistry dynamic of coastal waters (Sutton et al., 2019). In addition to upwelling and other climate-related processes, coastal waters are influenced by localized freshwater and atmospheric inputs, organic matter and nutrients from land, and processes in the underlying sediments. Similar variability has been observed at other monitoring stations along the California coast (e.g., M1 mooring in Monterey, Hog Island Oyster Company store station, Carlsbad Aquafarm shore station) (CenCOOS (Monterey), 2021; Chavez (Monterey), 2017; GOA-ON Explorer (shore stations), 2026; see references for URLs to access data from these stations). Knowledge of short-term variability of CO_2 in seawater is important to interpret changes attributed to anthropogenic processes at a given location. An analysis of pCO_2 and pH data collected at 40 monitoring stations (in four ocean basins, representing a range of ocean, coastal and coral reef locations) estimated the length of the record needed to distinguish anthropogenic trends from natural variability to be 8–15 years at open ocean sites (such as CCE1, estimated at 12 years) and 16–41 years at coastal sites (such as CCE2, estimated at 24 years), with a significant trend now having emerged at CCE1 (Sutton et al., 2019). *p*CO2 is currently increasing at a rate of approximately 0.8 µatm per decade at CCE1.

Because changes in the ocean interior occur slowly, the ocean is already "committed" to changes resulting from current atmospheric greenhouse gas concentrations, even after concentrations stabilize; thus, ocean acidification is irreversible on timescales relevant to human societies and ecosystems (IPCC, 2019).

Technical considerations

Data characteristics

Monitoring along the California coast includes moorings with carbon dioxide and pH sensors, regular measurements of inorganic carbon variables on oceanographic cruises, calculation of aragonite saturation state, and shore-based observations of

carbon chemistry in nearshore waters. These monitoring efforts are part of larger scale monitoring programs, including the US Integrated Ocean Observing System (IOOS) and the National Oceanic and Atmospheric Administration (NOAA) ocean acidification observing network, and are conducted in collaboration with a wide range of international, national, and regional partners. Many of these efforts can be viewed in real time through an online data portal (GOA-ON Explorer, 2026).

Integrated biological, chemical, and physical oceanographic monitoring help identify ecosystem responses to ocean acidification and climate change. Long-term ecological monitoring programs for intertidal and subtidal ecosystems (e.g., LiMPETS, MARINe, and PISCO), the Marine Protected Area Monitoring efforts (e.g., Ocean Science Trust), and oceanographic monitoring by the Applied California Current Ecosystem Studies (ACCESS) provide essential data to support a better understanding and interpretation of the impacts of ocean acidification for California.

The CCE1 mooring (140 miles southwest of Point Conception) was deployed in November 2008 as part of a multi-investigator, multi-disciplinary project by NOAA's Pacific Marine Environmental Laboratory. The project expanded to include the CCE2 mooring, at the shelf break, closer to Point Conception, in 2010. Sensors on these moorings measure aspects of biological, chemical, and physical oceanography as well as meteorology every three hours. This project is closely coordinated with other projects off of Southern California such as the California Cooperative Oceanic Fisheries Investigations, and the California Current Ecosystem Long Term Ecological Research.

Figure 3.1.1 features data from the Hawaii Ocean Time-series (HOTS) program for comparison. Since October 1988, this program has conducted observations about once per month of water column chemistry and biology at Station ALOHA, 62 miles north of Oahu, Hawaii. HOTS pH and pCO_2 values are calculated from measured parameters, with direct pH measurements also collected at sea.

Despite the central importance of direct measurements for detecting long-term changes in the ocean's carbon system, coordinated observing networks in the United States coastal and estuarine waters did not exist until the early 2010s, following the establishment of NOAA's Ocean Acidification Program (Jewett et al., 2020; Kennedy et

al., 2024). Historically, assessments of changes to the carbonate system relied on a handful of data records worldwide (none of which operated in California waters, and the longest of which began only in the early 1980s) (Bates et al., 2015). Recent studies have focused on ways in which to build monitoring frameworks and identify gaps (e.g., Turk et al., 2019; Taylor-Burns et al., 2020; Zulian et al., 2025).

Strengths and limitations of the data

Observational time-series are publicly available from only two moorings in southern California locations, and do not provide coverage of acidification conditions in many central and northern California coastal ecosystems, nor in nearshore or subsurface habitats. As a result, these data may not fully capture the spatial variability in ocean acidification conditions across California's diverse marine environments. Given that pH and/or pCO_2 of seawater are variable in many of California's marine ecosystems, carbonate chemistry time-series need to be of sufficient length and measurement frequency before trends beyond natural variability can be detected (Sutton et al., 2019). One of the two CCE moorings (CCE1) has been in operation long enough; CCE2 is expected to reach a sufficient record length for trend detection within the next five years. However, limitations to our ability to detect long-term trends in carbonate chemistry along California's coast include lapses in monitoring programs, due to funding limitations. Many other ocean acidification monitoring efforts do not yet have the frequency and length of observations to detect trends. Measurements of other carbonate chemistry variables (in order of preference: dissolved inorganic carbon, total alkalinity, pH), in addition to pCO_2, will allow additional insight into the changes associated with ocean acidification. Future expansion and extension of the current monitoring network for ocean acidification was a major recommendation of the West Coast Ocean Acidification and Hypoxia Panel (Chan et al., 2016), and the 2020–2029 Ocean, Coastal, and Great Lakes Acidification Research Plan: 2020–2029 which calls for increased ocean acidification monitoring in important nearshore and subsurface habitats. Ideally, a robust future monitoring system integrating ocean acidification, hypoxia, and biological observations will enable tracking of changing ocean conditions under either accelerated or mitigated emissions and climate change scenarios.

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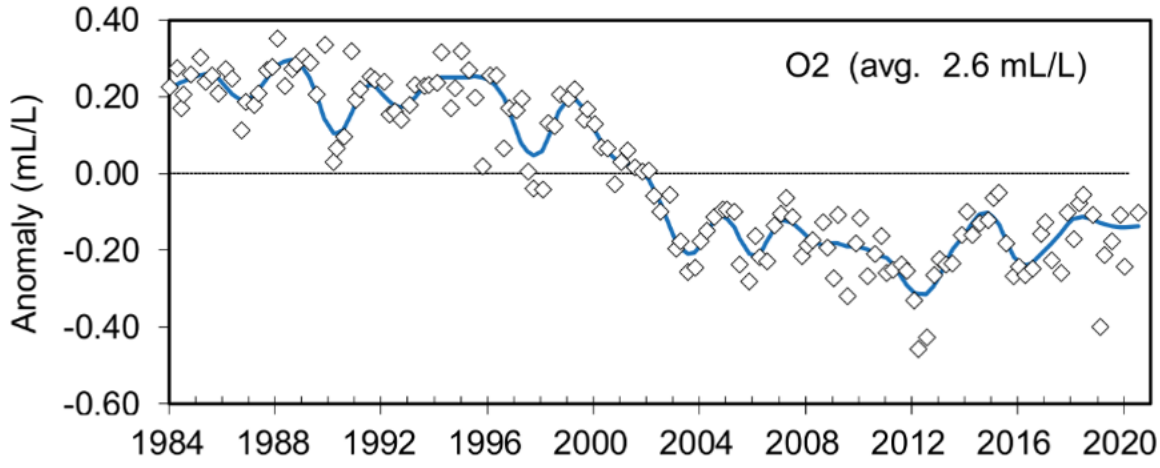
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3.2 Dissolved Oxygen in Coastal Waters

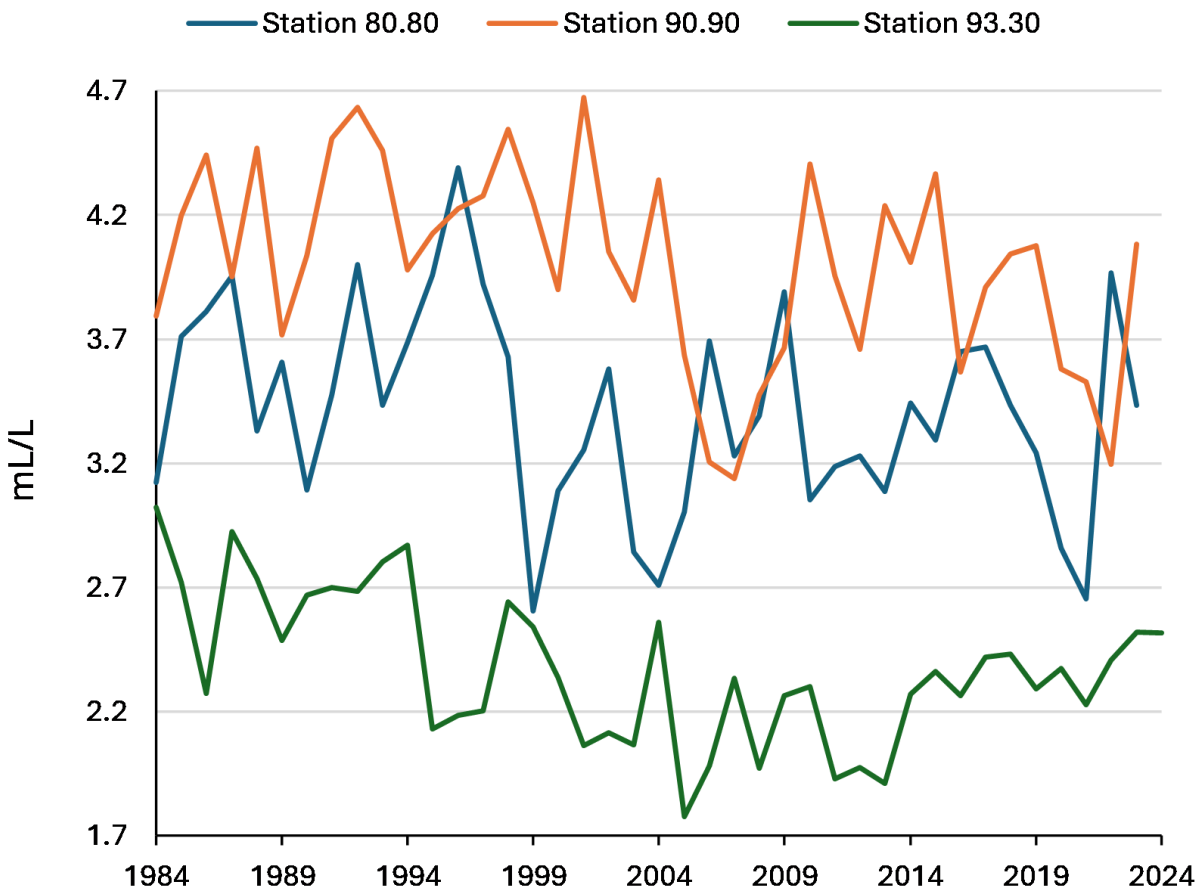
Dissolved oxygen concentrations are declining in ocean waters off Southern California, in part due to increasing coastal water temperatures.

Figure 3.2.1. Dissolved Oxygen (DO) Concentration Anomalies.



In the above graph, each diamond represents the annual DO anomaly from 1984-2020, calculated as the difference between the average DO concentrations measured across 66 CalCOFI monitoring stations and the long-term mean concentration (2.6 milliliters of dissolved oxygen per liter of seawater (mL/L)) (abbreviated “O2”) derived from the baseline period 1984 to 2013. The solid blue line represents the trend in annual averages. Measurements were taken on the σ_θ=26.4 kilograms per cubic meter (kg/m^3) isopycnal, corresponding to seawater at a density of 1026.4 kg/m^3. Source: Weber et al. (2021) Supplementary Figure 6

Figure 3.2.2. Annual Average Dissolved Oxygen Concentrations.



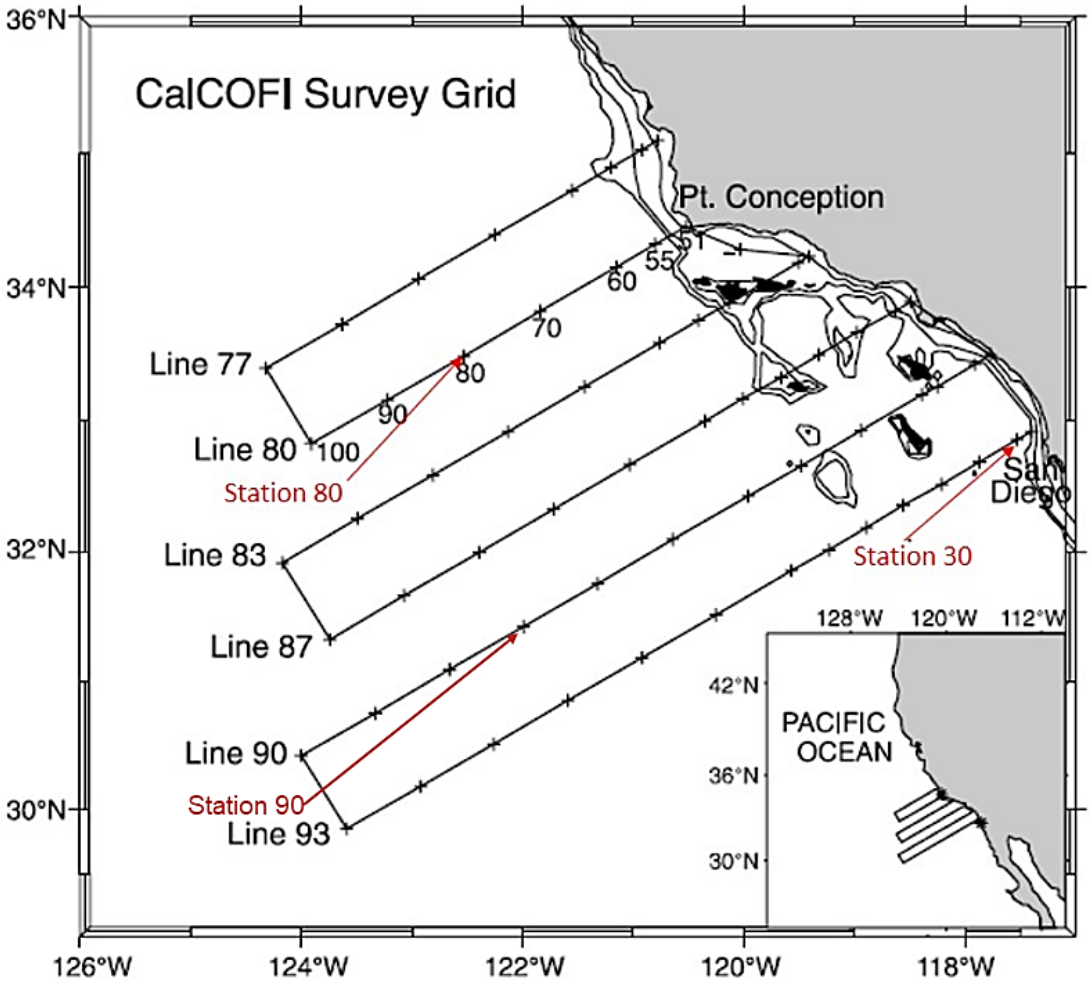
The graph shows DO levels (mL/L) at three monitoring stations along the southern California coast from 1984 to 2025 at a depth of 150 meters (m); data gaps between 1950 and 1980 preclude calculations of annual averages for that time period. Source: California Current Integrated Ecosystem Assessment (CCIEA, 2026)

What does this indicator show?

Instrumental measurements of dissolved oxygen (DO) concentrations point to increasing deoxygenation of coastal waters within the subsurface waters of the California Current System (CCS) in recent decades (**Figure 3.2.1**; Bograd et al., 2019; Evans et al., 2020; Smith Jr et al., 2022; Weber et al., 2021). These trends align with predictions that warming will increase hypoxia frequency in the CCS (Shi et al., 2023).

The CCS extends from British Columbia, Canada to Baja California, Mexico. The California Cooperative Oceanic Fisheries Investigations (CalCOFI) has been taking measurements of DO periodically off southern California from San Diego to Point Conception since 1950, and consistently at a grid of stations four times per year since 1984 (see **Figure 3.2.3** for locations). **Figure 3.2.1** is based on measurements from the 66 core stations in the CalCOFI survey area. **Figure 3.2.2** presents data collected at 150 m at three stations: Line 80, Station 80 (referred to as “80.80”); Line 90, Station 90 (“90.90”); and Line 93, Station 30 (“93.30”) (**Figure 3.2.3**).

Figure 3.2.3. Sampling Locations.



Modified from Bograd et al. (2008)

Throughout the CalCOFI survey area, at depths corresponding to the σ_θ-26.4 isopycnal – the depth at which seawater density is 1026.4 kg/m^3 – DO concentrations decreased significantly between the mid-1990s and the mid-2000s (**Figure 3.2.1**; Bjorkstedt et al., 2012, as cited in Thompson et al., 2019). Following this decline, DO concentrations have been relatively stable, but below the long-term average since 2000 (Weber et al., 2021). Overall, DO concentrations in this region (to at least 500 m depth) are now generally lower than those observed in the 1950s to 1960s (Bograd et al., 2008, 2015, 2019).

93.30 is representative of the influence of the northward-flowing California Undercurrent, which is a major supplier of deeper source waters (200 to 500 m) to the region and has a large influence on oxygen content for much of the survey area. At 80.80, offshore of Point Conception and within the core of the near-surface, southward-flowing California Current, DO concentrations have also declined sharply since the mid-1990's but have been generally increasing at 150-300 m in recent years. DO levels at 90.90 have generally decreased since 2000.

Why is this indicator important?

Declining DO levels are a significant environmental concern in coastal waters. Recent studies indicate that there is a measurable decline in DO content, exacerbated by various climatic and ecological factors. Declining DO concentrations in ocean waters and the associated changes in the depth and extent of low oxygen zones can lead to significant and complex ecological changes in marine ecosystems, including wide-ranging impacts on diversity, abundance, and trophic structure of communities (Levin et al., 2009; Somero et al., 2015; Stramma et al., 2010). Changing ocean chemistry, in combination with temperature changes, may lead to even greater and more diverse impacts on coastal marine ecosystems (Somero et al., 2015).

Offshore California waters contain an Oxygen Minimum Zone (OMZ), a layer of depleted oxygen concentrations that occurs at depths of approximately 600 to 1100 meters. The OMZ is expanding both vertically, moving closer towards the ocean surface (Bograd et al., 2008), and horizontally (Somero et al., 2015). The declines in oxygenation observed off the California coast are consistent with an observed

expansion of the low-oxygen zones elsewhere around the world, including in parts of the tropical Pacific and Atlantic Oceans (Breitburg et al., 2018; Stramma et al., 2008).

The expansion of oxygen-deficient zones can lead to a compression of favorable habitat for certain marine species and an expansion of favorable habitat for others. For example, following the 1997-98 El Niño event, the Humboldt squid (*Dosidicus gigas*) — which thrives in low-oxygen environments — expanded its range northward from Baja California to southeast Alaska, a shift that may have been affected by changes in the extent of oxygen-deficient zones (Gilly and Markaida, 2007). Studies have indicated that low-oxygen waters can reach nearshore coastal habitats via upwelling, with potential impacts on these habitats (Chan et al., 2019).

Oxygen plays a role in the cycling of nutrients such as nitrogen, phosphorus and iron. As a result, changes in oxygen levels can influence nutrient budgets, biological productivity and carbon fixation. In oxygen-depleted waters, anaerobic microbial processes can produce chemicals such as hydrogen sulfide, which is toxic to other organisms, and methane, a potent greenhouse gas (Breitburg et al., 2018).

What factors influence this indicator?

DO levels reflect a complex interplay between physical and biological drivers in the marine environment, including currents, upwelling, air-sea exchange, and biological productivity, respiration and decomposition. Warmer waters hold less oxygen, as the gas becomes less soluble, and surface warming produces stratification that reduces the overturning circulation essential in ocean ventilation processes. Warming also accelerates the rate of oxygen consumption by marine organisms (Breitburg et al., 2018; Somero et al., 2015). In addition to these processes, DO is influenced by high surface productivity, regional circulation of the North Pacific Ocean, and anthropogenic nutrient inputs to the coastal ocean, as discussed below.

Upwelling is a wind-driven physical process wherein deep, nutrient rich waters move upward into the shallow surface ocean. There is evidence that upwelling has increased in some locations along the California coast due to anthropogenic impacts (Bustos et al., 2024; García-Reyes and Largier, 2010; Quilfen et al., 2021). Upwelling brings nutrient rich waters to the surface, where it drives surface ocean productivity

(photosynthesis). The amount of surface water productivity affects DO concentrations because as biological material sinks downward from the surface ocean and decays, oxygen is utilized in the decay and decomposition process. Thus, DO concentrations decrease in the subsurface below regions of high biological productivity. Climate models indicate future changes in coastal upwelling within eastern boundary upwelling systems such as the CCS (Sydeman et al., 2014; Bograd et al., 2023). The projected changes in the CCS suggest a weak increase in coastal upwelling north of ~40°N but little change or even decreasing intensity further south, in the Southern California Bight (SCB), the curved section of coastline extending from Point Conception to northern Baja California (Rykaczewski et al., 2015). The impacts of these upwelling changes on subsurface oxygen will depend both on the intensity of wind forcing as well as changes in ocean stratification.

DO concentrations are also controlled by regional and global oceanographic processes. Waters undersaturated in oxygen off the coast of central California appear seasonally in spring, summer, and winter and vary in intensity (Ren et al., 2025). The SCB – the 400 miles of coastline from Point Conception in Santa Barbara County to Cabo Colnett, south of Ensenada, Mexico -- is impacted seasonally by the northward-flowing California Undercurrent, which likely impacts the trends seen at CalCOFI Station 93.30. Much of the SCB is included in the CalCOFI survey region. Declining oxygen concentrations in this region imply a change in the properties of equatorial source waters (Bograd et al., 2015, 2019). Equatorial waters transported via the California Undercurrent account for an estimated 81% of the deoxygenation trend in the CalCOFI region since 1993 (Evans et al., 2020).

Along the California coast, local nutrient inputs from human activities (e.g., agriculture, wastewater discharge) can also reduce DO concentrations in coastal waters. Fertilizers and nutrient enrichment from wastewater promote algal growth. As this material sinks and decays, it can create localized areas of low oxygen. Management of coastal pollution is an important aspect of minimizing changes in oxygen concentrations on a regional scale.

Scientists estimate that about 15% of global oxygen decline between 1970 and 1990 can be explained by ocean warming and the remainder by increased stratification. In coastal areas, especially nutrient-enriched waters, warming is predicted to exacerbate oxygen depletion (Breitburg et al., 2018). In its Sixth Assessment, the Intergovernmental Panel on Climate Change concluded that oxygen levels have declined in many upper ocean regions since the mid-20th century, and that deoxygenation will continue to increase in the 21st century (IPCC, 2021).

Technical considerations

Data characteristics

This indicator is based on data from the CalCOFI program. Established in 1949, CalCOFI conducts quarterly cruises (18 to 28 days long) to measure the physical and chemical properties of the CCS and census populations of organisms from phytoplankton to avifauna. Data collected at depths down to 500 meters include temperature, salinity, oxygen, phosphate, silicate, nitrate and nitrite, chlorophyll, phytoplankton and zooplankton biodiversity and biomass (CalCOFI, 2021).

DO measurements for CalCOFI Line 93.3, Station 30.0 (offshore of San Diego) and Line 80, Station 80 (within the offshore California Current core) were downloaded from the CalCOFI website. Quarterly averages were derived from oxygen concentrations reported for that calendar quarter. Since sampling did occur between 1950 and 1980, there are data gaps during this period.

Strengths and limitations of the data

Long-term datasets describing DO conditions along the California coast are limited, particularly in areas north of San Francisco. One analysis suggests that 20-30 years of data are needed to robustly detect long-term declines in DO above natural variability (Henson et al., 2016). All the CalCOFI datasets meet this criterion, thus CalCOFI currently represents the best resource for distinguishing long-term trends in DO from natural variability. However, CalCOFI has limited sampling availability in nearshore/coastal habitats, highlighting a need for additional coastal monitoring sites to characterize DO conditions in these areas.

These observations are also limited by sites where oxygen concentration measurements are currently monitored along the coast and do not reflect oxygen declines that may be occurring across the entire CCS. As described above, the observed DO concentrations could be influenced by both local thermodynamic and biological processes, and remote, large-scale changes. The oxygen concentrations can vary with the depth, temperature and time of year DO levels are measured.

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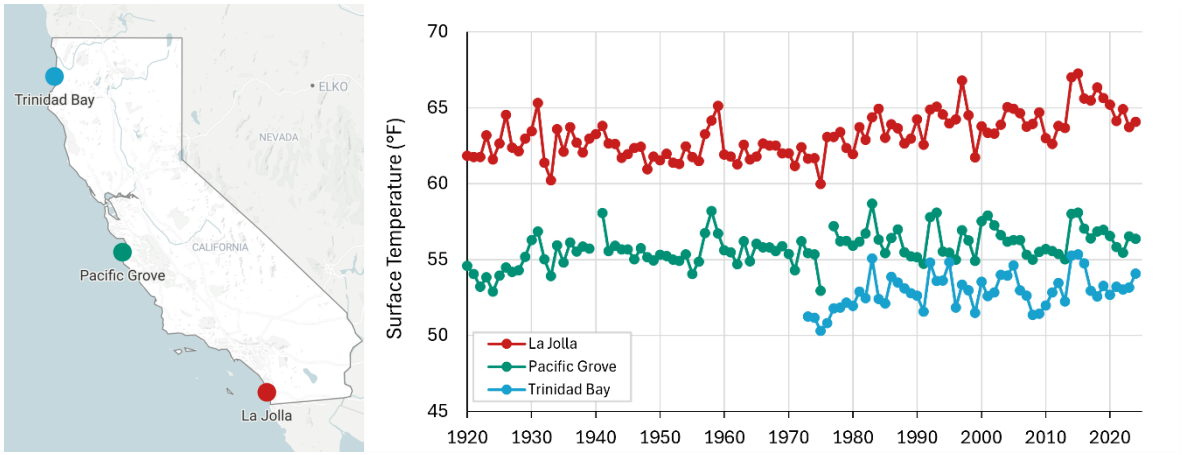
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3.3 Coastal Ocean Temperature

Measurements at California's shore stations show that nearshore coastal ocean temperatures have increased over the past century, particularly in Southern California. Similarly, satellite-based records over the past four decades show warming ocean waters off Southern California. In addition to these long-term trends, an unprecedented marine heatwave affected the West Coast of the United States from 2014 to 2016.

Figure 3.3.1. Annual Average Sea Surface Temperatures (SSTs).

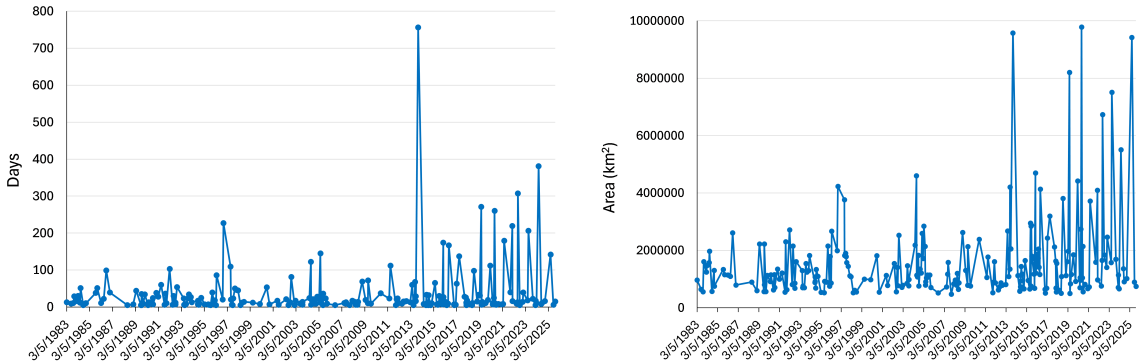


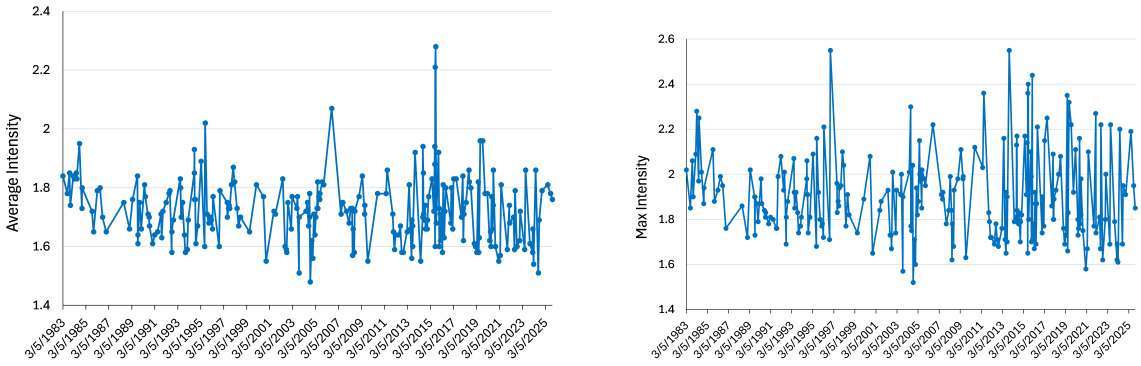
This graph shows annual average coastal ocean surface temperatures at Trinidad Bay (Northern California), Pacific Grove (Central California), and La Jolla (Southern California) shore stations. Records span different time periods depending on data availability, with observations extending from 1917 to 2025

*October to December 2025 are preliminary data

Source: SIO (2026)

Figure 3.3.2. Marine Heatwave Events.





The graphs show the total number of days, surface area, and intensity each year for all heatwaves since 1982 in the Northeast Pacific region along the coasts of California, Oregon, and Washington. Values are reported by the California Current Marine Heatwave Tracker, developed by oceanographers from NOAA Fisheries' Southwest Fisheries Science Center. Source: NOAA (2025)

What does the indicator show?

California coastal ocean temperatures have risen over the past century. Despite natural year-to-year fluctuations, long-term warming trends are evident in shore-station records (**Figure 3.3.1**). Sea surface temperatures have risen by 0.17 degrees Fahrenheit (°F), or 0.1 degrees Celsius (°C) per decade at Pacific Grove (1919–2025), and 0.26°F (0.15°C) per decade at La Jolla (1917–2025). At Trinidad Bay, temperatures increased at a rate of 0.28°F (0.16°C) over a shorter period (1973–2025). All three trends are statistically significant ($p < 0.05$), and additional stations along the coast show similar warming (**Table 3.3.1**), with the strongest increases at the southernmost sites, La Jolla, Granite Canyon, and San Clemente. Warming along California's coast is consistent with global trends — globally, average sea surface temperatures have increased at a rate of 0.14°F (0.08°C) per decade from 1901 to 2023 (US EPA, 2024).

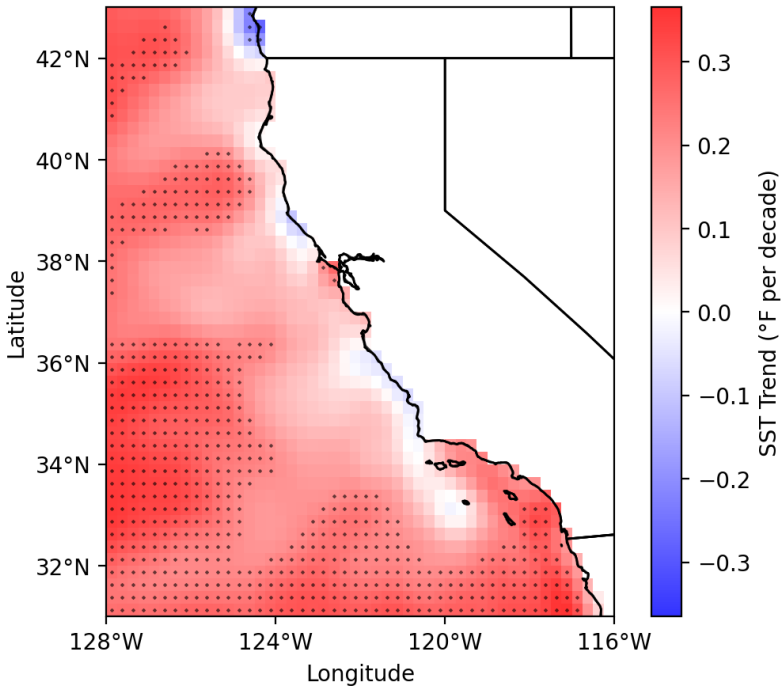
Table 3.3.1. Increasing Trends in Monthly Sea Surface Temperature.

Station	Dates	Decadal Trend	*p*-value*
Trinidad	01/1973 – 12/2025	0.27	< 0.001
Farallon Island	05/1925 – 12/2025	0.10	< 0.001
Pacific Grove[a]	01/1919 – 12/2025	0.18	< 0.001
Granite Canyon	03/1971 – 12/2025	0.28	< 0.005
Santa Barbara	01/1955 – 12/2025	0.30	< 0.001
Point Dume	12/1956 – 12/2025	0.07	0.29
Newport Beach	11/1924 – 12/2025	0.13	< 0.001
San Clemente	07/1965 – 12/2025	0.34	< 0.001
La Jolla	08/1916 - 12/2025	0.26	< 0.001

This table shows increasing trends in monthly sea surface temperature (°F per decade) for selected California coastal monitoring stations. Trends represent estimated long-term increases in monthly sea surface temperature through 2025. *p-values less than 0.05 indicate statistically significant increasing trends. [a]Data with documented uncertainty (Pacific Grove: 1976; Santa Barbara: 1995–2011; Point Dume: 1995–2006) were excluded from analysis.

From 1982–2025, monthly satellite-based sea surface temperature (SST) data from (National Oceanic and Atmospheric Administration) NOAA show mixed warming and cooling trends over the continental shelf that are generally not statistically significant ($p>0.05$), while offshore waters are generally warming ($p<0.05$, **Figure 3.3.3**). Both nearshore and offshore of the Southern California Border and Mexico exhibit a distinct warming trend, while cooling coastal trends are observed in Oregon.

Figure 3.3.3. Satellite-Based Sea Surface Temperature Trends.



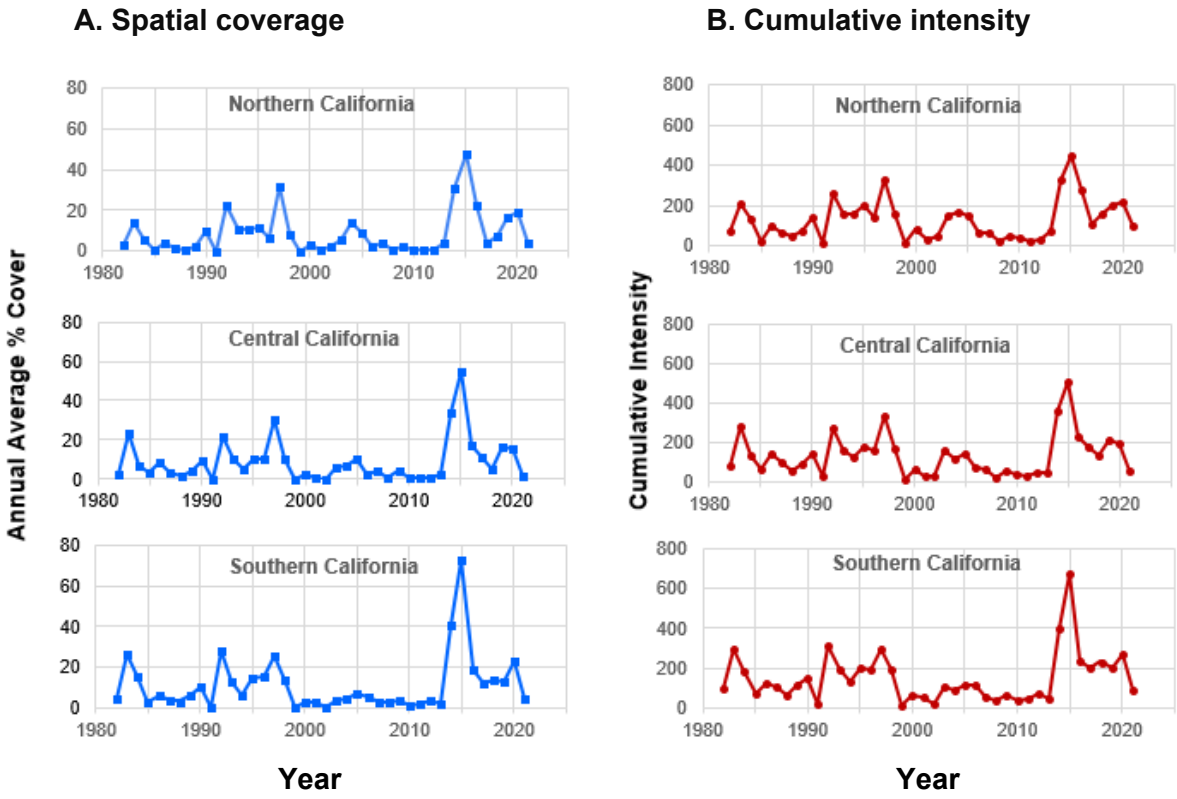
The map shows sea surface temperature trends along the California coast, in °F per decade, for the period 1982 to 2025. Colors indicate the magnitude and direction of sea surface temperature trends, with warmer colors representing increasing temperatures and cooler colors representing decreasing temperatures. Dotted areas denote locations with statistically significant trends ($p<0.05$). Source: NOAA (2026)

Marine heatwaves—events in which ocean temperatures are far above what is normal for a given place and time—significantly impact ecosystems, biodiversity, and regional economies (NOAA, 2025). Marine heatwaves have become more frequent worldwide and have grown more intense and longer lasting since the 1980s. The frequency of marine heatwaves approximately doubled from 1982 to 2016 (relative to the 1971-2000 climatology), and they have occurred each of the past seven years, from 2019–2025 (IPCC, 2021, NOAA, 2025). Over the past two decades, they have occurred in every major ocean basin (IPCC, 2021). In 2014 a large marine heatwave was identified as it began dominating the northeast Pacific Ocean. Eventually known as “The Blob”, this basin-scale marine heatwave was unique in the history of monitoring in the California Current Ecosystem (CCE) and persisted until mid-2016. While marine heatwaves have

occurred in the past, the magnitude and duration of the warming during this event was unprecedented for the west coast of North America (Di Lorenzo and Mantua, 2016; Gentemann et al., 2017). Researchers documented many ecological effects associated with “The Blob”, including unprecedented harmful algal blooms, shifting distributions of marine life, and changes in the marine food web (NOAA, 2025).

The large marine heatwaves that have occurred each year from 2019 to 2025 all typically began during the spring in the far offshore North Pacific, impacted the US west coast in the fall, and terminated during late winter. Five of the past six years saw the largest heatwaves recorded since monitoring began in 1982 in the region shown in **Figure 3.3.2**. In late May 2025, a major marine heatwave developed and expanded from late July to early August, reaching its maximum size of approximately 10 million square kilometers (km^2) on September 10, 2025. This event represents the largest marine heatwave (by area) observed within the Northeast Pacific region analyzed by NOAA. Earlier notable marine heatwaves occurred in 1983, 1992, 1997 (all associated with El Niños; these events originated in the south, rather than from the Central North Pacific) (Leising et al., 2015). **Figure 3.3.4** shows the area and intensity of marine heatwaves from 1982 to 2021 off Northern, Central, and Southern California in the same regions studied in **Figure 3.3.2**.

Figure 3.3.4. Marine Heatwaves off California (1982-2021).



A) Marine heatwave spatial coverage expressed as the annual average percentage of the region in heatwave status, defined as days when sea surface temperature exceeds the 90th percentile relative to the 1971 to 2000 climatology; B) Marine heatwave cumulative intensity, calculated as the annual sum of daily average sea surface temperature measurements above the long-term mean. Source: Data provided by Leising; also available at NOAA (2022)

Why is this indicator important?

Temperature is one of the best-measured signals of climate change. As atmospheric concentrations of greenhouse gases increase, excess heat is absorbed and stored by the oceans and atmosphere. The ocean's large mass and high heat capacity allow it to store large amounts of heat. It is estimated that over 90% of the observed heat energy increase on the Earth over the past 50 years has occurred in the ocean (Jewett and Romanou, 2017; NOAA, 2021; Rhein et al., 2013). In addition to absorbing excess heat, the ocean absorbs approximately 30% of carbon emissions. As a result, the ocean acts as a buffer against global warming (IPCC, 2019).

Shifts in sea surface temperatures along the California coast affect the distribution, abundance, and recruitment of many marine species, including commercially important ones. Temperature variability has been linked to changes in coastal populations (Goericke et al., 2007; IPCC, 2019; Sagarin et al., 1999), largely through its effects on physiology and the timing of key developmental stages. For example, multiple fish species are shifting their spawning times (mostly earlier) in the CCE (Chen et al., 2025; Asch, 2015). Seabirds may also be impacted by marine heatwaves through changes in habitat, behavior, ecological processes, or species interactions (Piatt et al., 2024). Altogether these changes can reshape marine communities by altering interactions with competitors, predators, parasites, facilitators, and prey.

Anomalously high temperatures during marine heatwaves dramatically impact marine ecosystems. Warm offshore waters can compress cool upwelling habitat into a narrow coastal band, altering species distributions (Santora et al., 2020). Marine heatwaves in the 1980s and 1990s that were associated with El Niño events disrupted ecosystems by altering water properties, food webs, and the transport of organisms (Ohman et al., 2017). The 2014–2016 marine heatwave caused mass strandings of marine mammals and seabirds (Cavole et al., 2016; Piatt et al., 2020) and initiated toxic algal blooms that harmed marine mammals (also see the *Marine Harmful Algal Blooms* chapter). Closure of the Dungeness crab fishery due to domoic acid produced by the toxic algal blooms resulted in an estimated $48 million in lost revenue statewide (Gentemann et al., 2017; Brown, 2016). Marine heatwaves contribute to the rapid and extensive loss of kelp forests in Northern and Southern California (Gleason et al., 2021, Cavanaugh et al., 2019). In Northern California this led to the closure of the recreational red abalone fishery and the commercial red sea urchin fishery (Gleason et al., 2021). Both kelp and abalone are culturally significant species to Native American tribes, such as the Chumash and the Scotts Valley Band of Pomo Indians (Santa Ynez Band of Chumash Indians, 2022; Amah Mutsun Tribal Band, 2022; Big Valley Band of Pomo Indians and Middletown Rancheria of Pomo Indians, 2021). Since kelp provide a wide range of ecosystem services as primary producers and as essential habitat for marine organisms, among other things, the loss of kelp forests has larger scale consequences (Bell et al., 2020; Gleason et al., 2021; Teagle et al., 2017; also see the *Kelp*



Populations chapter). For example, without kelp forests to act as buffers, the coast has become more vulnerable to coastal erosion from high energy storms and swell events; along with sea level rise, coastal erosion is threatening cultural sites along the shoreline in the Amah Mutsun's ancestral territory (Amah Mutsun Tribal Band, 2022).

Tribal Connection 3.3.1

Ocean temperatures are one variable impacting eelgrass beds, which are a critical part of the ecosystem in the Wiyot Tribe's homelands around Humboldt Bay or *Wigi*. The Wiyot Tribe writs, "*Sea level rise and increased storm severity, along with ocean warming and acidification, pose a threat to Wigi eelgrass habitat. Eelgrass is a vital habitat for many species, including Dungeness crab, juvenile salmonids, rockfish, and migratory birds (Merkel & Associates, Inc., 2017). As part of their mitigation efforts to help habitats and species migrate inland, the Tribe is working on an eelgrass suitability distribution model. This model will take temperature, salinity, depth, substrate conditions, and other eelgrass habitat parameters into account to help the Wiyot find locations for future eelgrass survival and protection*" (Wiyot Tribe, 2026).

Temperature changes also affect the chemical and physical properties of the ocean. Since warmer water is less dense than colder water, changes in sea surface temperatures can alter currents and transport patterns. Warming sea surface temperatures can cause more stable layers of seawater to form near the surface, thus increasing water column stratification; when this happens, upwelling and vertical mixing that transports nutrients, oxygen, carbon, plankton and other material across ocean layers is reduced (Roemmich and McGowan, 1995; Jacox and Edwards, 2011). Temperature also affects the solubility of gases in ocean waters. For example, warmer waters contain less oxygen and accelerate oxygen consumption by marine organisms (e.g., Somero et al., 2015; Breitburg et al., 2018).

Surface ocean water temperature affects the occurrence of coastal fog and the strength of winds, as well as the thickness of the marine atmospheric boundary layer. The latter is a primary factor controlling the inland intrusion of cool coastal air and therefore inland weather patterns. Warmer waters play a role in extreme weather events by increasing

the energy and moisture of the atmosphere. Warmer ocean temperatures also contribute to global sea level rise because warming water not only expands but also accelerates the melting of land-based ice sheets (IPCC, 2021). Additionally, Hurricane Hilary in August of 2023 caused record-breaking precipitation, flooding, and damage to Southern California in the form of an uncommon tropical cyclone. Coastal warming patterns of Southern California allowed for easier landfall for tropical cyclones that historically remained offshore (Miles and Xie, 2025).

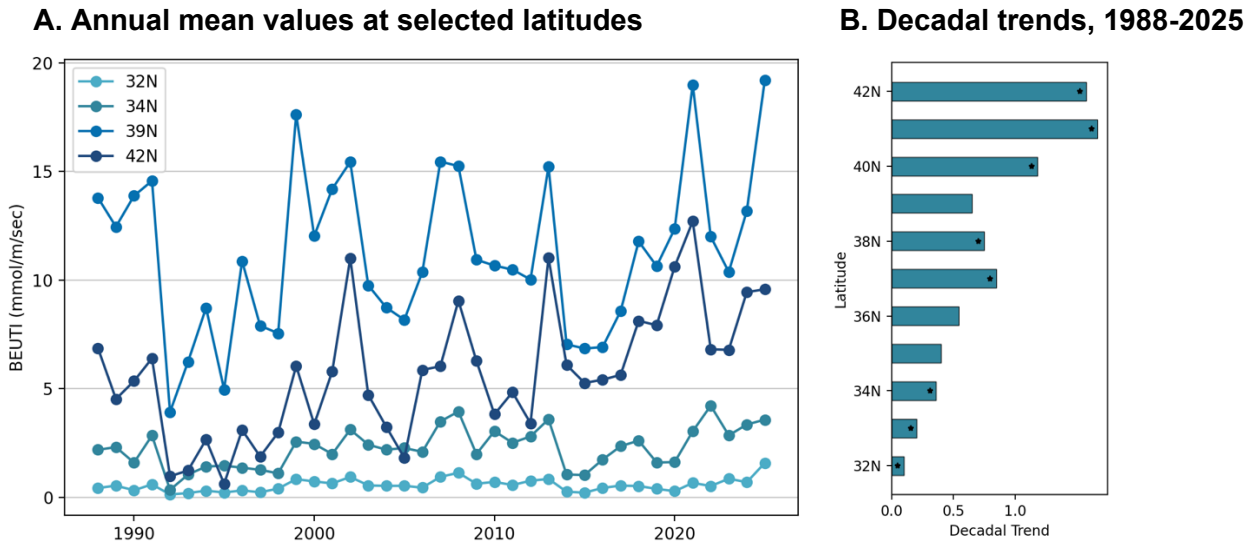
Globally, oceans are projected to continue to warm in the 21st century. Marine heatwaves are expected to further increase in frequency, duration, spatial extent, and intensity, although changes will not be globally uniform (IPCC, 2021). Given the severe impacts of marine heatwaves on the marine ecosystem and the coastal communities and economies it supports, NOAA oceanographers have developed the California Current MHW Tracker as a tool for describing current and past large marine heatwaves that could also help with forecasting future marine heatwaves (NOAA, 2022).

What factors influence this indicator?

Global sea surface temperatures have increased due to net heat flux from the atmosphere stemming from the greenhouse effect. Deeper regions of the oceans have also warmed to depths of 3000 meters during the past several decades (Levitus et al., 2001 and 2012). A combination of oceanic and atmospheric processes, including ocean currents, winds, and climate variability modes like El Niño can lead to the periods of extremely high ocean temperature, and their classification as marine heatwaves depends on the magnitude of ‘normal’ warming events in each location (Hobday et al., 2016).

Near-surface ocean water temperatures along the California coast are also influenced by seasonal upwelling. An index called the Biologically Effective Upwelling Transport Index, or BEUTI, tracks the amount of nutrients (nitrate) in vertically transported waters, providing information about upwelling relevant to biological responses (Jacox et al., 2018; **Figure 3.3.5**). BEUTI shows high interannual variability with a slight increase over time, especially at latitude 34°N in Southern California.

Figure 3.3.5. Biologically Effective Upwelling Transport Index.



A) Annual mean values of the Biological Effective Upwelling Transport Index (BEUTI) at selected latitudes along the California Coast: 32°N, south of San Diego; 34°N, Los Angeles; 39°N near Point Arena, and 42°N near the California-Oregon border; B) Linear trends in BEUTI per decade at different latitudes along the California Coast for the period 1988 to 2025. Black stars denote statistically significant trends (p values < 0.05). Source: NOAA ERDDAP (2025)

Coastal ocean temperature trends are shaped by the combined influence of surface warming and the cooling effect of upwelling. Surface temperatures tend to rise offshore and in sheltered waters, as seen at La Jolla, while open shelf waters, especially off Central and Northern California, remain cooler or unchanged during the upwelling season (Seabra et al., 2019; García-Reyes and Largier, 2010; García-Reyes et al., 2023). The lack of significant warming in these regions over the past four decades reflects upwelling's cooling influence. (Bakun, 1990; García-Reyes et al., 2015; **Figure 3.3.3**).

Natural variability in coastal temperature, wind, and circulation drives large year-to-year and decade-to-decade changes. El Niño-Southern Oscillation (ENSO) events cause major swings—El Niño warms California's coastal waters, while La Niña cools them—and occur every 5–10 years. Longer-term patterns like the Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO) also influence West Coast temperatures (UCAR, 1994; Di Lorenzo et al., 2008; Mantua et al., 1997). Marine

heatwaves reflect both long-term warming from climate change and amplified short-term fluctuations (Fumo et al., 2020).

Technical considerations

Data characteristics

Coastal California is home to the longest continuous record of sea surface temperatures on the US West Coast and the Pacific Rim. Long-term time series from three sites — Trinidad Bay in Humboldt County, Pacific Grove in Monterey County, and La Jolla in San Diego — are presented in this report; these sites were chosen based upon their long operational duration (~40 to 100 years), public data availability, and regional/geographic coverage. Data for the three sites and other California coastal sites have been collected by the Shore Stations Program (SIO, 2026). The time series at Scripps Pier, La Jolla Shores, which extends back to August 1916, is the longest running sea surface temperature data set in the state.

Trinidad Bay temperature measurements are taken daily by staff from the Humboldt State University Marine Laboratory, located on the rocky headland between the ocean and Trinidad Bay. Bay temperature is measured from the fishing pier on the southeast side of the headland. Pacific Grove measurements are taken daily by staff from Stanford University's Hopkins Marine Station from a beach on the north side of Point Cabrillo. This location is representative of coastal conditions on the south side of Monterey Bay. La Jolla temperature measurements are taken daily at Scripps Pier by representatives from Scripps Birch Aquarium. The proximity of the pier to the deep waters at the head of La Jolla submarine canyon results in data representative of oceanic conditions.

The NOAA Optimum Interpolation Sea Surface Temperature (OISST) reanalysis dataset merges satellite and in situ measurements from different platforms into a single gridded SST product. Along the California coast, the dataset provides a spatial resolution of approximately 13 nautical miles (nmi) (here averaged longitudinally to ~30nmi), and daily temporal resolution, starting in September 1981. The dataset is interpolated to fill gaps on the grid and create a spatially complete map of sea surface temperature. Satellite and ship observations are referenced to buoys to compensate for

platform differences and sensor biases (NOAA, 2026). Data is provided by NOAA/National Centers for Environmental Information.

Marine heatwave cover and cumulative intensity are products reported in the California Current Marine Heatwave Tracker, an experimental tool for tracking marine heatwaves from British Columbia to Baja, along the path of the California Current. The California Current is a large, southward-flowing ocean current that forms the eastern boundary of the North Pacific Ocean circulation and transports cool, nutrient-rich water along the west coast of North America from British Columbia to Baja California. The tool was designed to investigate the 2014-2016 marine heatwave (NOAA, 2022). Indices are developed to help track historical and near-real-time marine heatwaves. A marine heatwave is based on the definition in Hobday et al. (2016). However, no time constraint was used since values were summed over relatively large regions. The analysis presented here is based on a long-term baseline mean for the period 1971 to 2000, and the threshold was set at the 90th percentile of all values for the period 1982-2021. Further information about the tracker, including access to the data, is available at the Integrated Ecosystem Assessment webpage.

Five regions along the California Current are monitored, including three in California as shown in **Figure 3.3.4**. For each region, the spatial coverage is calculated as the annual mean of the daily percentage of the area in heatwave status. This describes the size of the marine heatwave each year. Intensity describes how hot the ocean waters are compared to a historical baseline. This index does not depend on whether it is in heatwave status. The cumulative intensity presented in **Figure 3.3.4B** is the sum of daily intensity values in a year for a given region, specifically the sum of average daily SST measurements above the baseline temperature. These temperature measurements are standardized for the location and time of day to ensure that the data are comparable over time.

Strengths and limitations of the data

A growing network of ocean monitoring along California is an important resource for separating natural and anthropogenic influences on increasing temperatures. The California Cooperative Oceanic Fisheries Investigations (CalCOFI) and NOAA National

Data Buoy programs represent the largest coordinated efforts to collect sea surface temperature data across broad spatial scales. In addition, California's regional Ocean Observing Systems (Central, Northern, and Southern California) provide coordinated, long-term monitoring of environmental conditions to support ocean management decisions as part of an eleven-region US Integrated Ocean Observing System (IOOS, 2026).

The NOAA satellite-based product provides a shorter sea surface temperature record than those of the shore stations, however its record has no spatial gaps and a larger cover offshore, allowing a better understanding of the different trends observed in this indicator along the California coast and over the continental shelf (NOAA, 2026). It is important to note that the data points closest to shore cover waters over the continental shelf, and do not represent temperatures near shore (beaches and intertidal) due to its coarser resolution. For nearshore values, the coastal values are more representative, although sparse in space.

Temperature and BEUTI were averaged annually before trends were calculated. This reduces the number of data points and therefore statistical significance. Data from: https://mjacox.com/upwelling-indices/.

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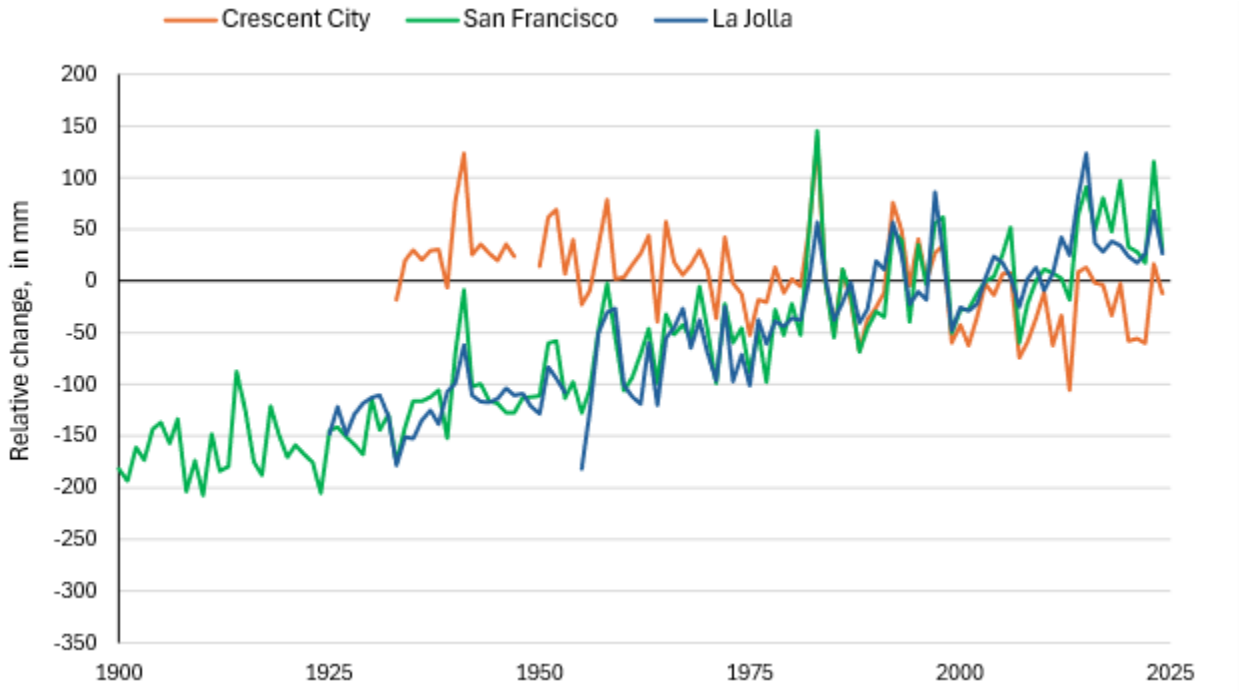
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3.4 Sea Level Rise

Sea levels along most of California's coast have risen over the past century, except in the far north where tectonic uplift has caused a small relative drop in sea level. Driven by warming oceans and melting land ice, sea level rise amplifies flooding, coastal erosion, and storm impacts, threatening public safety, infrastructure, ecosystems, and cultural resources.

Figure 3.4.1. Annual Mean Sea Level (millimeters) from 1900-2025 for the California Coast.



The graph shows the relative change in sea level relative to the land surface for three California coastal locations. Source: NOAA (2026)

What does the indicator show?

Sea levels are rising along much of California's coastline, with significant year-to-year (interannual) variability**.** **Figure 3.4.1** shows changes in relative sea levels measured at NOAA tide gauges along California's coast. Relative (local) sea levels reflect both changes in absolute sea level and vertical land motion (how fast the coast is sinking or rising). Trends at 16 tide stations in California are presented from north to south (NOAA, 2026). As illustrated in **Figure 3.4.2**, a negative trend (as shown by the downward arrow in the figure) indicates the land is rising faster than the ocean at that location. Trends close to zero indicate that the land is rising at essentially the same rate as the ocean although there are other factors at play also (such as ocean dynamics and gravitational effects) that affect regional sea level rise in addition to vertical land motion. For most of the state's coastline, local sea level rise rates (shown by upward arrows in **Figure 3.4.2**) over the period of record range from approximately 1 millimeter per year (mm/year) to nearly 3 mm/year. Relative sea levels are rising the fastest at Eureka's North Spit (5.0 mm/year), Redwood City (2.7 mm/year), and San Diego (2.2 mm/year). The high rates are due in part to land subsidence, which is the sinking of land caused by a combination of tectonics, sediment compaction, and groundwater withdrawal and subsequent subsidence. Relative sea levels have declined at Crescent City since records began in 1933, due to regional land uplift driven by the movement of the Earth's tectonic plates.

Figure 3.4.2. Annual Mean Sea Level Trends for California.



Location	Period of record	Trend (mm/year)
Crescent City	1933-2024	-0.77
North Spit	1977-2024	+5.0
Arena Cove	1978-2024	+1.1
Port Chicago (inland)	1976-2023	+2.0
Point Reyes	1975-2024	+2.1
Alameda	1939-2024	+0.92
San Francisco	1897-2024	+2.0
Redwood City (inland)	1974-2024	+2.7
Monterey	1973-2024	+1.7
Port San Luis	1945-2024	+0.98
Santa Barbara	1973-2024	+0.99
Santa Monica	1933-2024	+1.5
Los Angeles	1923-2024	+1.1
Newport Beach (inactive)	1955-1993	+2.2
La Jolla	1924-2024	+2.0
San Diego	1906-2024	+2.2

The map shows annual mean sea level trends at selected stations along the California coast. Records span different time periods depending on data availability, with observations extending from 1897 to 2024. Source: NOAA (2026)

The trend towards higher sea levels in California is consistent with global observations (IPCC, 2023; Griggs et al., 2017). Global (absolute) sea level rise is accelerating — the current rate is triple the 20th century rate (OPC, 2024a). In the last 100 years, average sea levels off California's coast rose by up to 6-8 inches, comparable to global trends. By 2050, average statewide sea levels are expected to rise another 0.5 feet (ft) to 1.2 ft relative to 2000 levels. By 2100, the midpoint of sea level rise projections is 3.1 ft, but higher amounts are possible. The range of plausible sea level rise becomes increasingly large towards 2100 and beyond due to uncertainties associated with physical processes that drive sea level, such as ice sheet loss from Greenland and Antarctica. Sea levels may rise by 2.6 ft to 11.9 ft by 2150, and even higher amounts cannot be ruled out (OPC, 2024a).

Why is this indicator important?

Understanding relative (local) sea level rise is important to recognizing how low-lying coastal communities and ecosystems will be affected by flooding, habitat loss, and damage to infrastructure (Blackwell et al., 2020). Millions of residents, infrastructure, housing, natural resources, and economies along California's coast face serious and costly threats from rising sea levels (OPC, 2024a).

Rising sea levels coincide with more frequent and extreme storms, which are drowning beaches, eroding bluffs, flooding homes and businesses, and damaging roads and other essential public infrastructure (OPC, 2024a; see the *Coastal Flooding* chapter). As sea level rise continues to accelerate throughout this century and beyond**,** coastal flooding, beach erosion, bluff retreat, loss of ecosystems, salinization of soils, shallower groundwater, and impeded drainage will further increase along low-lying coasts worldwide without adequate adaptation efforts (IPCC, 2019). Coastal erosion (**Figure 3.4.3**) poses an increasing threat to public safety, infrastructure, and property (Vitousek et al., 2017; Limber et al., 2018; USGS, 2019), while **Figure 3.4.4** shows what the impacts of coastal floods and storms can look like. And although tsunamis are rare in California, rising sea levels are expected to gradually increase their destructive potential in the long term, with near term impacts dependent on coastal water levels (e.g., tides) at the time of tsunami arrival (Dura et al., 2021; Griggs, 2024; Sepúlveda and Mosqueda, 2025).

Figure 3.4.3. Coastal Cliff Erosion Hazards and Impacts.

A) Isla Vista



B) Capitola



C) Big Sur coast



D) Pacifica



A) Cliff retreat threatening coastal homes in Isla Vista. B) Cliff failure on Depot Hill in Capitola along the northern Monterey Bay coastline. C) The Mud Creek Slide along the Big Sur coast closed State Highway One for months. D) The weak bluff materials in Pacifica have continued to erode during major storm events in recent years, and these three apartment buildings were eventually demolished. Source: Patrick Barnard (photo top left) and Gary Griggs

Nearly 50% of California's beaches could disappear under a 1-meter sea level rise scenario (Vitousek et al., 2023). In Southern California, 31 to 67% of beaches are predicted to become completely eroded by 2100 (Vitousek et al., 2017). The magnitude of beach loss varies regionally, with the greatest projected losses occurring along Southern and Central California, where narrow beaches, coastal armoring, and limited

sediment supply constrain landward migration. Northern California beaches are generally wider and less armored, which may allow for greater persistence under some sea level rise scenarios (Vitousek et al., 2017 and 2023). Sea level rise and coastal flooding also threaten beach and dune species such as the western snowy plover and other shorebirds that nest in low-lying coastal areas. Many of the state's tidal wetlands are also projected to be nearly or entirely lost by the end of the century under moderate to high sea level rise scenarios. Subtidal habitats like California's giant kelp forests (*Macrocystis pyrifera*) and seagrass beds—critical for species including the endangered Southern sea otter (*Enhydra lutris nereis*) and red abalone (*Haliotis rufescens*)— are expected to be affected as sea level rise alters water depth, light availability, and wave energy, potentially forcing communities to shift shoreward or experience localized losses, rather than disappear entirely. In addition, small changes in flooding, inundation, salinity, temperature, and other abiotic factors can trigger abrupt change in structure and function. For example, storm events can have substantial impacts on kelp, seagrass, and macroalgal communities, from changes in the relative abundance of species within a community to total habitat loss. The combined stress of increasing sea levels and other climate-driven disturbances threaten the sustainability of aquatic and terrestrial plant species and benthic and fish communities (Thorne et al., 2024).

Higher sea levels can also contribute to rising groundwater tables, increasing saltwater intrusion into freshwater aquifers, increasing corrosion of underground infrastructure, undermine structural foundations, mobilizing subsurface contaminants, and leading to surface pooling of water. These effects are most pronounced in low-lying coastal and deltaic regions, where elevated ocean levels reduce groundwater drainage to the coast and increase hydraulic pressure inland. In particular, the Sacramento-San Joaquin Delta that supplies fresh water to two-thirds of the state's population and millions of acres of farmland is particularly vulnerable to groundwater aquifer saltwater intrusion due to its low elevation, extensive levee system, and strong surface water–groundwater connectivity. The extent of intrusion varies by location and sea level rise scenario making it difficult to define a single intrusion boundary statewide (OPC, 2024a).

Figure 3.4.4. Storm and flood damage in Santa Cruz in January 2023.



Damage to a public roadway and pedestrian path (left) and flooding of a coastal road (right) due to the simultaneous arrival of very large waves and high tides. Source: Gary Griggs

Tribal Connection 3.4.1

The Wiyot Tribe lives around Humboldt Bay or *Wigi* and nearby coastal and upland areas. They are experiencing a loss of spiritual, archaeological, and biological cultural sites as sea level rises. They write: "*Inundation of cultural sites such as Tuluwat* [Island] *is a major concern of the Tribe for the next century. Located in the center of Wigi, Tuluwat is the center of the universe for the Wiyot people. Since time immemorial, the Wiyot people have served as stewards of Tuluwat, performing an annual World Renewal Ceremony to bring balance to the land and its people. Tuluwat is home to sacred village and gathering sites, as well as a historic shell midden. […]. Sea level rise and larger storm surges contribute to gradual beach loss and acute scarping, or the erosion of front dunes by waves. These processes are destroying the habitat of bulb species that the Wiyot Tribe depends on, such as various Indian potatoes (Brodeia and Dichelostemma congestum), native lilies (Fritillaria affinis), and more.*" (Wiyot Tribe, 2026).

Coastal erosion and sea level rise, along with warming ocean temperatures and ocean acidification, collectively threaten cultural sites and resources along the shoreline for the Amah Mutsun and Chumash Tribes. Coastal erosion has damaged cultural sites, and as sea levels rise, sites previously used for gathering are no longer accessible (SCTLS, 2021; see Amah Mutsun and Santa Ynez Chumash Tribal reports). For example, traditional areas for the Chumash Tribe to gather Olivella shells (**Figure 3.4.5**), used in shell money, jewelry, and regalia, are often no longer accessible. Without access to traditional sites, knowledge can be disrupted, and the weight of that loss is felt by generations of tribal members (PBMI and SYBCI, 2021).

Figure 3.4.5. Olivella Shells Carved by the Chumash.



Source: Science News (2021)

Multiple efforts across California are underway to plan for, prepare for, and adapt to rising sea levels to protect coastal ecosystems, infrastructure and communities (OPC, 2024b). Nature-based solutions such as wetland restoration can help attenuate the impacts of waves and storm surges and provide additional ecological benefits including habitat creation and enhancement, carbon sequestration, improved water quality, and increased biodiversity (Nederhoff et al., 2025; Taylor-Burns et al., 2025). To support local adaptation strategies, online coastal flooding hazard maps using data by the scientific and research community in California may be accessed at: CalAdapt, Our Coast Our Future, Hazard Exposure and Reporting Analytics (HERA), and CoSMoS. These maps include predicted flooding for the San Francisco Bay and California coast resulting from storm events for different sea level rise scenarios.

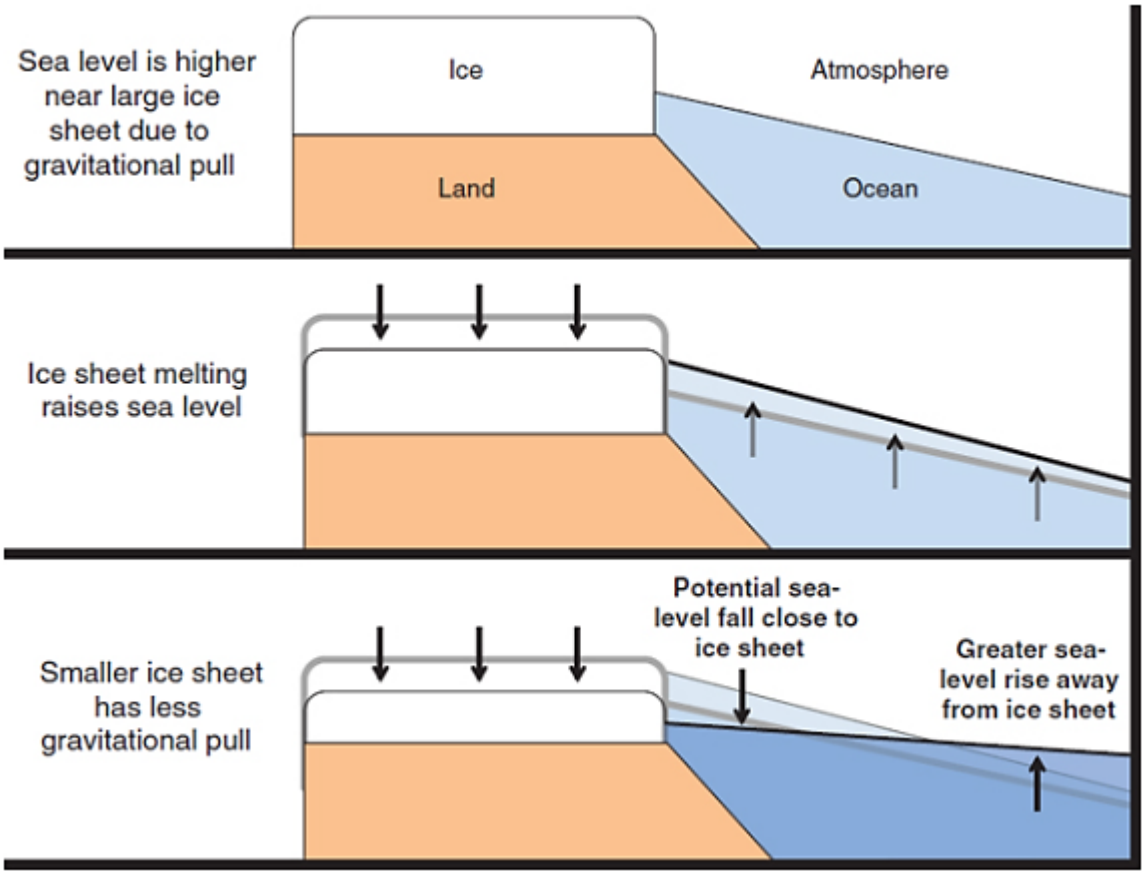
What factors influence this indicator?

The main contributors to sea level rise on a global scale are thermal expansion of ocean water as it continues to warm and the input of freshwater from melting ice sheets and glaciers**.** The warming oceans and melting ice are both consequences of our warming climate — human influence on the climate has likely been the main driver of global sea level rise since at least 1971 (IPCC, 2023). Relative sea level rise (the rise of the ocean relative to land) at any specific location is driven by a combination of these global processes plus sterodynamic sea level change (combined effect of changes in temperature, salinity, winds, and currents), ice-mass loss, and vertical land motion. Episodically, the local sea level is modulated by processes that produce higher-than-normal coastal water levels, such as storm surges, wave runup, and extreme (King) tides. Factors affecting sea level rise along California's coast are described in further detail below.

Melting of glaciers and ice sheets

Water from melting mountain glaciers and ice sheets is the main source of global mean sea level rise today (IPCC, 2019; Slater et al., 2020). The ice sheets in Greenland and Antarctica, while not expected to melt completely even on millennial time scales, contain enough ice to raise the global mean sea level by 24 feet and 187 feet, respectively. Observations show that ice mass loss from these ice sheets has accelerated substantially over recent decades, with loss rates increasing by a factor of two to three since the 1990s, driven by rising air and ocean temperatures (Griggs et al., 2017). Additionally, as an ice sheet loses mass to the ocean, its gravitational pull on the surrounding ocean is reduced. The reduced gravitational pull on the ocean causes sea levels near the ice sheet to fall, but farther away (including off the coast of California), relative sea levels will rise (**Figure 3.4.6**; OPC, 2024a).

Figure 3.4.6. Gravitational Effects of Ice Sheet Melting.



The visual shows how sea level is higher than the global average near large ice sheets due to gravitational pull. When the ice melts, global sea level rises. The reduced gravitational pull from the smaller ice sheet causes sea level near the ice to fall and rise farther away. Source: NAS (2013)

Heat-driven expansion

As the ocean warms, seawater expands, contributing to rising sea levels (IPCC, 2019). This heat-driven expansion, also known as the steric effect, was the single greatest contributor to global mean sea level rise over the past century, accounting for approximately half of the observed sea level rise (Griggs, et al., 2017). The ocean has absorbed more than 90% of the excess energy associated with anthropogenic greenhouse gas emissions, resulting in sustained ocean warming and continued sea level rise.

Sterodynamic sea level change

Sterodynamic sea level change refers to the combined effect of steric (temperature and salinity) changes and changes in ocean dynamics (winds and currents). Temperature and salinity are expected to be the primary drivers of sterodynamic sea level rise along the California coast, with ocean circulation and wind patterns influencing regional variability (OPC, 2024a). Globally, sterodynamic processes account for a substantial fraction of observed sea level rise—on the order of one-third to one-half over the 20th century—although the relative contribution varies by region and over time (IPCC, 2019; OPC, 2024a).

Land subsidence and uplift

Tribal Connection 3.4.2

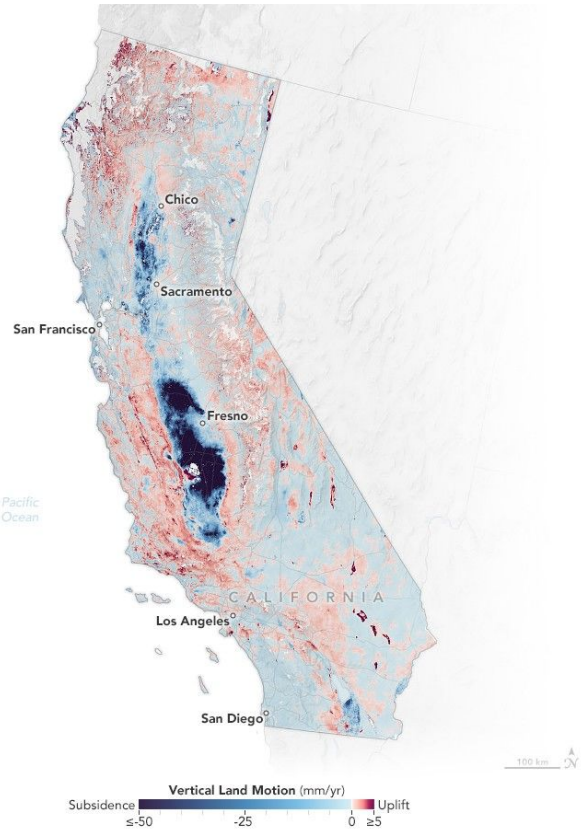
Less than 100 miles south of Crescent City, where relative sea level is dropping, is Humboldt Bay, where relative sea level is rising the fastest. This juxtaposition of greatest drop and greatest rise is due to the tectonic plate phenomenon known as the Triple Junction. The Wiyot Tribe live in some of the lowest lying areas most vulnerable to sea level change. They write, "*Relative sea level is rising 2–3 times faster in the southern portion of Wigi* [Humboldt Bay] *than anywhere else on the California coast. Analysis of temporary tide gages around Wigi suggests that the rate is as high as 6.2 millimeters per year around Hookton Slough in the southern part of Wigi near Table Bluff Reservation [of the Wiyot Tribe] (Anderson, 2018; Patton et al., 2023). […]. The Tribe has experienced an increasing number of high tide flood events over the past 40 years*." (Wiyot Tribe, 2026).

Vertical land motion is the primary driver of local variations in sea level rise along the state's coastline. As previously mentioned, vertical land motion is due to a combination of tectonics, sediment compaction, and groundwater withdrawal and subsequent subsidence (OPC, 2024a). Groundwater pumping and other fluid withdrawals from the subsurface, as well as sediment compaction, can lead to high rates of local subsidence, as in the California Bay-Delta, and along the San Francisco Bay shoreline. Much of California's coast is subsiding due to regional changes in land levels (Blackwell et al., 2020). A radar study of an approximately 100 kilometer (km) wide swath of land along

California's coast during the years 2007-2018 estimated that between 4.3 million and 8.7 million people in California's coastal communities live on areas of subsiding land (**Figure 3.4.7**; Blackwell et al., 2020).

Many of the islands in the California Bay-Delta have dropped below sea level. Drainage to allow for farming has resulted in extensive subsidence, as well as exposed the Delta's organic soils to microbial activity that converts much of the soil matter into carbon dioxide and nitrous oxide – both of which are greenhouse gases that contribute to climate change (Delta Stewardship Council, 2025; NASA, 2017). Conversely, plate tectonics can cause land uplift along the coast to outpace relative sea level rise, as is happening in Crescent City in northern California, where NOAA's records show a drop in relative sea level over time. The far north coast is the only area along California where the sea level is dropping relative to the land surface (Russell and Griggs, 2012).

Figure 3.4.7. Land Subsidence Along the Coast of California.



The map shows vertical land movement rates (mm/year) in California from 2015-2023. Blue areas indicate land subsidence and red areas indicate land uplift.

Source: NASA (2025)

Groundwater pumping

Groundwater that is pumped for agriculture, industry, and domestic use transfers more water to the ocean, thereby contributing to sea level rise along the California coast (Griggs, et al., 2017). In addition, groundwater extraction can cause the drawdown of aquifers to cause subsurface compaction (land sinking), accelerating local or relative sea level rise. In California, this effect is most pronounced in heavily pumped regions, including the Sacramento–San Joaquin Delta, San Francisco Bay shoreline, and parts of Southern California, where subsidence rates of several millimeters per year have been observed and can locally exceed rates of global mean sea level rise (Blackwell et al., 2020; Griggs et al., 2017).

Technical considerations

Data characteristics

Sea level measurements came from federally operated tide gages located along the California coast which are managed by the National Water Level Observation Network, within NOAA, as well as from satellite altimetry operated by NASA. Data are available online at NOAA's Tides and Currents webpage and NASA's sea level webpage.

Tide stations measure sea level relative to specific locations on land where the gauges are mounted. Short-term changes in sea level (e.g., monthly mean sea level or yearly mean sea level) are determined relative to a location's Mean Sea Level, the arithmetic mean of hourly heights observed over a specific 19-year period called the "National Tidal Datum Epoch" (NTDE) established by NOAA's National Ocean Service. The NTDE accounts for the effect of the 18.6-year lunar nodal cycle on variations in the tidal range. The current NTDE is 1983-2001 (previous NTDEs were for the periods 1924-1942, 1941-1959, and 1960-1978); NTDEs are updated about every 20 years (NOAA, 2000; Szabados, 2008). This epoch is now undergoing revision and will be replaced by the fifth iteration of the NTDE, spanning the years 2002-2020. The proposed release date for new NTDE products is after 2027.

The U.S. federal government began collecting sea level measurements in the mid-19th century to support accurate navigation and marine boundary determinations. Data from these early observation efforts, along with continued monitoring, are used to assess

long-term changes in sea level at multiple locations in California. Monitoring efforts have expanded over the years to include more locations with tidal stations, allowing for analysis of sea level trends at more regions, although for shorter time scales (NOAA, 2006).

Strengths and limitations of the data

Monthly mean sea levels along the California Coast tend to be highest in the fall when the ocean temperatures are warmest and lowest in the spring, when the waters are coolest, with seasonal differences of approximately 6 inches (15 centimeters (cm)). Local warming or cooling driven by offshore shifts in water masses and changes in wind-driven coastal circulation patterns also seasonally alter the average sea level by 8.4 inches (21 cm; Flick, 1998). For day-to-day activities, the tidal range and elevations of the high and low tides are often far more important than the elevation of mean sea level.

As noted above, vertical land motion complicates regional estimates of sea level rise. Much of the California coast is experiencing elevation changes due to tectonic activity and glacial isostatic adjustment. Mean sea level is measured at tide gauges with respect to a tide gauge benchmark on land, which traditionally was assumed to be stable. This only allows local changes to be observed relative to that benchmark. Additional data from global positioning systems (GPS) are useful to record vertical land movement at the tide gauge benchmark sites to correct for tectonic activity. Satellite altimetry has been used since the 1990s to track sea level rise at the global scale with uniform coverage and provide an additional check on sea level rise rates derived from tide gauges alone (Abdalla et al., 2021; NOAA, 2020).

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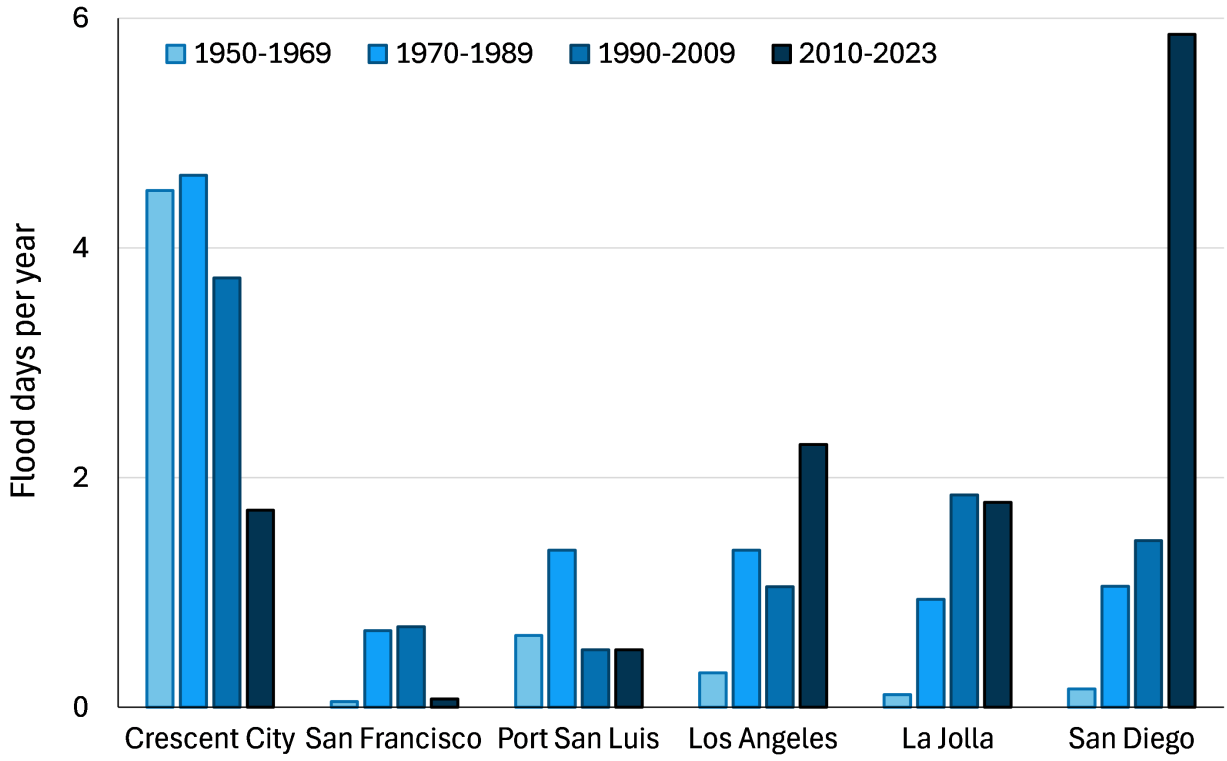
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3.5 Coastal Flooding

Coastal flooding has become more frequent in multiple parts of the California coast in recent decades due to the rise in sea levels and the episodic occurrence of extreme storm events. Trends are expected to worsen. On the far north coast, where the land surface has risen due to the movement of the Earth's tectonic plates, there has been a small relative decline in sea level and a decrease in flooding frequency over time.

Figure 3.5.1. Average Number of Coastal Flood Events Per Year.



The average number of days per year in which coastal waters exceeded a local threshold for flooding at six sites along the California coast. While sea levels are rising along most of the coast, land uplift on parts of the north coast—such as at Crescent City—is outpacing sea level rise, resulting in reduced average days of coastal flooding.

Source: US EPA (2025)

What does the indicator show?

This indicator is a proxy for coastal flooding. A *flood day* is defined as any day when coastal water levels exceed a location-specific threshold, which is a water level

established for each tide gauge that corresponds to the onset of minor coastal flooding based on local conditions.

Coastal flooding is classified as minor, moderate, or major based on the potential severity of impacts. All location-specific thresholds used for this indicator correspond to minor coastal flooding and were developed by NOAA (**Table 3.5.1**; also see Sweet et al., 2018).

Table 3.5.1. Local Minor Flood Thresholds.

Location	Minor flood threshold (m)
Crescent City	0.58
North Spit	0.58
Point Reyes	0.57
Alameda	0.58
San Francisco	0.57
Monterey	0.57
Port San Luis	0.57
Santa Monica	0.57
Los Angeles	0.57
La Jolla	0.57
San Diego	0.57

The table shows minor flood thresholds for stations along the California coast in meters (m) above mean higher high water (MHHW), i.e., the average daily highest tide.

NOAA defines minor coastal floods as water levels approximately 0.5 m above the multi-year average of the daily highest water levels. These floods are expected to cause little to no property damage but create public inconvenience, often referred to as "nuisance flooding", and mostly affect low-lying and exposed assets or infrastructure, such as roads, harbors, beaches, public storm-, waste- and fresh-water systems and private and commercial properties (Sweet et al., 2018). Moderate and major floods (approximately 0.8 m and 1.2 m above the multi-year average of the daily highest water levels) are historically uncommon along California's coast but are expected to occur more often as sea level rise accelerates (see the *Sea Level Rise* chapter for metrics tracking increasing sea levels along California's coast). Overall, the indicator shows that

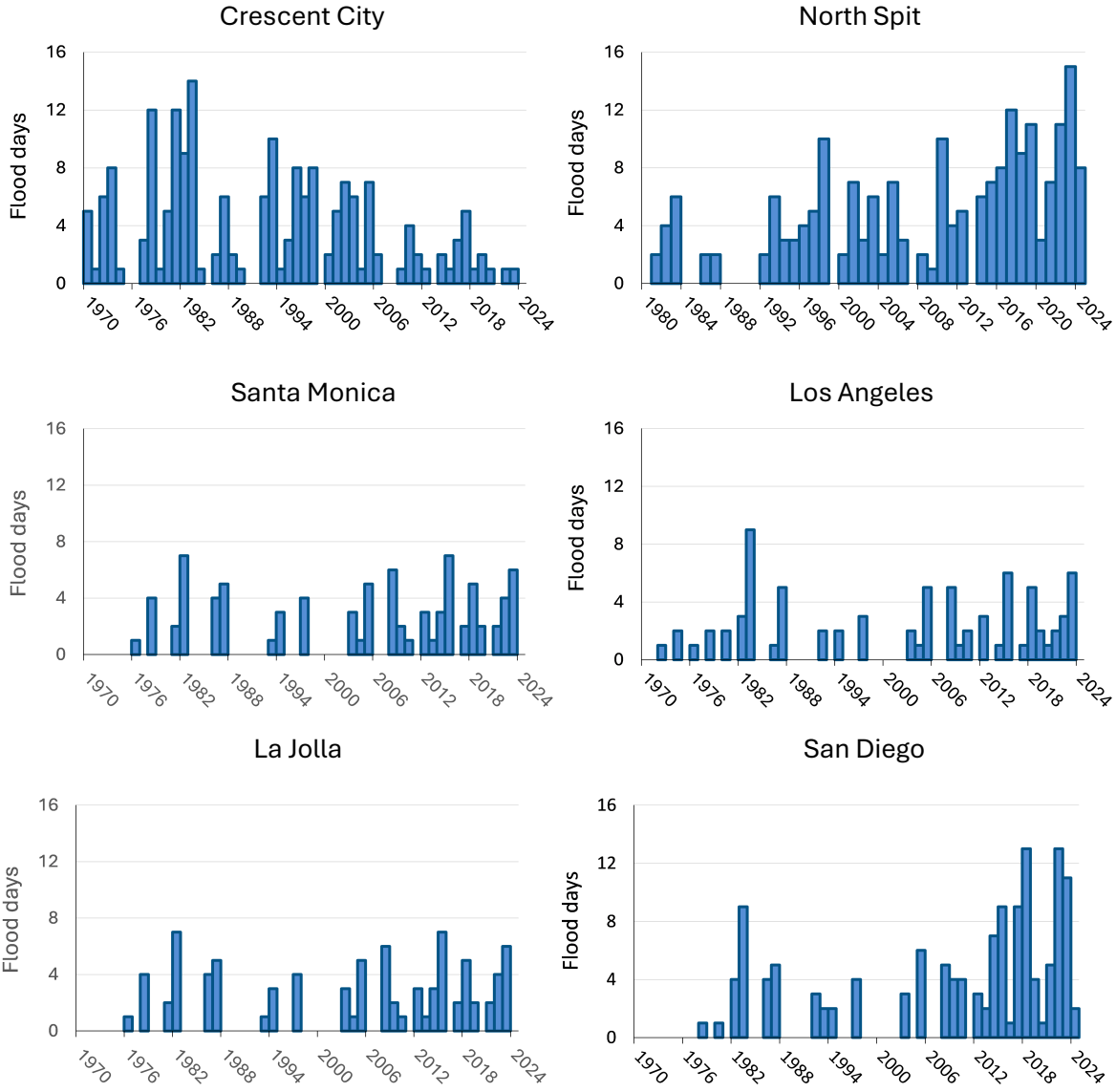
flood days occur more frequently at multiple stations along the California coast compared to previous years.

Figure 3.5.1 shows twenty-year averages of annual flood days since 1950 for selected stations where complete data for each period are available (except for the 2010–2023 period where only 14 years are available). Los Angeles and San Diego have experienced more frequent flood days in the more recent and shorter time period (2010–2023). Accelerating sea level rise and other factors that likely contribute to this trend are discussed below in “What factors influence this indicator?”.

Figure 3.5.2 presents time series data of annual flood days for selected stations along the California coast that were part of a larger NOAA analysis of past, present, and future impacts of floods along U.S. coasts, using data going back to the 1970s.

Flood days are increasing at North Spit at Humboldt Bay in Northern California, as well as Santa Monica, Los Angeles, La Jolla, and San Diego in Southern California. No long-term trend is observed for stations in the Bay Area (Point Reyes, Alameda, San Francisco). Parts of the north coast (e.g., Crescent City) are experiencing significant land uplift, exceeding sea level rise and resulting in fewer coastal flood days.

Figure 3.5.2. Number of Minor Flood Days.



The following graphs show the number of days per year in which coastal waters exceeded a local flooding threshold at multiple stations along the coast.

Source: USGCRP (2025). These data, curated and processed by the US Interagency Taskforce on Sea Level Change (2024), were obtained from the National Sea Level Explorer.

Why is this indicator important?

Recurrent coastal flooding can cause significant impacts, including:

- Property damage to both public infrastructure and private development;
- Frequent transportation disruptions, including road and rail corridor closures;
- Reduced stormwater drainage capacity;
- Limitations or reduction in coastal access; and
- Deterioration of habitat and infrastructure not designed to withstand frequent inundation or exposure to saltwater.

These impacts are of particular concern because close to 70% of Californians live near the coast, with millions more who visit each year, and $250 billion of property is at risk of flooding this century (Barnard et al., 2019; California Sea Level Rise Guidance, 2024).

Critical infrastructure in many locations lies less than 4 feet above the high tide, including two international airports – Oakland and San Francisco – and approximately 172,000 homes (DWR, 2016). International airports at San Diego and San Jose are also low lying. Rising sea levels place these airports at greater risk of floods (Griggs, 2020). Loss of service at either airport would result in major economic consequences regionally, nationally, and internationally (San Francisco Bay Conservation and Development Commission, 2012). Other critical infrastructure will also become more vulnerable to storms and flooding (Caldwell et al., 2013; CEC, 2017; Hummel et al., 2018), such as:

- Ports and harbors;
- Natural gas lines, water, electric, fiber optic and sewer lines; and
- Wastewater treatment plants and their outfalls

Extreme coastal flooding once projected for the future is already here, impacting California's coastal cities and counties. Repeated storms over the past three winters have damaged infrastructure, homes, businesses, and vital community resources—causing an estimated $4.7 billion in losses between December 2022 and March 2023 alone (NOAA, 2025a; also see the *Precipitation* chapter). The growing intensity and

frequency of these storms, and the scale of their social and economic impacts, underscore the urgent need to strengthen and accelerate coastal management strategies (Griggs and Davar, 2025).

On January 5, 2023, for example, a major coastal flood event occurred along the northern Monterey Bay coastline, where offshore wave heights reached 28 feet coinciding with seven foot high tides and strong onshore winds (California Sea Level Rise Guidance, 2024). The event caused severe bluff erosion along West Cliff Drive in Santa Cruz, destruction of the historic wooden pier at Seacliff State Beach, flooding of coastal streets and roads in Capitola and Rio del Mar (**Figure 3.5.3**), and damage to both private development and public infrastructure along the northern Monterey Bay shoreline.

In early January 2026, communities along California's coast and around San Francisco Bay experienced exceptionally high tides known as "King Tides", which are the regularly occurring highest tides of the year. When King Tides coincide with floods or storms, water levels can rise higher, potentially causing significant damage to the coastline and coastal property. Some of the King Tide levels in early January were among the highest seen in decades, leading to flooding in streets, parks, and public spaces. Although King Tides themselves are not related to climate change, the kinds of flooding seen during King Tides are an excellent indicator of what more frequent high tide flooding will look like as sea levels continue to rise in the coming decades. Flooding that historically occurred only few times per century could become an annual or even daily occurrence in some communities by mid-century if coastlines are not prepared (CCC, 2025; OPC, 2026; Taherkhani et al., 2020; Thompson et al., 2021).

Figure 3.5.3. Flooding of the Esplanade Parking Area at Rio Del Mar in January 2024.



Coastal flooding can also impact human health by increasing the risk of wastewater infrastructure failures, potentially exposing people to pathogens and harmful chemicals. Many sites that use, store, or emit hazardous substances—including power plants, refineries, industrial facilities, former military sites, dry cleaners and service stations - are additionally located along California's coast (Lasky et al., 2026). Flooding at these sites can result in both intentional and unintentional releases of hazardous materials, exposing surrounding communities due to damaged infrastructure, power outages that disable monitoring and control systems, and impediments to operator access that limit the ability to safely operate, shut down, or respond to emergencies (Radke et al., 2016; Young et al., 2004). For example, flooding from Hurricane Harvey in Houston in 2017 resulted in widespread boil-water notices, millions of pounds of excess air pollutant

emissions, and an explosion and controlled burn at a chemical plant necessitating resident evacuations (Berberian et al., 2024; Cardinal and Xie, 2018; CSB, 2018).

In California, over 400 hazardous coastal sites are projected to face increased risk of coastal flooding by 2100 due to sea level rise under a scenario of continued high greenhouse gas emissions, more than all other U.S. states except Louisiana, Florida, New Jersey, and Texas (Cushing et al., 2023). San Francisco Bay alone is surrounded by over 5,000 sites with buried contaminants, including active and closed landfills, as well as “brownfields” that are undergoing or require cleanup, all of which are at risk from surface and groundwater flooding. Sea level rise poses risks for such facilities, which can experience flooding events that potentially expose nearby residents to hazardous substances (Hill et al., 2023). Rising seas will result in shallower coastal groundwater, leading to emergent groundwater (when groundwater rises to or above the surface of the ground) in some areas. Across California, shallow and emerging groundwater is expected to impact ~480 billion in property with 1 m of SLR, 6 times more than high tide overland flooding (Befus et al., 2020; Lasky et al., 2026; Wood et al., 2020). Coastal floods and elevated groundwater levels driven by sea level rise can interact, compounding flood impacts and risks to coastal communities (Rahimi et al., 2020).

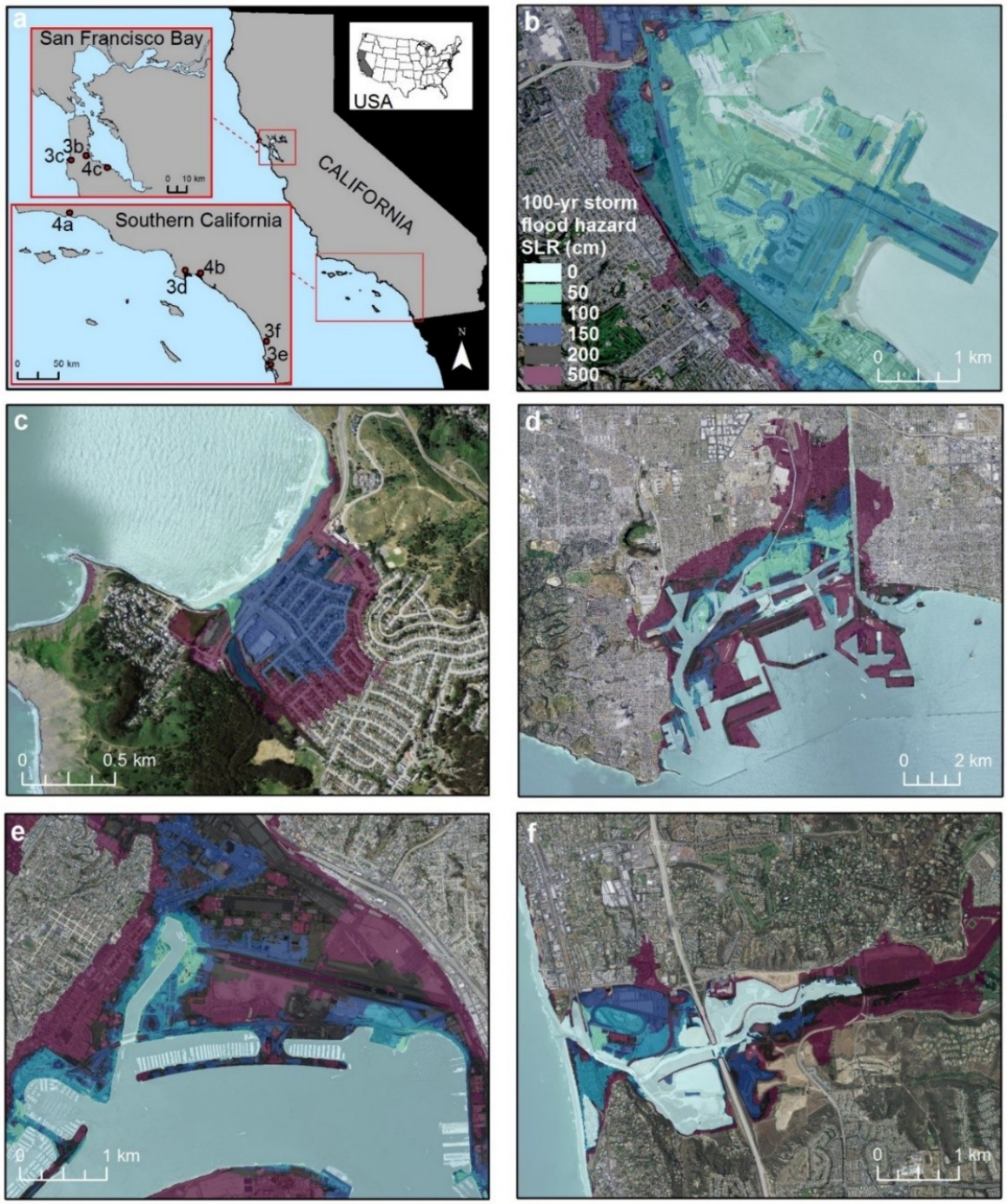
Coastal flooding can also occur alongside other types of floods (such as heavy rainfall), to create a larger and more impactful compound flood event. This amplified flooding can lead to longer flood durations, wider geographic areas affected, and greater risks to people and property (Green et al., 2025; Wang et al., 2025). As sea level rise accelerates, and coincides with other climate change occurrences (e.g., frequent periods of heavier rainfall), more frequent and severe compound flooding events may emerge as one of the most noticeable and damaging impacts of climate change in California.

Climate-driven coastal hazards can amplify social inequities**.** In California, low-income communities are often located in areas with aging infrastructure and limited drainage capacity, which increases their vulnerability to coastal flooding and its impacts (Rahimi et al., 2020). Flood-related hazards disproportionately affect communities that are least able to prepare for or recover from disasters. For example, hazardous facilities at risk of

flooding are disproportionately located in low-income communities and communities of color (Cushing et al., 2023; Hill et al., 2023). Disadvantaged communities are over five times more likely to be located within 1 kilometer (km) of one or more hazardous facilities at risk of flooding by 2050, and over six times as likely by 2100 (Cushing et al., 2023). Compared to higher-income communities and property owners, people with lower incomes and residents of rental units face disproportionately greater impacts from coastal floods (CCC, 2015; LAO, 2020). They are more likely to be displaced by flooding or related impacts because they cannot relocate, rebuild or are less able to prepare their residences for floods; face barriers to evacuation that reduce control over safety; and lack adequate resources and insurance to replace lost or damaged property. Using a dynamic model (the Coastal Storm Modeling System or CoSMoS) that incorporates the effects of coastal storms in addition to estimates of sea level rise, projected areas of coastal flooding could impact over 600,000 people and $200 billion in property statewide over the next century (**Figure 3.5.4**; Barnard et al., 2019).

Low-lying coastal areas are important to many California tribes such as the Wiyot, Yurok, and Amah Mutsun Tribal Band. Flooding can damage or erase sacred sites, traditional gathering areas, and fishing grounds that are integral to Tribal identity and practices.

Figure 3.5.4. Projected Overland Flood Exposure in Select Locations.



Projected overland flood exposure over the next century based on results from the Coastal Storm Modeling System (CoSMoS: Barnard et al., 2019). (a) Study locations in the San Francisco Bay Area and Southern California; (b) San Francisco International Airport, point 3b on

the map in panel A, legend showing 0, 0.50, 1.00, 1.50, 2.00, and 5.00 meters of SLR; (c) City of Pacifica, point 3c on panel A's map; (d) Port of Los Angeles and Port of Long Beach, point 3d on panel A's map; (e) Port of San Diego and San Diego International Airport, point 3e on panel A's map; and (f) City of Del Mar, point 3f on panel A's map.

*Figure generated using ArcGIS v. 10.4.2, by Esri. Local base maps from ArcGIS Online, World_Terrain_Base, and ESRI_Imagery_World_2D, accessed 2 Oct 2018. Projections can be viewed interactively and translated into socioeconomic exposure.

Source: Barnard et al. (2019).

What factors influence this indicator?

Coastal flooding is becoming increasingly common due to sea level rise, changing storm patterns, sinking land, and the loss of natural coastal barriers (Henny and Kim, 2025). Human influence on the climate was very likely the main driver of global sea level rise since at least 1971 (IPCC, 2023), and the current rate of global sea level rise is three times higher than the 20th century rate (May et al., 2023). Sea level rise rates vary by location but are generally rising along the California coast (see the *Sea Level Rise* chapter). During very high tides, like King tides, higher sea levels can cause a larger land area to be flooded to greater depths, amplifying impacts (NOAA, 2025b).

Along with global sea level rise, storm surges (short-term rises in sea levels due to prevailing onshore winds and low atmospheric pressure), wave runup (the rise in coastal water levels as waves break and rush up the beach), astronomical tides (the regular rise and fall of the sea surface in response to the gravitational pull of the moon and sun on the ocean), and El Niño events and seasonal variations (California Sea Level Rise Guidance, 2024) all contribute to coastal water levels in California. Storm events caused by atmospheric rivers (long corridors of atmospheric moisture that are common in California) are becoming stronger and happening more often (Henny and Kim, 2025).

Damage observed along California's shoreline over recent decades is due to higher sea levels, and the co-occurrence of high tides along with storm surge and very large waves, which are gradually becoming larger and more energetic in certain locations (Griggs, 2025). They are expected to intensify in the coming decades (California Sea Level Rise Guidance, 2024). Short-term increases coastal water levels during storms

will likely result in the greatest damages to infrastructure and coastal development along the coast of California over the next several decades (Barnard et al., 2019; Griggs et al., 2017; Griggs, 2025). In addition, as sea levels rise, many coastal sites will experience more frequent and widespread flooding during high tides and storms. Sea level rise is raising coastal water levels and driving shoreline further inland, closing the gap between the ocean and coastal infrastructure (coastal squeeze), meaning that more typical, less extreme tides and storms may cause flooding, and that flooding will likely become more widespread, deeper, and more severe over time (USGCRP, 2025).

Technical considerations

Data characteristics

The coastal flooding indicator is based on water level measurements from NOAA tide gauges, which record sea level relative to the land surface. As a result, the indicator reflects both changes in flood frequency occurring from changes in ocean water levels and local land level motion, providing a measure of relative sea level rise rather than absolute sea surface height.

Flood days are defined as days when observed water levels exceed location-specific flood thresholds established by NOAA National Weather Service in coordination with local emergency managers. These thresholds are designed to signal the onset of minor coastal flooding and trigger public notification of impending flood risks.

The data for **Figure 3.5.1** were downloaded from the Climate Change Indicators in the United States website (US EPA, 2025). The data set for **Figure 3.5.2** was downloaded from the National Sea Level Explorer (USGCRP, 2025). Local flood thresholds for each station in **Figure 3.5.1** and **Figure 3.5.2** are presented in **Table 3.5.1** above.

The number of flood days reported for each station reflects observed exceedances of local thresholds and is used to characterize changes in the frequency of coastal flooding over time at each location.

Strengths and limitations of the data

The methodology to calculate flood thresholds used to determine flood days is useful because it enables scientists to calculate a flood threshold for any location along the coast, provided sufficient years of data have been collected. However, these flood

thresholds are a proxy for flooding, and do not necessarily correspond to a specific level of observed disruption or damage. Every location is unique in terms of land cover, topography, locations of roads and other infrastructure (how close they are to sea level), and the presence of flood defenses such as seawalls or levees. As a result of these differences, flooding that reaches the threshold in one location might only cause a minor inconvenience for a small population, while waters that reach the threshold in another city may flood large sections of a low-lying downtown area. For this reason, when considering the impacts of flooding, it is more useful to compare changes over time at a single location than it is to compare patterns across different locations (US EPA, 2025). In addition, shifts in the frequency of rare but damaging extreme floods may be masked.

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California Ocean Protection Council

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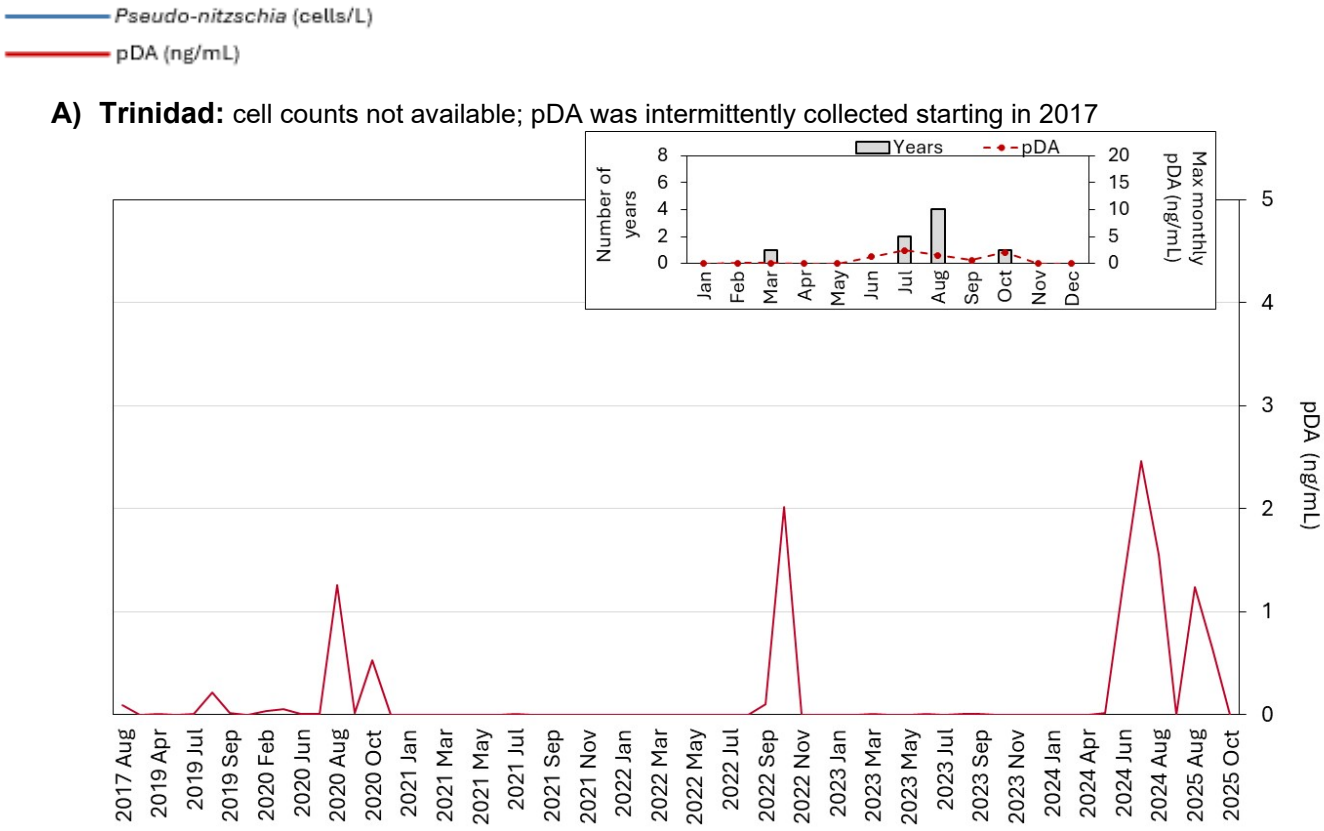
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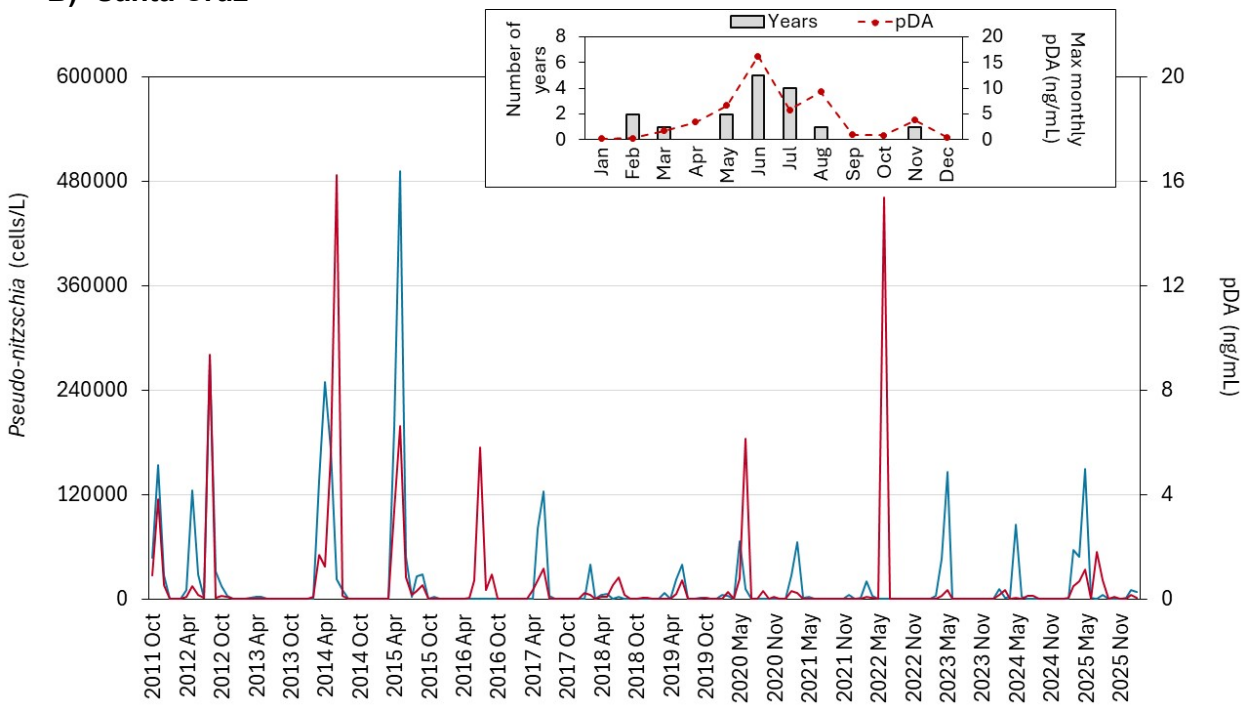
3.6 Marine Harmful Algal Blooms

Marine harmful algal blooms (HABs) are influenced by warming ocean temperatures. They can produce marine biotoxins, such as domoic acid (DA) and paralytic shellfish toxins (PSTs), or otherwise disrupt marine ecosystems. *Pseudo-nitzschia* spp., a diatom which can produce DA, has been of particular concern due to its impacts on marine wildlife, public health, and fisheries (recreational and commercial) in California. Tracking marine HABs along the California coast has become increasingly important as climate change continues to alter the conditions that affect HAB growth and toxicity, and as marine HAB-associated illnesses among marine mammals and birds in southern California have become more prevalent in recent years.

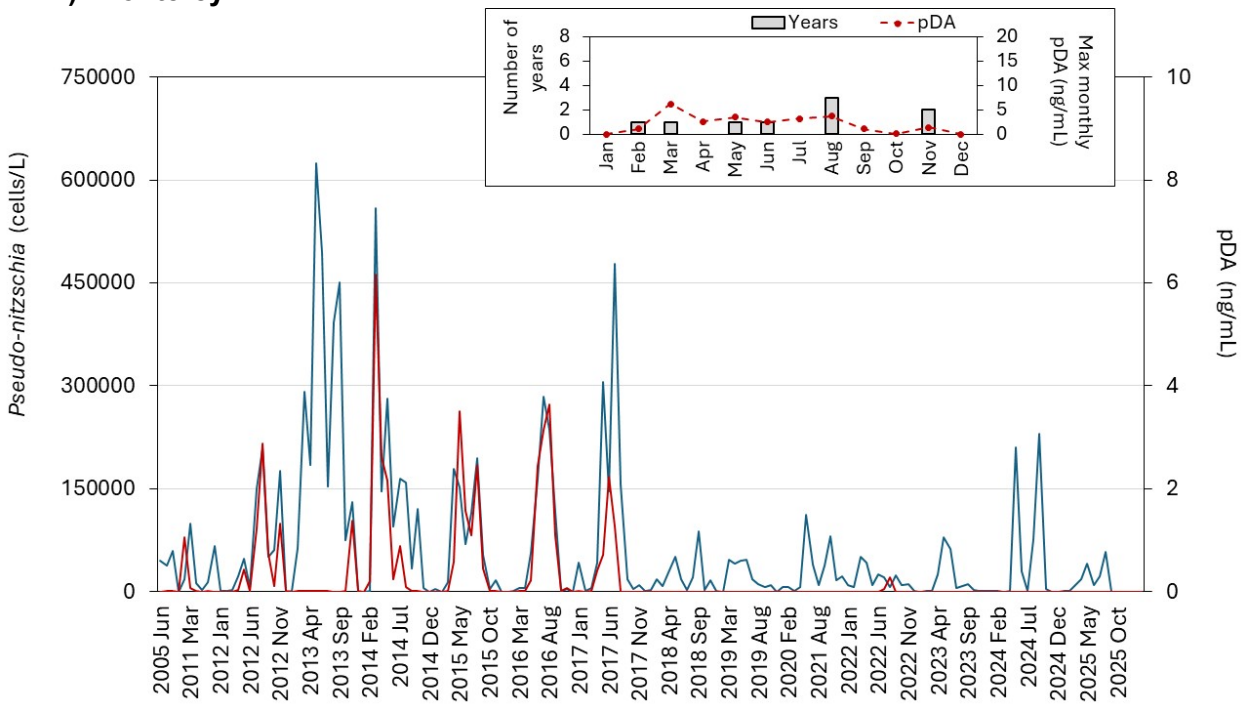
Figure 3.6.1. *Pseudo-nitzschia* seriata Size Class and Particulate Domoic Acid (pDA) Levels at Selected Stations.



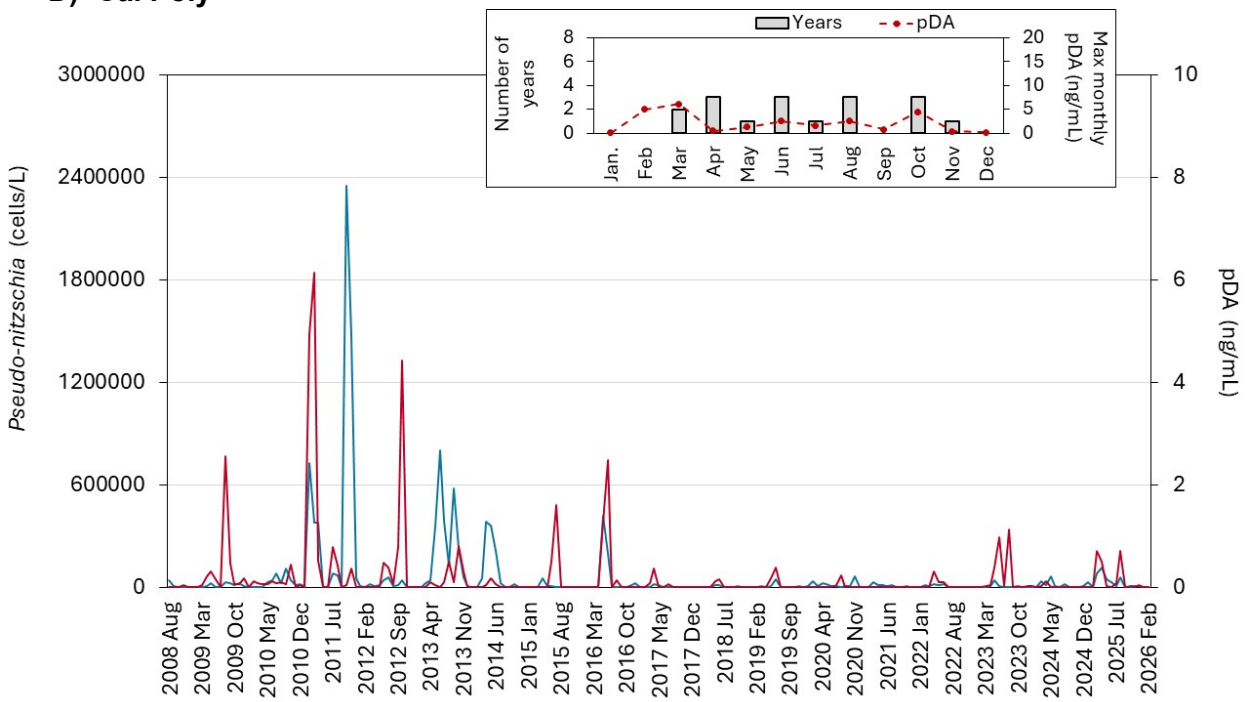
B) Santa Cruz



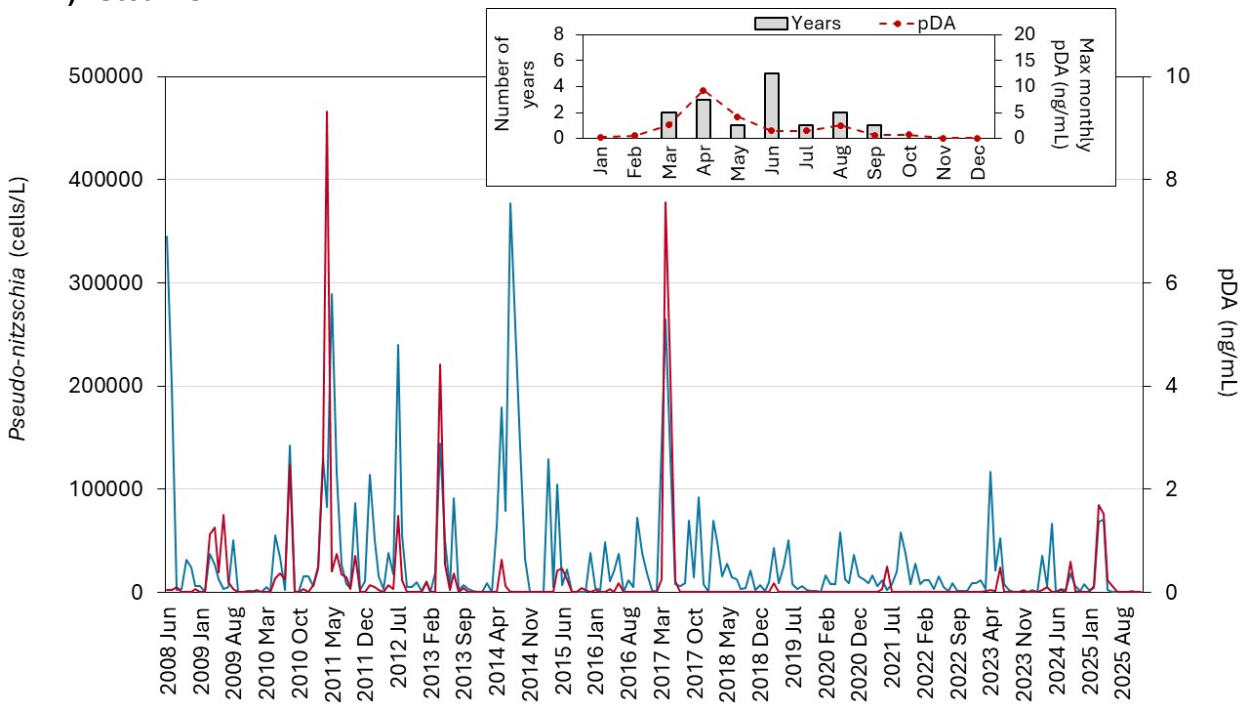
C) Monterey



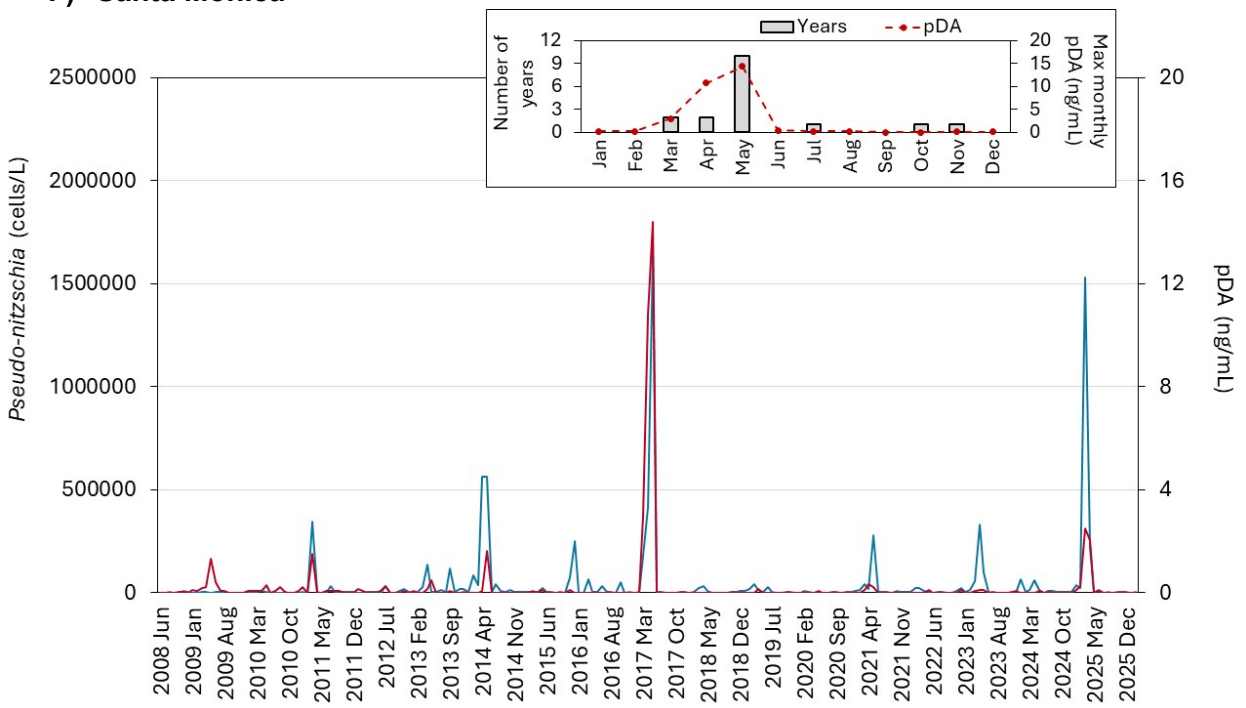
D) Cal Poly



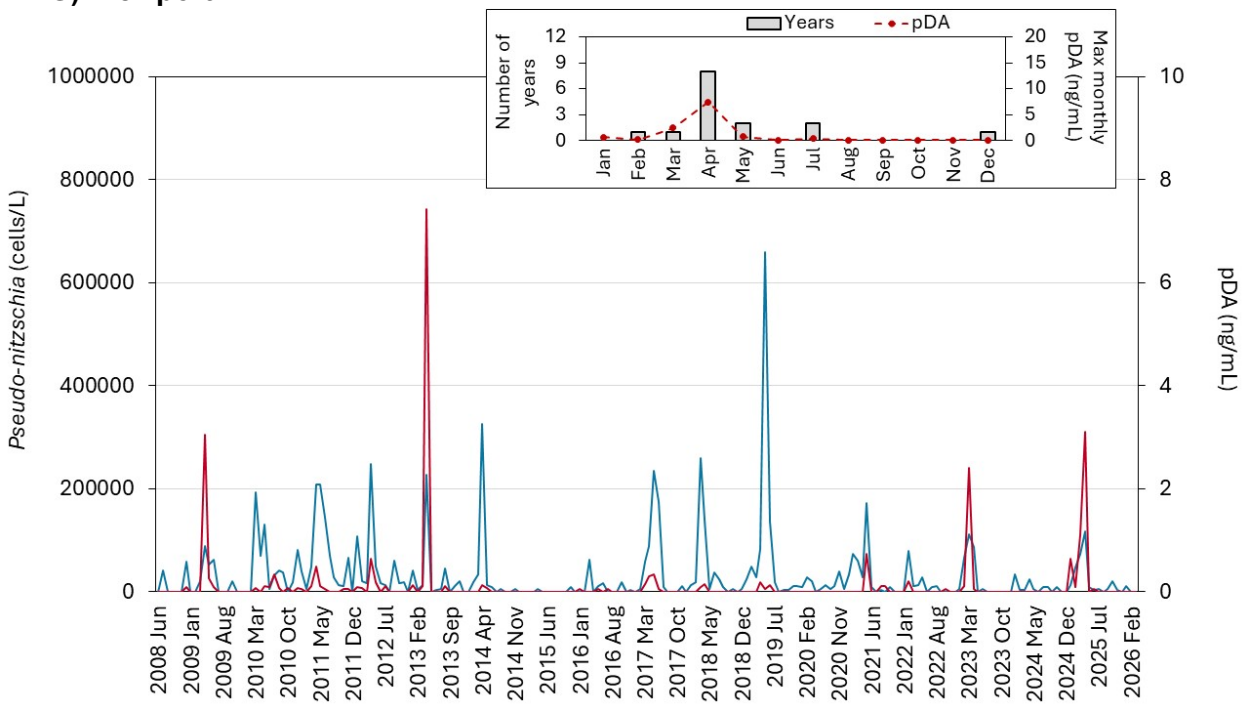
E) Stearns



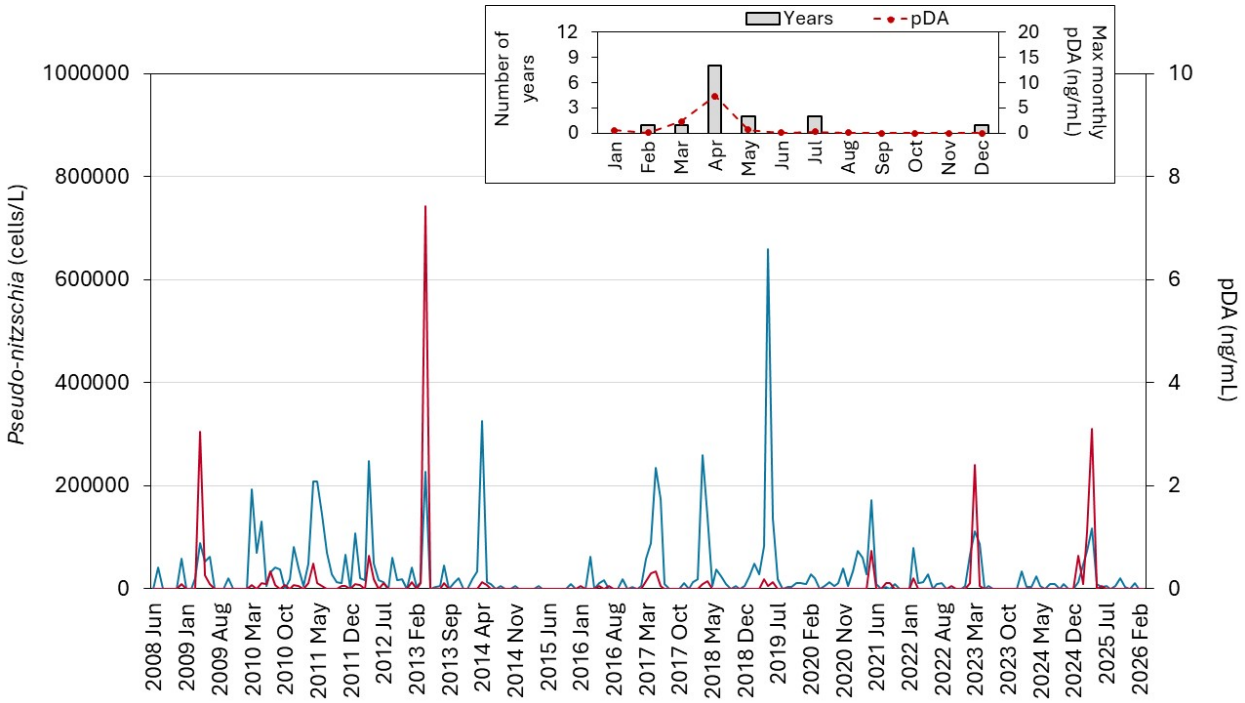
F) Santa Monica



G) Newport



H) Scripps



I) Map of stations



The graphs show time series of monthly maximum abundance of Pseudo-nitzschia seriata size class (cells/L, blue line) and particulate domoic acid (pDA, nanogram per milliliter (ng/mL), red line) concentrations at selected Harmful Algal Bloom Monitoring and Alert Program (HABMAP) stations in California, north to south. Grab water samples were filtered and the domoic acid concentration (in ng/mL) of all material collected on the filter was analyzed for pDA. The eight graphs on the right display the overall maximum pDA by month (across all years, line) and the number of years in which the annual maximum pDA occurred that month (count, column). Source: Analysis by Stanton (2026) using data from the HABMAP obtained from NOAA's Environmental Research Division's Data Access Program (ERDDAP). Map from SCCOOS (2026)

What does the indicator show?

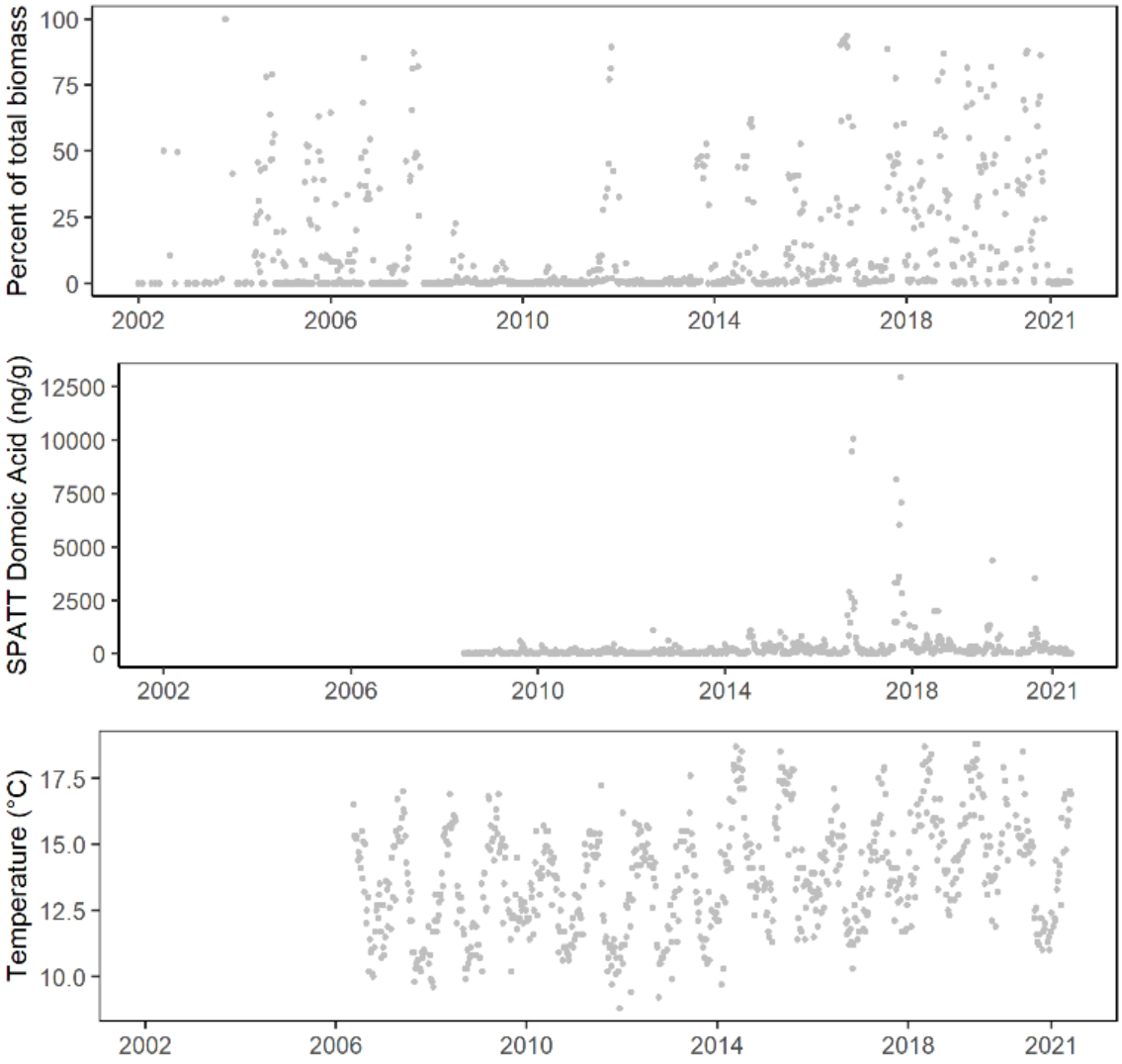
Marine HABs have increased in frequency and geographic range worldwide since the 1980s due to ocean warming, marine heatwaves, and oxygen loss in coastal waters—factors that climate change is already influencing along the coast of California (IPCC, 2019; see the *Coastal Ocean Temperature* and *Dissolved Oxygen in Coastal Waters* chapters). Marine HABs commonly consist of an overgrowth of algae (diatoms or dinoflagellates) that may produce biotoxins and can result in adverse wildlife and human health effects, ecological disasters, and significant economic losses (Anderson et al., 2021; Sakamoto et al., 2021; Yu et al., 2023). Monitoring marine HABs along the California coast is increasingly important as climate change continues to alter the ocean conditions that promote marine HABs and may influence Pseudo-nitzschia cell growth and/or production of DA (Anderson et al., 2026; Sandoval-Belmar et al., 2023). These data document the repeated occurrence of DA-producing *Pseudo-nitzschia* HAB events at multiple sites along the California coastline in recent years, an overall pattern that is expected to continue, although the geographic distribution and seasonality are expected to shift (Saha et al., 2026).

Marine HAB dynamics along the California coastline have regional and site-specific variability, as exemplified by the time-series of monthly maximum cell counts for the *Pseudo-nitzschia* seriata size class cells and pDA concentrations from HABMAP sampling sites (**Figure 3.6.1**). **Figure 3.6.1** (inset) also shows overall maximum pDA by month and the number of years in which the annual maximum pDA occurred in each month. The seasonality of monthly maximum pDA across all years and the frequency of maximum pDA in a given month generally coincided. However, there were examples where the maximum pDA occurred in an atypical month, particularly earlier in the year, and was the highest overall concentration across all years. For example, at Cal Poly Pier, the monthly maximum pDA most frequently occurred (three years each) in April, June, August, and October; however, the monthly maximum pDA concentrations across all years was in March, primarily because of the high pDA in March 2011 (6.14 ng/mL). Both *Pseudo-nitzschia* seriata size class cell counts and pDA concentrations were typically lowest in winter (December-February) and higher in spring (March to May) with some HAB events occurring during summer and fall. Overall maximum pDA

concentrations were lower (below 3 ng/mL) at the sites furthest north (Trinidad; note more limited data) and south (Scripps Pier). Individual peaks in *Pseudo-nitzsc*hia seriata size class cell counts and pDA concentrations for each monitoring site were generally concurrent, but there were some exceptions. For example, a large *Pseudo-nitzschia* seriata bloom event occurred at Cal Poly Pier in October 2011 without a corresponding peak in pDA concentrations; conversely, in October 2012 a relatively large spike in pDA concentrations was accompanied by comparatively low *Pseudo-nitzschia* seriata cell counts.

Figure 3.6.2 presents a time series for the relative abundance of specific dinoflagellate taxa, dissolved domoic acid (dDA), and sea surface temperature in Santa Cruz Wharf. Analyses indicated that both dinoflagellate abundance and dDA concentrations were positively correlated with temperature (not shown; Kudela pers. comm., 2021). These results indicate that with warming oceans, DA concentrations and dinoflagellate abundance will increase, particularly within Central and Northern California.

Figure 3.6.2. Santa Cruz Wharf



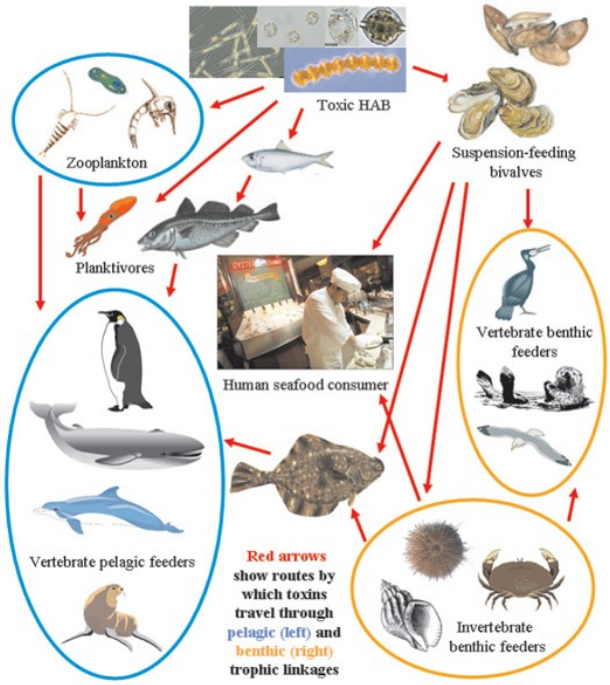
The figures show the relative abundance index of several “red tide” forming taxa combined (*Alexandrium*, *Cochlodinium*, and *Gymnodium/Akashiwo*) compared to overall total phytoplankton biomass (top panel), dDA concentrations in Solid Phase Adsorption Toxin Tracking (SPATT) (middle panel), and sea surface temperature (bottom panel) data over time at Santa Cruz Wharf. Source: HABMAP and Kudela, personal communication (2021)

Why is this indicator important?

Marine HABs can harm marine ecosystems by producing marine biotoxins (DA and PSTs) that move up the food chain, contaminating seafood and causing illness or death in human consumers, marine mammals, and seabirds (**Figure 3.6.3**). Additionally,

other marine dinoflagellate “red tides” can cause fish kills, deplete oxygen, reduce light penetration, and damage seabird feathers (Skelton et al., 2024).

Figure 3.6.3. How HAB Toxins Move Up the Food Chain.



Ingestion of DA–containing *Pseudo-nitzschia* cells leads to toxin buildup in mussels, oysters, clams, and planktivorous fish (sardines, anchovies, etc.). Other species may be exposed by eating contaminated prey or sediments. Anchovies are a dominant vector. While DA can harm marine mammals and seabirds, they typically do not cause die-offs in the vector invertebrate and finfish species themselves. Source: US National Office for Harmful Algal Blooms 2021

Consumption of DA–contaminated seafood can cause Amnesic Shellfish Poisoning in humans, with symptoms ranging from gastrointestinal illness to seizures, memory loss, and even death. Current FDA regulatory standards for DA in seafood may be insufficient to protect exposed individuals at all life stages (Campbell et al., 2024) and/or across different patterns of consumption (Grattan et al., 2016). To protect the public from acute DA toxicity, fishery actions are triggered when DA in seafood samples exceed regulatory limits, leading to significant economic losses and broader social impacts in coastal communities (Hunsicker et al., 2026). Recreational bivalve shellfish fishery impacts from marine biotoxins are typically greatest and recently increasing

(2010-2024) in northern California (Smith, 2026) where the recreational razor clam fishery is located, particularly because razor clams are very slow to remove DA from their tissues compared to other bivalves (e.g., mussels).

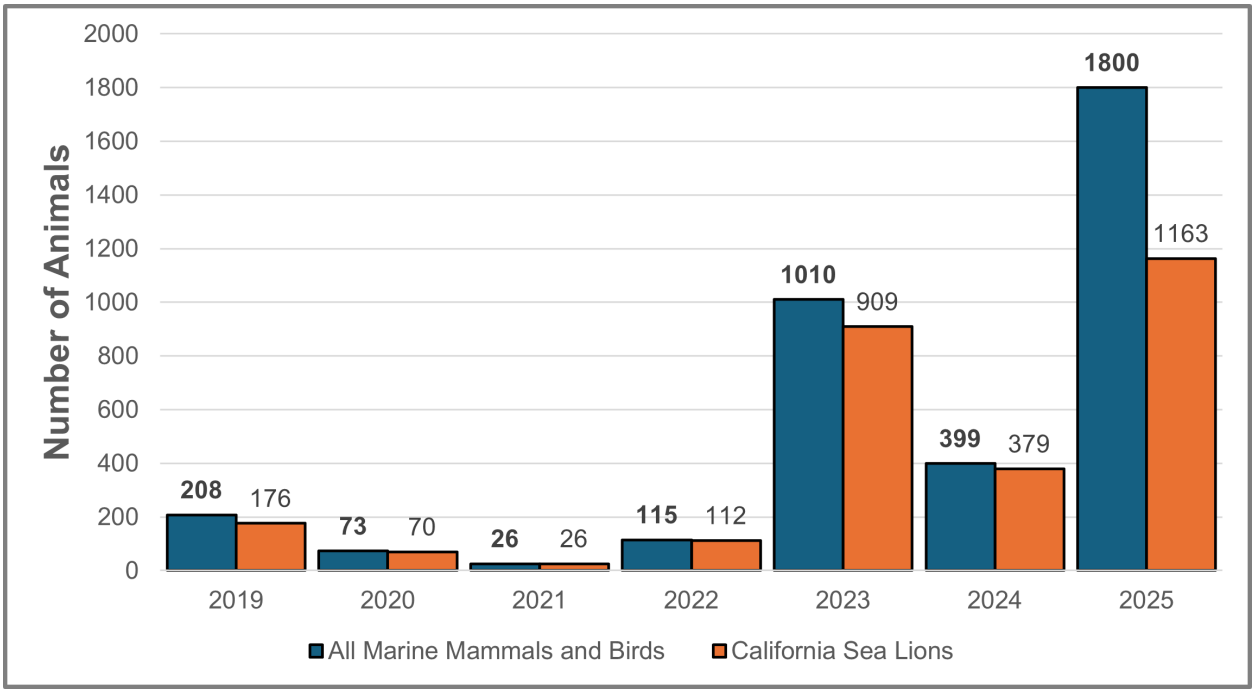
Tribal Connection 3.6.1

Missed catch opportunities due to HABs have far-reaching cultural impacts, beyond economics, on coastal tribes, including the Wiyot Tribe located around Humboldt Bay or *Wigi*. The Wiyot Tribe writes, "*Pseudo-nitzschia blooms off the coast of Wigi have had a particularly negative impact on the Dungeness crab and razor clam fisheries, both species that the Wiyot rely on for subsistence. [...]. Dungeness crab is fished commercially and recreationally in Humboldt County, and razor clams are fished recreationally. The Tribe has suffered cultural and economic losses as a result of missed catch and consumption opportunities of these and other species impacted by HABs. Razor clam consumption advisories or closures have been in place in Humboldt County over the majority of the past decade due to domoic acid. While there are more varied reasons for closures and restrictions in the Dungeness commercial and recreational fisheries, fishery-dependent communities around Wigi were shown to be particularly economically and socially vulnerable to the 2015-2016 domoic acid closure events (Moore et al., 2019)"* (Wiyot Tribe, 2026).

DA poisoning in California marine mammals has been documented since at least 1990, with increased occurrences observed after 1998 (Anderson et al., 2021; Scholin et al., 2000; Smith et al., 2023). Marine mammal strandings are most prominent in Southern California where the primary breeding colonies are located. From 2019-2020, reported California marine mammal and bird strandings related to DA have been tracked and submitted to CDC's One Health Harmful Algal Bloom System (OHHABS), with California sea lions representing the majority of strandings (**Figure 3.6.4**). A major DA event developed in the Southern California Bight in early spring 2025. This event was unique in that it began earlier in the year, coinciding with early-stage pregnancy in California sea lions, lasted more than three months, and included more dolphin and whale strandings. Concurrent PST detections were also observed in some areas. This was

also the fourth year in a row that a large marine mammal stranding event was associated with a DA event in Southern California, with all events linked to upwelling conditions (Hunsicker et al., 2026).

Figure 3.6.4. Marine HAB-associated Illnesses in Mammals and Birds.



The graph shows marine HAB-associated illnesses in all marine mammals and birds (blue bars) reported to OHHABS from 2019 – 2025. California sea lions (orange bars) are also shown as a subset of all marine mammals and birds reported annually. Source: OEHHA Marine HAB-Related Illness Tracking (2026)

PSTs are produced by dinoflagellates such as *Alexandrium*, *Gymnodinium*, and *Pyrodinium,* and can accumulate in seafood. *Alexandrium* is highly toxic and can produce unsafe levels of PSTs at even relatively low cell counts and with no visible indicators (CDPH, 2021). PST exposure can cause paralytic shellfish poisoning (PSP) illness symptoms in humans ranging from numbness and gastrointestinal illness to respiratory failure and death (Anderson et al., 2021). A major 1927 outbreak near San Francisco led to over 100 illnesses, including six deaths (Price et al., 1991), leading to the establishment of the first U.S. shellfish PST monitoring program. The last major PSP

outbreak in California occurred in July 1980 with 98 illnesses and two deaths. In August 1991, 11 non-fatal PSP illnesses, including three hospitalizations, were reported for persons who had eaten mussels they had collected in northern Sonoma County. In March 2018, one non-fatal PSP illness requiring hospitalization occurred in a patient who ate mussels collected in northern Marin County. In 2025-2026, five non-fatal probable PSP cases were reported (CDPH, 2026).

California also experiences “red tides” with visibly discolored water and high biomass of other marine dinoflagellates, such as *Akashiwo sanguinea*, often occurring in warm fall conditions. Although most visible “red tides” of marine dinoflagellates are “non-toxic” (Kudela et al., 2015), people exposed to marine HABs through water contact may experience irritation of the eyes, skin, or respiratory system, even when toxins are not present.

What factors influence this indicator?

Globally, shifts in marine HABs distribution, increased abundance, and increased toxicity of marine HABs have been associated with warming conditions (Bindoff et al., 2019), along with interrelated factors such as upwelling and nutrients. While warmer water conditions generally favor marine HABs, there are some exceptions, including an apparent upper maximum temperature for some endemic strains of *Pseudo-nitzschia* (Smith et al., 2018) and cooler, nutrient-enriched water from upwelling as a positive driver for *Pseudo-nitzschia* in Monterey Bay, the Santa Barbara Channel, and the San Pedro Channel (Sandoval-Belmar et al., 2023). In typical years, water temperatures in some areas of Southern California may exceed the 20°C threshold (Smith et al., 2018), consistent with lower *Pseudo-nitzschia* seriata size class cell counts and pDA concentrations observed at Scripps Pier, and greater impacts concentrated north of Los Angeles County such as those seen during the 2015-2016 marine heatwave (McCabe et al., 2016). Modeling analyses of HAB occurrence along the southern Oregon and California coast from 1995 to 2020 (Saha et al., 2026) similarly suggests that during the spring to summer months, pDA probability decreases south of 36°N latitude (approximate latitude of Santa Cruz) and increases north of 36°N latitude, and that probability also increases during fall and winter nearshore events mainly between 36-

42°N latitude, possibly due to shifting upwelling intensity. At Stearns Wharf (Santa Barbara) and Goleta Pier, *Pseudo-nitzschia* abundance and pDA concentrations were higher during upwelling versus non-upwelling periods, but because of high variability, these relationships were not significant for the offshore stations (Umhau et al., 2018).

Ocean circulation patterns, including the Pacific Decadal Oscillation (PDO), North Pacific Gyre Oscillation (NPGO), and the two phases of the El Niño Southern Oscillation (El Niño and La Niña), may also influence marine HABs, but the responses appear to vary by region along the California coastline. Over longer time periods, increased shellfish DA concentrations in Northern California correlate with El Niño and PDO (McKibben et al., 2017), while pDA concentrations in Southern California strongly correlate with La Niña episodes (Smith et al., 2018) and negative NPGO, but are not significantly affected by PDO (Sandoval-Belmar et al., 2023). Research near Cal Poly Pier in Central California found a significant relationship between PDO and phytoplankton composition, with diatoms and dinoflagellates as the dominant phytoplankton in the fall during negative and positive PDO phases, respectively (Barth et al., 2020). While these observations suggest that further increases in sea surface temperatures may limit DA events within Southern California to the fall and winter periods, the late winter/early spring onset 2025 event demonstrated significant impacts on marine animals. The forthcoming 2026-2027 El Niño may replicate conditions similar to the 2015-2016 DA event (NOAA, 2026) with potentially significant impacts to marine life and fisheries.

Nutrient inputs from natural upwelling events and anthropogenic sources (including urban runoff) play a role in marine HABs. In southern California, terrestrial nitrogen input enhanced coastal diatom production. Surface pDA along the coast increased on average by 25% with anthropogenic inputs (Sandoval-Belmar et al., 2026). Silicate and phosphorus limitations are consistently correlated with pDA (Smith et al., 2018). A change in the silica concentrations within upwelling waters of Southern California was associated with an increase in *Pseudo-nitzschia* bloom frequency (Bograd et al., 2015) and with the NPGO. Kudela et al. (2003) looked at the correlation between nutrient runoff and *Pseudo-nitzschia* bloom events in Monterey Bay and did not find a relationship between the two. Lane et al. (2009) developed several models for *Pseudo-*

nitzschia in Monterey Bay and identified that Pajaro River discharge was a key negative factor in the Fall-Winter model, meaning discharge resulted in fewer fall blooms. However, Kudela et al. (2008) suggests that urea may be a key variable in bloom events associated with runoff; higher urea concentrations at the Santa Cruz Wharf correlate with higher *Pseudo-nitzschia* abundance. Urea is not often measured in water quality samples, and the lack of these data may have limited previous studies in California from identifying a positive correlation between nutrient runoff and blooms.

Dinoflagellates respond differently to these factors and, at the event scale, dinoflagellate blooms are primarily driven by changes in the intensity and direction of local winds (Fischer et al., 2020). It is unclear whether long-term increases in temperature and upwelling intensity will favor or inhibit dinoflagellate blooms overall, particularly because inter-annual variability is the dominant pattern in this record (Fischer et al., 2020; Smith et al., 2018).

Technical considerations

Data characteristics

Phytoplankton and pDA data were obtained via the Environmental Research Division's Data Access Program (ERDDAP) in March 2026. SPATT dDA data for Santa Cruz was obtained from Dr. Kudela in 2021. Weekly phytoplankton samples are collected by the Harmful Algal Bloom Monitoring and Alert Program (HABMAP) at nine pier locations throughout California; seven of these stations have historical data. In addition to phytoplankton, water quality samples are taken to measure marine biotoxins, temperature, salinity, and nutrients. Surface water samples were taken from each station and a 100-mL water sample preserved to analyze phytoplankton abundance. To calculate the relative abundance index, the Utermöhl method was used to subset the sample and count phytoplankton under a dissecting microscope. Relative abundance was calculated by looking at the abundance of the general compared to the total phytoplankton population (Barth et al., 2020). The relative abundance is then reported as: (1) none; (2) rare, less than 1% (3) present, 1 to 9%; (4) common, 10 to 49%; and (5) abundant, greater than 50% (Radan, 2021).

Strengths and limitations of the data

The HABMAP nearshore station data included above are robust, collected at consistent intervals, and with similar methods since 2008, providing a valuable time series dataset for those areas that are publicly available. The limited publicly available pDA data for Trinidad Pier makes it difficult to analyze trends in that region. Furthermore, these nearshore, surface water data may not be representative of what is happening offshore or in deeper waters. Umhau et al. (2018) found that offshore stations often had higher DA concentrations than nearshore stations. These near-shore data do not always correspond with risk predictions by California-Harmful Algae Risk Mapping (C-HARM) that utilizes simulations of the physical circulation using a Regional Ocean Model System (ROMS) to predict water temperature, salinity, upwelling, advection. C-HARM output may be more closely correlated with marine mammals that strand along the coast due to DA toxicosis (Anderson et al., 2016).

As noted above, the *Pseudo-nitzschia* abundances are typically reported as two size classes (not individual species) due to the lack of microscopic species-specific identifiers. Future availability of rapid, low-cost genetic identification of *Pseudo-nitzschia* species may inform potential relationships between individual *Pseudo-nitzschia* species abundance and DA concentrations, and how these are impacted by changes in environmental conditions, such as temperature fluctuations and nutrient composition (Lema et al., 2019).

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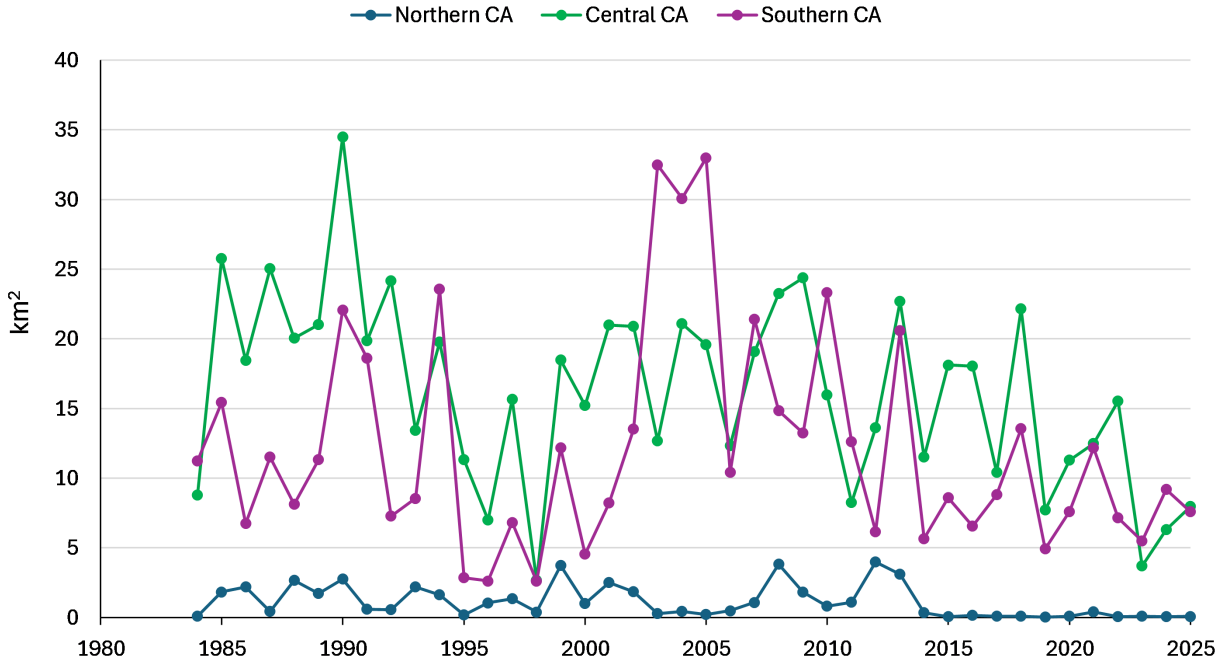
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3.7 Kelp Populations

Kelp provides ecosystem services including critical habitats for marine life and valuable fisheries that support coastal economies, shoreline protection, and carbon storage. While kelp forests naturally fluctuate in response to changing ocean conditions, kelp are known for being resilient. This changed during the unprecedented 2014-2016 marine heatwave, when unusually warm ocean conditions, sea star wasting disease, and a rapid expansion in sea urchin populations combined contributed to widespread kelp loss. Climate change is expected to increase the frequency and intensity of marine heatwaves, increasing the likelihood of these types of ecosystem disturbances. Northern California's bull kelp canopy area declined by 95% and has yet to recover.

Figure 3.7.1. Annual Maximum Kelp Area.



This figure shows the annual maximum area (km^2) covered by kelp for Northern, Central, and Southern California regions. Bull kelp was the dominant species in forests of the Northern region, while giant kelp dominates the Central and Southern regions. Source: Bell et al. (2026)

What does the indicator show?

Kelp is a large brown alga that grows in dense stands reaching the surface, creating kelp forests in cold, shallow coastal waters. Satellite imagery dating back to 1984 shows

variability but overall resilience in kelp canopy areas across the state prior to the unprecedented Northeast Pacific marine heatwave that began in 2014 and persisted through 2016. The heatwave coincided with and was further intensified by the 2015-2016 El Niño, resulting in prolonged periods of unusually warm ocean conditions (**Figure 3.7.1**; Bell et al., 2020; California Ocean Protection Council, 2021; Reed et al., 2011). The marine heatwave had variable effects on kelp in each of California's major geographic regions: Northern California (California/Oregon border to San Francisco Bay), Central California (San Francisco Bay to Point Conception), and Southern California (Point Conception to the California/Mexico border, including the Channel Islands) (see map of regions in **Figure 3.7.2**). Bull kelp is an annual species and the dominant kelp in Northern California. Northern California represents the southern extent of this species' range and is where the bull kelp forests experienced a greater than 95% loss in canopy from 2013 to 2014 (Rogers-Bennett and Catton, 2019; Bell et al., 2026). Giant kelp is a perennial species and the primary kelp species in Central and Southern California. These regions encompass the center and northern extent of the species' range. Giant kelp forests in central California have exhibited patchy declines prior to 2014, with low years in the late 1990's and again in recent years (2020-2025). The marine heatwave generally had minimal effects on giant kelp forests in Southern California. However, in recent years (2020-2025), giant kelp canopy areas have been below average, similar to cases observed in central California (Cavanaugh et al., 2019; California Ocean Protection Council, 2021).

Figure 3.7.2. Bull Kelp and Giant Kelp.



The photos show vibrant kelp forests along the coast of California: bull kelp on the left and giant kelp on the right. Kelp forests provide critical ecosystem services such as harboring endangered or commercially important species, sequestering carbon, preventing shoreline erosion, and oxygen production. Left photo by Chad King/Monterey Bay National Marine Sanctuary/NOAA; right photo by Velvetfish/istock

Why is this indicator important?

Kelp forests are among the most productive and biodiverse ecosystems on the planet. In combination with their proximity to the shore, the productivity and biodiversity of these ecosystems generate a wide range of ecosystem services including supporting (e.g., primary production, habitat), regulating (e.g., water flow, coastal erosion), provisioning (e.g., commercial and recreational fisheries), and cultural (e.g., recreational, artisanal) service (Malone et al., 2022). Kelp forests help mitigate ocean acidification by utilizing large amounts of dissolved carbon dioxide (CO_2) from seawater during photosynthesis, creating local, less-acidic refuge that protect shellfish and other marine life. Globally they are estimated to fix as much as twice the carbon fixed in Canada's boreal forests (Duarte et al., 2022).

Both giant kelp (*Macrocystis pyrifera*), which dominates in southern and central California, and bull kelp (*Nereocystis luetkeana*), which dominates in northern California, are foundation species that provide a variety of ecological functions. Kelp forests form complex three-dimensional habitats and host a diverse wide array of invertebrates, fishes, marine mammals, and birds. Kelp is an important food source for

herbivores and detritivores and underpins nearshore food webs (California Ocean Protection Council, 2021). Additionally, kelp plays an important role in coastal nutrient cycling, offshore provisioning of deep kelp falls (Britton-Simmons et al., 2009), and may help to mitigate ocean acidification at local scales (Steneck et al., 2002; Springer et al., 2010; Carr and Reed, 2016; Miller et al., 2018; Nielsen et al., 2018; Hirsh et al., 2020; Lamy et al., 2020) while having limited potential to buffer shorelines against waves during storms (Elsmore et al., 2024).

Declines in kelp populations are a key indicator of climate-driven changes affecting California's coastal marine ecosystems. Because kelp responds rapidly to changes in ocean temperature, nutrient availability, and marine heatwaves, long-term changes in kelp canopy reflect the cumulative effects of warming oceans and associated ecological disturbances, such as disease outbreaks and shifts in predator-prey interactions (see the *Coastal Ocean Temperatures* chapter for more information on nearshore warming along the coast). Other species also show the impacts of warming such as the nudibranch (a shell-less sea snail) found in California called *Phidiana hiltoni* that has expanded its range north along the California coast in response to warming ocean conditions (OEHHA, 2018). Population declines in other nudibranch species have occurred at Duxbury Reef, located north of San Francisco, where particularly high densities of *P. hiltoni* have been observed (Goddard et al., 2011). These declines appear to have resulted from *P. hiltoni* preying on other nudibranchs and competing for common prey species. The range shift of these predatory species may be disrupting food webs and altering community composition at sites along the California coast where its populations are dense.

Kelp is also critical to the well-being of California's coastal residents and the state's coastal economy. California's indigenous peoples, who have inhabited and stewarded the coast for millennia, continue to rely on kelp forest ecosystems for food, medicine, and ceremony. Kelp supports a variety of commercially and recreationally important fisheries, including recreational red abalone (*Haliotis rufescens*), commercial red sea urchin (*Mesocentrotus franciscanus*), and groundfish, including rockfishes (*Sebastes* spp.) (California Ocean Protection Council, 2021). Kelp is an important food source and habitat for many of these species. Following the decline of the bull kelp forest in

northern California, red abalone populations experienced widespread starvation and declines in abundance, contributing to the closure of California's recreational red abalone fishery in 2018, which had generated more than $44M USD for the local economy (Reid et al., 2016). Commercial red sea urchin divers were also similarly affected as urchins had reduced marketable roe production due to the loss of kelp food resources, resulting in federal disaster relief declarations.

What factors influence this indicator?

Factors such as ocean temperature, nutrient availability, pollution, disturbances from large waves, and grazing from sea urchins strongly influence kelp growth and persistence. Cool, nutrient-rich waters typically promote strong kelp recruitment and rapid growth, while warm, nutrient-poor conditions can reduce productivity and increase mortality (García–Reyes et al., 2022). Physical disturbances such as large waves and storms can remove kelp from the seafloor, and intense grazing by sea urchins can transform kelp forests into persistent "urchin barrens". The limited recovery of kelp across much of northern California has been linked to a widespread ecosystem transition toward urchin barrens (NOAA, 2020; Rogers-Bennett and Catton, 2019).

Between 2013 and 2014, more than 95% of bull kelp along northern California's coastline disappeared, accompanied by a surge in kelp-eating purple sea urchins (*Strongylocentrotus purpuratus)* and densities continue to remain high. Significant kelp declines also occurred along portions of the central and Southern California coast, including the Monterey Peninsula. Purple sea urchins proliferated in response to the loss of their natural predators, the sunflower sea star (*Pycnopodia helianthoides*), due to a sea star wasting disease (Gravem et al., 2021) linked to a bacterium (Prentice et al., 2025). Anomalously warm ocean temperatures were associated with greater morbidity of sunflower stars from this disease (Harvell et al., 2019) but the onset of the disease occurred prior to ocean warming.

At the same time, the 2014-2016 marine heatwave created unusually warm, nutrient-poor conditions (García-Reyes et al., 2014) that stressed kelp populations (McPherson et al., 2021; Rogers-Bennett and Catton, 2019). Together, the marine heatwave, sea star wasting disease, and increased sea urchin grazing shifted large areas of the

ecosystem from kelp forests to persistent sea urchin barrens, limiting recovery even after ocean temperatures moderated. Notably, kelp in marine protected areas (managed regions where fishing and other types of human disturbances are limited) off the California coast initially rebounded more quickly than other kelp after the 2014-2016 marine heatwave. This rebound effect was most pronounced in Southern California, likely because predators may have kept sea urchin populations in check, reducing grazing pressure on kelp. In Southern California, populations of grazing sea urchins may be regulated by predatory fish and California spiny lobster (*Panulirus interruptus*) that are rare elsewhere in California (Ortiz-Villa et al., 2025). In Central California, the southern sea otter (*Enhydra lutris*) is an important sea urchin predator (Smith et al. 2021) also not found elsewhere in California following the historic fur trade—sea otters have been absent from most of the Pacific Coast for more than 100 years, since their near extinction following the maritime fur trade in the 1700s and 1800s (US FWS, 2026).

Figure 3.7.3. Kelp Forest and an Urchin Barren in California.



The photo on the left shows a vibrant California kelp forest. The photo on the right shows an urchin barren caused by urchins overgrazing on kelp and consequently, converting the kelp

forests into sea urchin barrens. Credit: Left photo by Monterey Bay National Marine Sanctuary Foundation. Right photo by David Witting (NOAA). Source: SeaGrant California.

Technical considerations

Data characteristics

The proportional cover of emergent kelp canopy (i.e., the amount of kelp canopy that is directly floating at the surface of the ocean, hereafter referred to as kelp canopy area) was estimated with Landsat satellite imagery from 1984 to the present. Atmospherically corrected 30 meters (m) resolution multispectral imagery was used from five Landsat sensors: Landsat 4, Landsat 5, Landsat 7, Landsat 8, and Landsat 9.

Poor-quality observations, including cloud coverage, were identified and removed. For each month, enough imagery was collected so that each pixel in the study area was covered at least five times. Land areas were masked out using a digital elevation model produced by the USGS Coastal National Elevation Database.

Strengths and limitations of the data

Satellite imagery is a powerful tool for monitoring the distribution of canopy-forming kelps and studying the drivers that control their abundances. The Landsat data spans the period from 1984 to the present and covers multiple global regions including the majority of North America's west coast, Argentina, Southern Africa, and Peru, and is incrementally growing to cover kelp habitat worldwide (Bell et al., 2026).

Satellite imagery provides a valuable tool for monitoring the distribution of canopy-forming kelps and studying the drivers that control their abundances. Canopy-forming kelps are distinctive when viewed from above, particularly in the near infrared spectral region, and suitable for remote mapping (Jensen et al., 1980; Deysher, 1993). Satellite platforms such as Landsat and Planet support the monitoring of kelp forests on local to global spatial scales and allow for historical comparison on seasonal to decadal time scales (Bell et al., 2026).

While Landsat data are highly effective in detecting long-term regional trends, local-scale applications might require higher resolution data to detect sparse and/or fringing kelp patches (Cavanaugh et al., 2026; Hamilton et al., 2020). For example, areas very

close to shore or offshore rocks (typically within one Landsat pixel; ~30 m) or areas that are exposed during low tide will be removed by the land-masking procedure and thus the kelp canopy area within these pixels will not be measured. Additionally, areas with sparse kelp canopy may not be detected by the classifier. For example, Hamilton et al. (2020) performed a miss rate analysis for bull kelp canopies in Oregon and found that pixels with less than 10% canopy cover were often missed, while pixels with greater than 15% canopy cover were rarely missed. Local-scale analyses that require a census of all fringing/sparse canopies or a determination of kelp species should investigate other imaging methods that provide high spatial resolution imagery, such as aerial overflights or unoccupied aerial vehicles (i.e., drones). These methods may also be able to provide data acquired at specific tidal states that may be useful to some research applications (Bell et al., 2026). Overall, the long time series of satellite imagery of kelp canopy provides a robust tool for assessing the health of California's kelp and their associated kelp forest ecosystem. As such, this metric serves as an invaluable indicator of ocean health during a period of unprecedented change.

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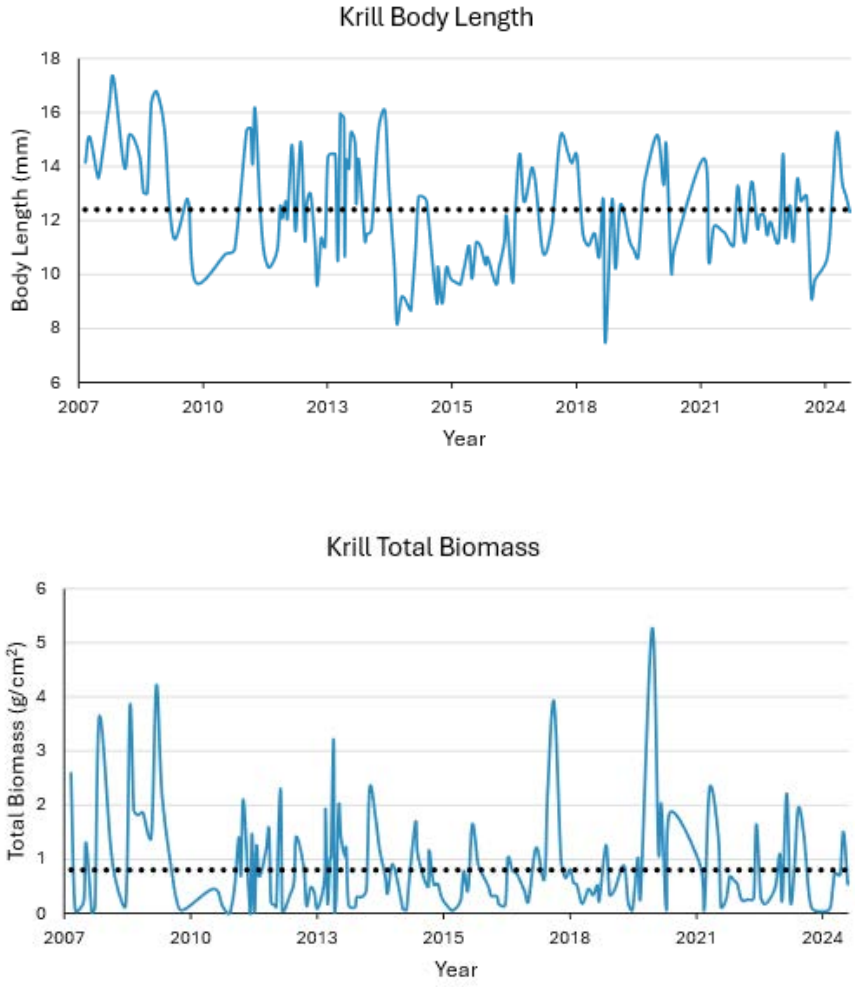
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3.8 Krill Length and Biomass

North Pacific krill (*Euphausia pacifica*) are a key prey species in the California Current Ecosystem. Krill respond strongly to ocean climate conditions: warm events such as marine heatwaves and El Niño reduce krill size and biomass, while cooler conditions support recovery. As a result, changes in krill length and biomass provide a sensitive indicator of ecosystem health.

Figure 3.8.1. North Pacific Krill Length and Biomass.



The graphs show the monthly mean adult North Pacific krill length (top) and total North Pacific krill biomass (bottom) measured off Trinidad Head, CA, 2007-2024. Total biomass represents the combined weight of all North Pacific krill in the survey area. The dotted black line indicates the long-term monthly mean (2007-2024). Source: Leising et al. (2025), based on work by Eric Bjorkstedt.

Figure 3.8.2. Trinidad Head Line Location.



The following show the Trinity Head Line (THL) off the coast of northern California. The THL extends 5 - 37 km offshore and consists of five long-term monitoring stations. Source: Left map: CeNCOOS (2026); Right map: Map created with Datawrapper

What does the indicator show?

Mean body length of adults and total biomass of *E. pacifica* indicate productivity at the base of the food web, krill condition, and energy content for predators (Robertson and Bjorkstedt, 2020). Krill body length and biomass vary from year to year, with declines during an unprecedented marine heatwave from 2013 to late 2015 called ‘the Blob’ that engulfed the west coast followed in the 2015-2016 winter by one of the strongest El Niño events of the last 145 years (**Figure 3.8.1**; NOAA, 2019; Scripps, 2026; USGS, 2020). Since the onset of this unusual heatwave, krill body lengths have generally increased except in 2019 during El Niño conditions. Exceptionally high biomass was seen in summer of 2020 but has declined in recent years (Harvey et al., 2022). North

Pacific krill (*Euphausia pacifica*) are sampled year-round along the THL off the coast of northern California (**Figure 3.8.2**).

Why is this indicator important?

The California Current Ecosystem is a highly productive upwelling current system that supports biodiversity and serves as foraging habitat for many species of migratory fish, marine mammals, and seabirds that travel across the vast Pacific Ocean basin. This ecosystem supports an important ocean economy, including recreational and commercial fishing, tourism, shipping, military training, and emerging ocean aquaculture and offshore wind (NOAA, 2023a).

Krill are among the most important prey groups in the California Current Ecosystem. Krill is the near-exclusive prey for giant blue whales, and seabirds like auklets and shearwaters. Commercially valuable salmon, rockfish, flatfish, sardines and squid thrive on krill. When krill are abundant, animals migrate thousands of miles to feed on them. When the krill population declines, the stability of the entire marine ecosystem is compromised. Larger and more abundant krill provide more energy to predators whereas smaller or fewer krill reduces the energy transfer up the food chain, affecting predator survival, reproduction, and population trends (Kaplan et al., 2025). As a result, animal migration patterns may shift, species unable to forage elsewhere may starve; some seabird species may experience complete breeding failure for, and local ecosystems may collapse (NOAA, 2023b).

Of the 85 krill species worldwide, the two dominant species in northern and central California are *Thysanoessa spinifera* and *Euphausia pacifica,* both of which are less than an inch long. By grazing on microscopic plants (phytoplankton) and microscopic animals (zooplankton), krill transfer energy to larger organisms higher in the food web. From late spring into fall, krill may swarm in swirling bait balls as dense as 100,000 per cubic yard. At times broad, pink swaths of it may stretch for miles and can be seen from the air (NOAA, 2023b).

Krill feed primarily on phytoplankton, which are microscopic organisms that form the foundation of marine ecosystems. When phytoplankton are abundant due to favorable conditions (like cold, nutrient-rich waters), krill can grow larger and reproduce more

successfully. Larger average body sizes and higher total biomass of krill thus generally indicate high primary productivity (Fiechter et al., 2020; NOAA, 2025).

What factors influence this indicator?

Both natural climate variability and human-driven climate change can influence krill body length and biomass, by altering ocean conditions in the California Current Ecosystem. Changes in water temperature, dissolved oxygen, currents, upwelling, and food availability affect krill growth, survival, reproduction, and distribution. The California Current Ecosystem experiences natural climate variability that alters water and air temperature, winds, currents, mixing of ocean waters, water chemistry, and precipitation. Dissolved oxygen (DO) is influenced by processes such as currents, upwelling, air-sea exchange, primary production, and respiration. Low DO (aka hypoxia, concentrations <1.4 ml DO/l) can vertically compress habitat and cause stress or die-offs in sensitive species (Chan et al., 2008). As the ocean absorbs increased anthropogenic atmospheric CO_2, ocean acidification occurs which reduces pH and dissolved carbonate in seawater and is stressful to many marine species (Feely et al., 2008; Busch and McElhany, 2016). Harmful algal blooms (HABs) can further disrupt marine food webs and prey availability (see the *Marine Harmful Algal Blooms* chapter). Changes in krill abundance associated with shifting ocean conditions have been linked to widespread impacts, including starvation of pelicans and a significant mortality event for Cassin's auklets (Leising et al., 2025).

Climate warming and increased marine heatwaves pose significant long-term risks to krill by reducing the cold, nutrient-rich habitat that krill are dependent on (Dorman et al., 2023; Fiechter et al., 2026). Large-scale climate variability also influences krill dynamics. Warm El Niño-Southern Oscillation (ENSO) events, warm phases of the Pacific Decadal Oscillation, and marine heatwaves are consistently associated with lower krill abundance (Marinovic et al., 2002; Brinton and Townsend, 2003; Brodeur et al., 2019; Cimino et al., 2020).

Krill biomass reflects both abundance and body size, and both are sensitive to oceanographic conditions. Coastal upwelling enhances nutrient supply, stimulates primary production, and cools surface waters, supporting higher phytoplankton biomass

and improved feeding conditions for krill (Shaw et al., 2010; García-Reyes et al., 2014). Chlorophyll-a (chl-a), a proxy for phytoplankton abundance, is positively associated with krill abundance and growth (Lavaniegos et al., 2019; Cimino et al., 2020; Robertson and Bjorkstedt, 2020). In contrast, higher ocean temperatures are associated with reduced abundance and slower growth (Marinovic and Mangel, 1999). Adult *Euphausia pacifica* also have body length declines as temperatures rise, particularly above ~14°C (~57°F) when metabolic efficiency decreases (Iguchi and Ikeda, 1995; Alonzo and Mangel, 2001; Robertson and Bjorkstedt, 2020). For example, mean adult length declined sharply with the arrival of warm 'blob' waters in mid-2014, individuals larger than 12 mm effectively disappeared from samples taken. Larger adults (>15 mm) were briefly abundant during a period of intense upwelling in early 2015, but again disappeared as the 2015-16 El Niño renewed unusually warm conditions along the coast. During this period, the typical seasonal pattern of increasing adult size during spring and summer was diminished, such that mean adult length remained at or below the long-term average (12.9 mm ± 3.03 SD) and on several occasions was as low as 60-70% of the long-term average (Robertson and Bjorkstedt, 2020).

Technical considerations

Data characteristics

The THL sits between two distinct circulation regimes. To the north, a region characterized by strongly seasonal upwelling and downwelling along a relatively straight coastline. To the south, in the Southern California Bight - the curved coastline between Point Conception and San Diego – there is more complex circulation shaped by coastal topography and mesoscale features, and upswelling is generally more intense and less seasonal. In addition, the area between Cape Blanco and Cape Mendocino is heavily shaped by coastal headlands, which generate upwelling jets and eddies that structure local circulation and productivity (Leising et al., 2025).

Euphausia pacifica is sampled year-round along the THL off northern California (Harvey et al., 2022). Krill sampling occurs monthly during 12-hour cruises. The krill body length was measured in millimeters (mm) from the back of the eye to the base of the telson (Leising et al., 2025).

Strengths and limitations of the data

Krill length and biomass are universally-used metrics to help determine the health of the California Current Ecosystem (Leising et al., 2025). Long-term ecological time series are critical for understanding ecosystem variation and ecological relationships, and for informing ecosystem-based management (Harvey et al., 2020; Sydeman et al., 2013). However, future data updates are uncertain due to changes in federal funding and resources.

OEHHA acknowledges the expert contribution of the following to this report:

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3.9 Brandt's Cormorant Reproductive Success

Over a 30-year period from 1995-2025, the reproductive success of Brandt's cormorants has exhibited increasing variability.

Figure 3.9.1. Brandt's Cormorant Reproductive Success.



This figure shows Brandt's cormorant reproductive success on Alcatraz Island near the mouth of San Francisco Bay, from 1995 to 2025, measured as the mean number of chicks produced per breeding pair per year. Source: Julie Thayer, Farallon Institute (2026)

What does the indicator show?

As conspicuous upper trophic level consumers that respond quickly to changes in prey abundance and food availability, seabirds can be effective indicators of change in marine ecosystems, and specifically the structure of coastal-pelagic food webs (Cairns, 1987; Furness and Camphuysen, 1997; Piatt et al., 2007; Hazen et al., 2019; Velarde et al., 2019). Seabird reproductive success is a particularly well-known and accepted early-warning (i.e., sentinel) indicators of food webs and corresponding prey resource availability, as this parameter responds to shifts in prey availability on high-frequency seasonal and local scales (Cairns, 1987 and 1992; Ainley et al., 1994; Boyd and Murray, 2001; Sydeman et al., 2021; Descamps et al., 2022; Karnovsky et al., 2025; Watanuki et al., 2025).

Brandt's cormorant reproductive success is influenced by the availability of nearshore marine food resources and the ocean conditions that influence these prey resources. Ocean conditions such as sea surface temperature, upwelling, and ocean productivity influence the abundance and distribution of forage fish that Brandt's cormorants rely on. Brandt's cormorants are piscivorous, consuming both benthic (bottom) and pelagic (water column) fishes including northern anchovy, flatfishes, and rockfishes (Elliott et al., 2014; Webb et al., 2015; Robinson et al., 2019). As a result, changes in reproductive success can reflect changes in prey availability and/or broader marine ecosystem conditions.

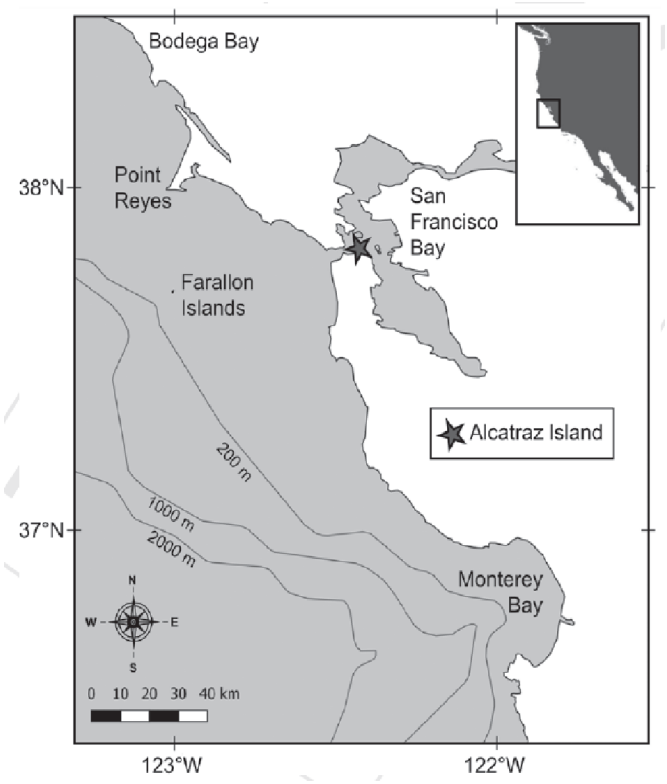
Brandt's cormorant reproductive success is an integrative ecological indicator rather than a direct measure of climate change. Annual reproductive success is influenced by multiple factors, but marine climate affects ocean conditions and subsequent prey availability that is critical to breeding success. As a result, changes in reproductive success provide insight into how marine ecosystems are responding to changing ocean climate.

Brandt's cormorant is a resident seabird with high visibility on breeding colonies. Brandt's Cormorants can lay up to 5 eggs in a season, resulting in more potential variability in reproductive success than most seabirds that lay fewer eggs per clutch (e.g., Common Murres lay only 1). These factors contribute to the value of Brandt's

cormorant as a sensitive indicator of local food supplies, regional prey fields, and underlying marine conditions.

Brandt's cormorant reproductive success is measured as the mean number of offspring produced per breeding pair per year and has been monitored consistently since the early 1990s when Brandt's cormorants colonized Alcatraz Island near the mouth of San Francisco Bay (**Figure 3.9.2**). Cormorant reproductive success at Alcatraz is significantly correlated with that from other California colonies, particularly between Point Sur and Point Reyes (Saenz et al., 2006; J. Thayer/Farallon Institute unpublished analyses; data outside this central California region are limited).

Figure 3.9.2. Map of Brandt's Cormorant Breeding Colony on Alcatraz Island Near the Mouth of San Francisco Bay.



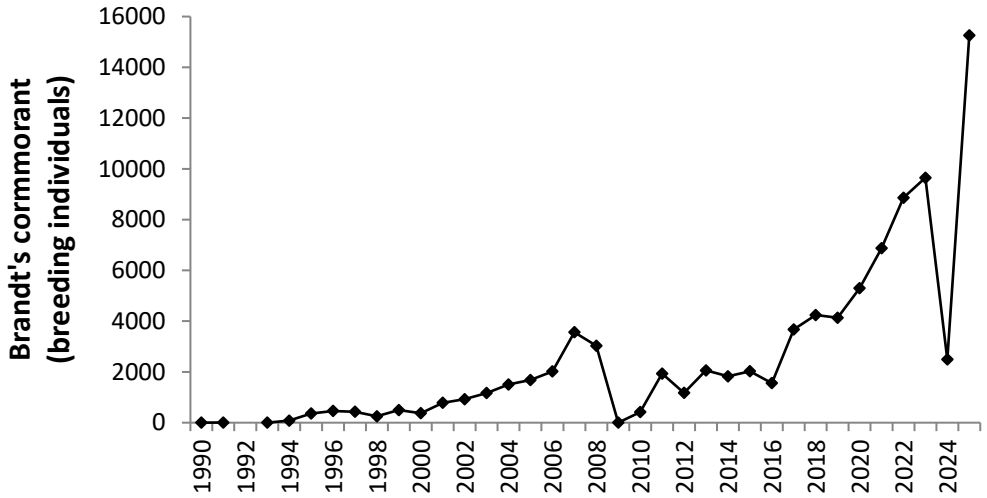
Source: Map provided by Julie Thayer, Farallon Institute (2026)

Brandt's cormorant reproductive success is high when there is an abundant variety of prey fish, as in 1995-2007 (except for during the 1998 El Niño event). Reproductive

success declined drastically in 2008 and 2009 (**Figure 3.9.1**) when the northern anchovy population crashed (MacCall et al., 2016; Thayer et al., 2017) and sanddab and other demersal fish species were also less abundant (Santora et al., 2021). Reproductive success rebounded by 2013, but inter-annual differences since 2008 have become quite large, indicating increasing variability (coefficient of variation [CV] pre 2008 = 0.13; CV post 2008 = 0.45). For example, in 2025, reproductive success was high and the breeding population was also elevated (**Figure 3.9.3**), following low reproductive success (and breeding population) in 2024. While there are limited standardized, direct measures of nearshore fish distribution and abundance (due to sampling limitations; see Technical Considerations below), some trawl data suggested that flatfish such as sanddab were above average in 2025 but below average in 2024 (Leising et al., 2025). Similarly, seabird diet data suggested that anchovy were much more available in 2025 than in 2024 or 2026 (J. Thayer/Farallon Institute unpublished data; Hunsicker et al., 2026).

Preliminary 2026 data show extremely low reproductive success with limited availability of anchovy and less diverse prey species in cormorant diet. The population of cormorants attempting breeding is also low (similar to 2024 levels; **Figure 3.9.3**), and a very large cormorant mortality event has been documented so far this year.

Figure 3.9.3. Brandt's Cormorant Breeding Population.



The above graph shows Brandt's cormorant breeding population on Alcatraz Island, near the mouth of San Francisco Bay, from 1990 to 2025. Source: Julie Thayer, Farallon Institute (2026)

Why is the indicator important?

Studies of seabirds suggest that ocean warming and other forms of marine climate change are affecting coastal food webs. Forage fish such as anchovy are one of the top food resources for predators in the California Current System, not only for seabirds (Anderson et al., 1980; Ainley et al., 1981; Sydeman et al., 2001; Warzybok et al., 2018), but also for Chinook salmon (Thayer et al., 2014), California halibut (Szoboszlai et al., 2015), and other important nearshore fishery species, as well as mammals such as humpback whales (Kieckhefer, 1992; Clapham et al., 1997), harbor seals (Gibble et al., 2011), and California sea lions (Robinson et al., 2018; Lowry et al., 2022).

Measurements of Brandt's cormorant reproductive success provides a strong signal of changes in ocean conditions, as reflected in prey availability, in the ecosystem over the period of time when the birds are reproductively active each year (approximately March through August), and may also reflect conditions preceding the breeding season (Schroeder et al., 2009; Elliott et al., 2016).

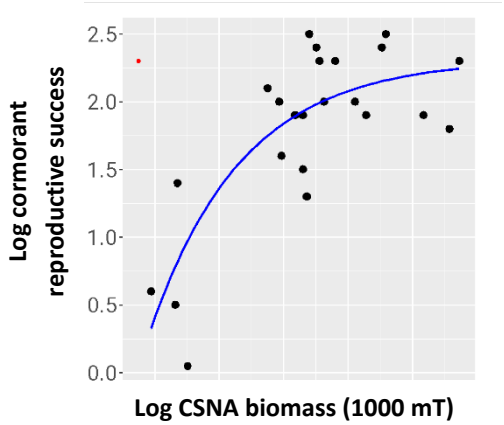
Therefore, Brandt's cormorant reproductive success can represent ecosystem conditions and prey fields encountered by a broad community of marine predators,

which is difficult to monitor and assess directly. Brandt's cormorant indicators are also cheaper to monitor than shipboard fisheries surveys and reveal characteristics of the nearshore foodweb where it is hard for large survey vessels to maneuver.

What factors influence this indicator?

Marine climate conditions influence prey community composition, abundance, and distribution, which in turn influence Brandt's cormorant reproductive success. Cormorant prey such as rockfishes and flatfishes tends to prefer cooler marine climate conditions (Cloern et al., 2010; Ralston et al., 2015; Schroeder et al., 2019), while anchovy may be more available in relatively warmer conditions (Ralston et al., 2015; Fleming et al., 2015; Santora et al., 2017). Brandt's cormorant reproductive success is significantly related to metrics of prey fish populations, such as abundance of anchovy (**Figure 3.9.4**).

Figure 3.9.4. Brandt's Cormorant Reproductive Success and Biomass Estimates of the Central Stock of Northern Anchovy.



The following figure shows the relationship between the log of Brandt's cormorant reproductive success, and the log of biomass estimates of the central stock of northern anchovy, measured in units of 1000 metric tons (mT). Source: CSNA, Thayer et al. (2022).

Technical considerations

Data characteristics

Data collection on Brandt's cormorants is supported by the National Park Service/Golden Gate National Recreation Area, enabling a long-term monitoring program on Alcatraz. Standardized methods have been used to record Brandt's cormorant population size and reproductive success annually since 1995.

The relationship of Brandt's cormorant reproductive success with anchovy metrics is curvilinear, meaning it is more complicated to interpret than a linear (straight) relationship, but indicates "favorable", "middling" or "poor" anchovy availability which can be helpful for management.

Strengths and limitations

Brandt's cormorant reproductive success aligns with regional biomass indices for the central stock of northern anchovy (**Figure 3.9.4**), but not as well with smaller-scale trawl indices of patchily-distributed and very fast-swimming prey such as anchovy. Nearshore information is important for understanding anchovy as prey, since anchovy populations contract inshore into bays and estuaries at low biomass levels (MacCall, 1990; Checkley et al., 2017). To better establish the spatial extent of the Alcatraz Brandt's cormorant reproductive success indicator, more work should be done comparing this data with that at other California colonies, particularly in far northern and southern California as data become available.

OEHHA acknowledges the expert contribution of the following to this report:

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3.10 California Sea Lion Pup Demography (No Update)

Unusually warm sea surface temperatures have been associated with declines in pup births, increased pup mortality and poor pup condition among California sea lions.

About this indicator: This chapter was originally published in the 2018 Indicators of Climate Change in California report and has not been updated for this edition. Data and references reflect conditions as of 2018.

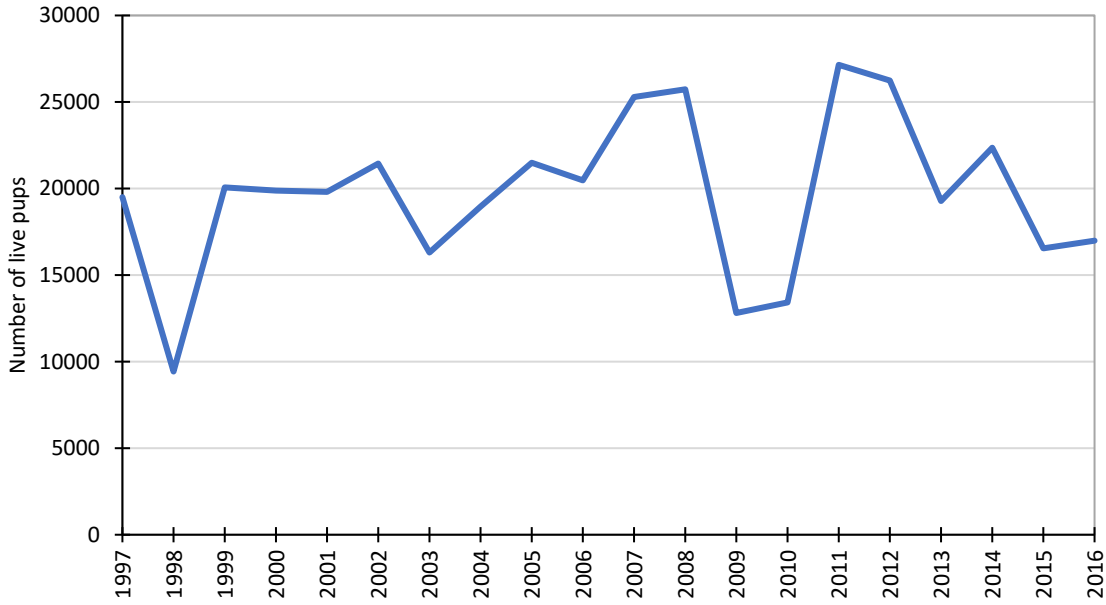
The California sea lion (Zalophus californianus) is a permanent resident of the California Current System. Females give birth to a single pup between May and June. For about 11 months, lactating females travel to sea for 2-5 days to feed and return to nurse their pup.

The Point Bennett Study Area at San Miguel Island off Santa Barbara is a large sea lion breeding area used as a long-term index colony for monitoring pup production and mortality.



Photo: Eric Boerner, NOAA

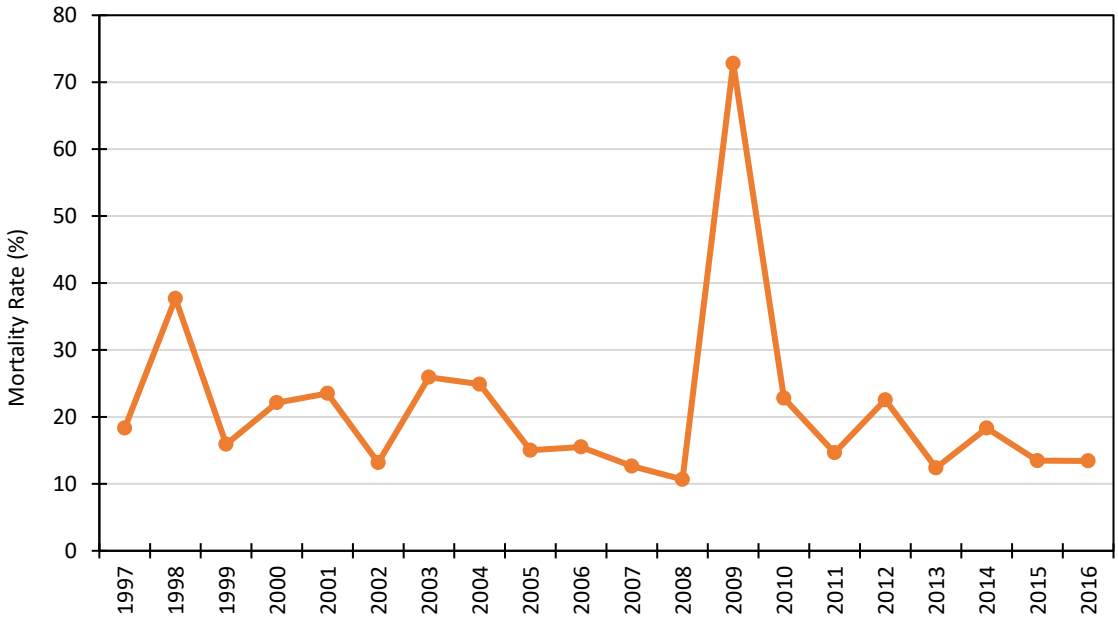
Figure 3.10.1. Sea Lion Live Pup Count*.



* Based on live pups counts conducted July 20-30 annually

Source: Harvey et al. (2017)

Figure 3.10.2. Sea Lion Live Pup Mortality Rate*.



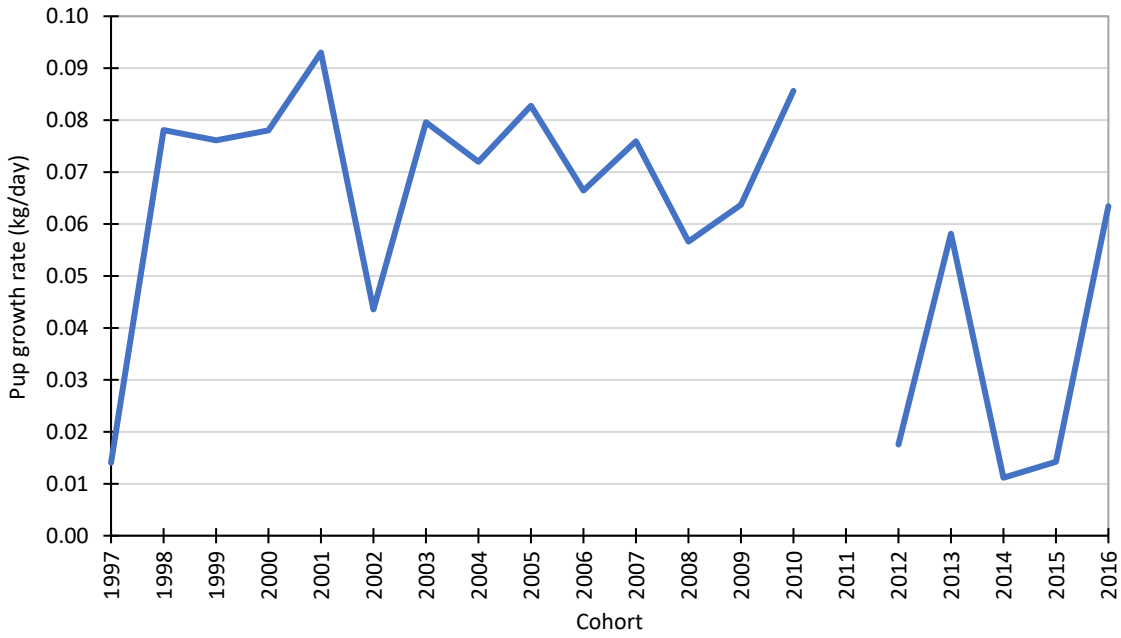
* At 5 weeks of age in the Point Bennett Study area

Source: NMFS, unpublished data (2017)

What does the indicator show?

Sea lion demographic parameters fluctuate with oceanographic conditions, particularly warm surface water temperatures. The indicator consists of three metrics based on monitoring of California sea lion population indices (pup births, pup mortality, and pup growth) and oceanic conditions between 1997 and 2016 at San Miguel Island's Point Bennett Study Area (see map, **Figure 3.10.4**). (Melin et al., 2010).

Figure 3.10.3. Sea Lion Live Pup Growth Rate*.



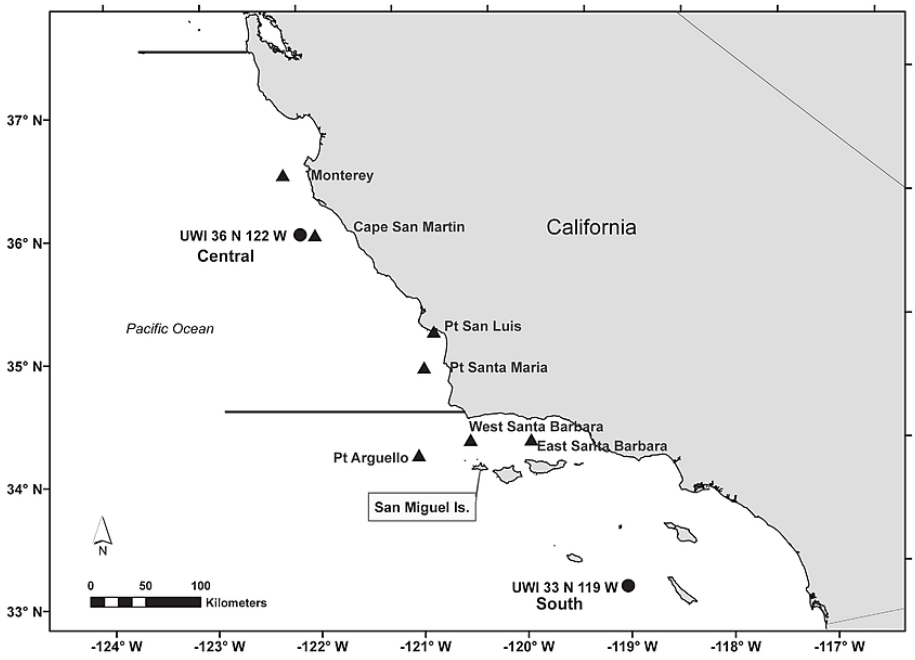
*Estimated mean daily growth rate of female pups between 4 and 7 months of age; no count was conducted in 2011.

Source: Harvey et al. (2017)

Annual pup counts at San Miguel Island between 1997 and 2016 ranged from a low of 9,428 to a high of 27,146 (**Figure 3.10.1**). The counts occurred in 1998, 2009, and 2010, all years characterized by warm ocean conditions (Wells et al., 2017).

Pup production is a result of successful pregnancies and is an indicator of fish and cephalopods that serve as prey for sea lions. The high pup counts in 2011 and 2012 suggest that pregnant females experienced good foraging conditions in these years when cooler ocean conditions prevailed. The number of births declined again in 2015 and 2016 in response to warmer ocean waters due to a marine heat wave and El Niño conditions in 2015 (McClatchie, 2016; Wells et al., 2017).

Figure 3.10.4. Location of San Miguel Island



Source: Melin et al. (2010)

Figure 3.10.2 shows that in 2009, early pup mortality among sea lions during the first 5 weeks of life was exceptionally high, almost four times greater than the long-term average (73% in 2009, compared to approximately 20% long-term). The high pup mortality rates in 1998 and especially 2009 were associated with anomalously high sea surface temperatures (SSTs). However, during more recent warm ocean events in 2014-2015, pup mortality was near average, while pup growth rate during this period was low. This suggests that lactating females were able to support their pups for the short-term (first 5 weeks) but that females could not provide enough energy for long-term growth of their pups.

Pup growth from birth to 7 months of age is an indicator of the transfer of energy from the mother to the pup through lactation, which is related to prey availability during this time period. The lowest female pup growth rates occurred in 1997, 2014, and 2015 (**Figure 3.10.3**). (No data are available for 2011; researchers were unable to conduct a count that year.) These years were characterized by unusually warm ocean

temperatures that were associated with El Niño conditions (1997, 2015) and a marine heat wave (2014-2015) (Wells et al., 2017). Pup growth for the 2014 cohort was the lowest observed over the time series. As ocean conditions returned to near-normal in 2016, pup growth improved, returning to the long-term average (Wells et al., 2017). The very low growth rate for the 2012 cohort occurred during an unusually cold period of ocean conditions during winter 2012/2013 that normally would have resulted in good growth rates; the causes of the low growth rates for the 2012 cohort remain unexplained.

Why is this indicator important?

Sea lions and other marine mammals are prominent animals that reflect ecosystem variability and degradation in the ocean environment. Animals at higher levels in the food chain provide insights into relationships among marine community structure and oceanographic conditions (Weise, 2008). Scientists use marine mammals as sentinels of ocean production and changes in food webs, and increasingly include them in studies of changing oceanographic conditions (Moore, 2008).

Sea lions are among the most abundant top predators of the food chain in the coastal and offshore California waters. They are vulnerable to the seasonal, annual and multiyear fluctuations in the productivity of the ocean. Sea lion prey such as fish and cephalopods are also influenced by particular sets of environmental conditions along the California coast.

One of the greatest threats to the California sea lion comes from changes in their food resources due to climate and other influences (Learmonth et al., 2006). Air and ocean temperatures are warming and projected to continue to warm, especially in the summer. The biological impacts of these changes may be a lower rate of ocean productivity and thus less food for many species. This can lead to shifts in the geographical distributions of marine species (for example to higher latitudes or deeper waters), and cause changes in community composition and interactions (IPCC, 2014). More resilient species may gain predominance and abundance while others become less competitive or easier prey. Shifts in the abundance and distribution of prey have had serious consequences for sea lion reproduction and survival.

Tracking pup population indices provides insight into how the California sea lion population is responding to environmental and anthropogenic changes. Although the population of California sea lions in coastal waters from the United States-Mexico border to southeast Alaska has steadily increased since the early 1970s, recent declines in pup production and survival in this area suggest that the population may have stopped growing (Laake et al., 2018).

What factors influence this indicator?

The California Current System (CCS) has a large impact on the food supply and survival of sea lion pups along the coast. A regional process known as “upwelling” carries the deep, cooler waters transported by the current upward, closer to the surface where photosynthesis by phytoplankton occurs. This productive zone supports important commercial fisheries as well as marine mammal and sea bird populations. CCS waters are influenced by large-scale processes resulting from the El Niño-Southern Oscillation (ENSO). El Niño conditions associated with the warm phase of ENSO occur irregularly at intervals of two to seven years, often leading to a weakened upwelling, low-nutrient waters and higher SSTs. Increased summertime SSTs due to decreased upwelling strength of ocean currents is reported to reduce availability of prey in the sea lion foraging zone.

Sea lion pups are solely nutritionally dependent on their mother’s milk for the first six months of their lives. Sea lion pup survival is highly dependent on the lactating mother’s ability to find food in coastal waters near the colony. While their mothers are at sea on feeding trips, the pups are fasting at the colony. When prey availability is reduced near the colony, lactating females must travel farther to obtain food, resulting in longer periods away from their pups. Consequently, their fasting pups are more vulnerable to starvation. Further, if the female does not obtain enough prey for her own nutritional and energy needs, she may not be able to provide sufficient energy for her pup to grow. Newly weaned pups just learning to forage on their own may also be vulnerable when prey availability is low because they have less fat to sustain periods of poor feeding conditions and fewer behavioral options to acquire food (e.g., limited diving

ability). During periods of reduced prey conditions, increased numbers of malnourished sea lion pups are found stranded along the coast.

The low pup count, highest pup mortality rate and record number of strandings in 2009 were associated with anomalous oceanographic conditions along the California coast between May and August. During that year, upwelling was the weakest in the past 40 years; this was accompanied by uncharacteristically warm June SSTs. Negative upwelling patterns and warmer SSTs during the summer required lactating females to take longer than average foraging trips (averaging 7 days, approaching the maximum duration for which pups survive without nursing, 9 days). Additionally, the diet of California sea lions in 2009 varied significantly from other years, with cephalopods and rockfish occurring more frequently. The combination of longer foraging trips and a diet principally of rockfish and cephalopods did not provide adequate energy for lactating females to support their pups.

Since 2013, fisheries surveys confirm that the primary prey fish of sea lions (e.g., anchovy, sardine, hake) have not been abundant in the foraging area, probably in response to warmer ocean conditions (McClatchie, 2016; Wells et al., 2017). This was especially evident in 2014-2015, when the Pacific Coast experienced unusually warm SSTs due to the marine heat wave and El Niño conditions (Leising et al., 2015). Consequently, nursing females were not able to provide enough energy for their pups to grow, pups weaned too early or weaned in poor condition, and large numbers of pups stranded along the California coast in 2015 (McClatchie, 2016). When ocean conditions began returning to neutral conditions in 2016, sea lions responded fairly quickly with higher numbers of pup births, reduced pup mortality and improved pup condition and growth, further supporting their utility as an indicator of CCS conditions.

Harmful algal blooms periodically occur along the California coast, especially during years when water temperatures are unusually warm. During the 2014-2015 marine heatwave, a record-breaking algal bloom extended across the entire west coast, and included the phytoplankton *Pseudo-nitzschia*, which produces the neurotoxin domoic acid. This toxin can enter the marine food web, contaminate sea lion prey species and pose a threat to foraging sea lions and their offspring. Although incidents of sea lion

poisoning from domoic acid have been reported, scientists have not quantified the effects of this toxin on sea lion pup births and growth. However, in a warming marine environment, harmful algal blooms and related toxins may become an increasingly important threat to the coastal food web, including the sea lion population.

Technical considerations

Data characteristics

San Miguel Island, California (34.03˚N, 120.4˚W), contains one of the largest colonies of California sea lions. The Point Bennett Study Area contains approximately 50% of the births that occur on San Miguel Island and provides a good index of trends for the entire colony. This site has been used as a long-term index site since the 1970s for measuring population parameters.

Population indices (live pups, pup mortality, pup growth) were measured by observers at San Miguel Island. Because of the large size of the colony, index sites were used to estimate population parameters.

Live pups were counted after all pups were born (between 20–30 July) each year. Observers walked through the study area, moved adults away from pups, and then counted individual pups. A mean of the number of live pups was calculated from the total number of live pups counted by each observer. The total number of births was the sum of the mean number of live pups and the cumulative number of dead pups counted up to the time of the live pup survey.

Pup mortality was assessed to calculate mortality at 5 weeks of age, 14 weeks of age, and the total number of pups born. Pup mortality surveys conducted every 2 weeks from late June to the end of July were used as an index of pup mortality at 5 weeks of age and to calculate total births for the study area. A final survey was conducted the last week of September to estimate pup mortality at 14 weeks of age. On each survey, dead pups were removed from the breeding areas as they were counted. The total number of observed dead pups for each survey described the temporal trend in pup mortality and was an estimate of the cumulative mortality of pups at 5 weeks or 14 weeks of age. Cumulative pup mortality rate was calculated as the proportion of the number of pups

born in each year that died by 5 weeks of age or 14 weeks of age of the total number of pups born in each year.

Female sea lion **pup growth rates** are shown in **Figure 3.10.3**. Data for male pup growth rates (not presented) show the same trend over this 18-year period. To estimate sea lion pup growth rate, between 310 and 702 pups were selected from large groups of California sea lions hauled out in Adams Cove (part of the Point Bennett Study Area) over 4–5 days in September or October in each year (pups about 14 weeks old). Pups were sexed, weighed, tagged, branded, and released. Because the weighing dates were not the same in each year, the weights were standardized to an October 1 weighing date. A mean daily weight gain rate multiplied by the number of days from the weighing date to October 1 was added or subtracted from the pup weight based on the number of days before (–) or after (+) October 1 when the pup was weighed. The number of days between October 1 and the actual weighing day was included as a parameter (days) in models to describe the annual variability in pup weights. Similarly, pups were recaptured in February a second time and weights were adjusted to a February 1 date to determine growth rate between October 1 and February 1. Growth rate data are missing in 2011 because the investigators were unable to conduct field sampling in February of that year.

The response of sea lions to warmer ocean conditions was determined from models of SST and the sea lion population indices (Melin et al., 2012). Sea surface temperature anomalies were calculated from seven buoys along the central coast (from San Luis Obispo to the San Miguel Island area). This length of coastline represents the foraging range of the juvenile and lactating female sea lions. The buoy data were obtained from the NOAA National Data Buoy Center (http://ndbc.noaa.gov/rmd.shtml). The mean daily SSTs from the seven buoys were used to calculate mean monthly SSTs and averaged to create monthly sea surface temperature anomaly indices for the years 1997 to 2016 used in the analysis.

Strengths and limitations of the data

The study area represents about 45% of the US sea lion breeding population (Melin et al., 2010), thus providing a representative measure of trends in population responses to

changes in the ocean environment. Because the area is large, index sites across the colony were used to measure population parameters. Instead of using total counts for pup production and mortality, mean values were used to estimate these parameters.

The use of SST from buoys represents a very localized view of ocean conditions at the surface but does not reflect more complex oceanographic processes occurring offshore or deeper in the water column that also may influence prey availability and the resulting population responses.

OEHHA acknowledges the expert contributions of the following to this report:

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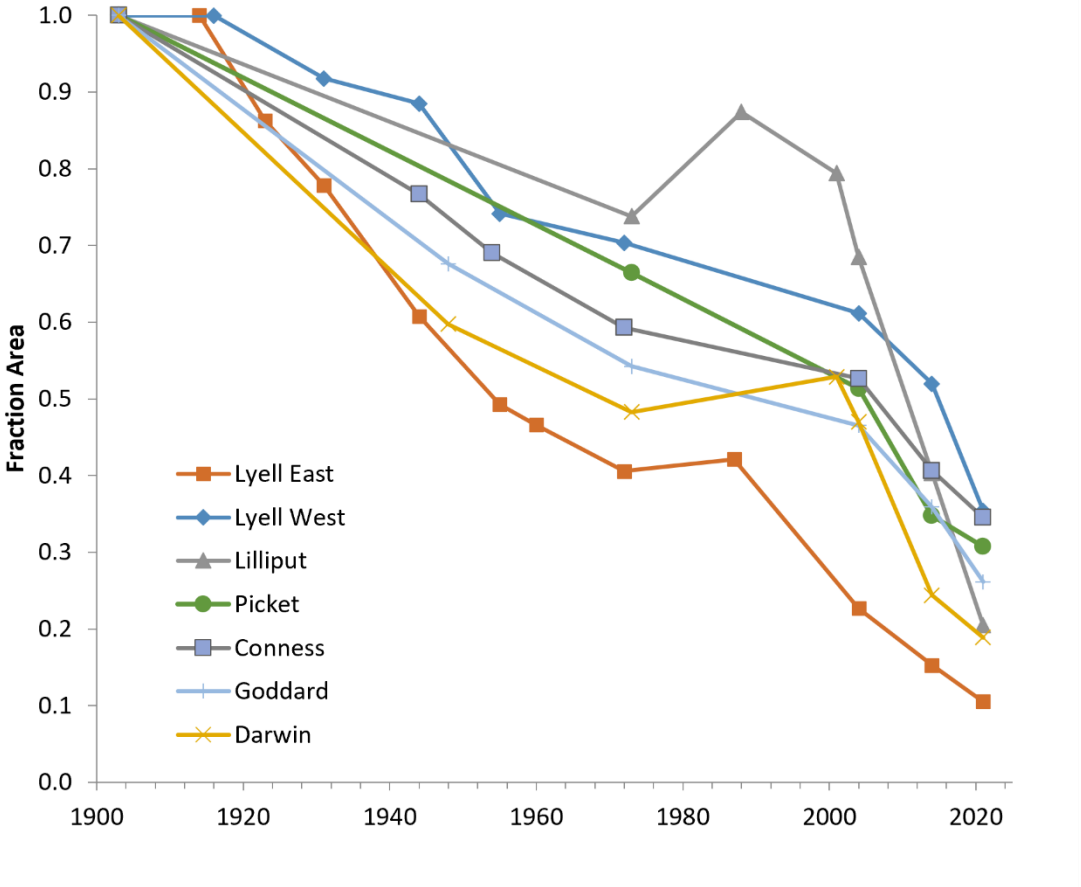
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3.11 Glacier Change

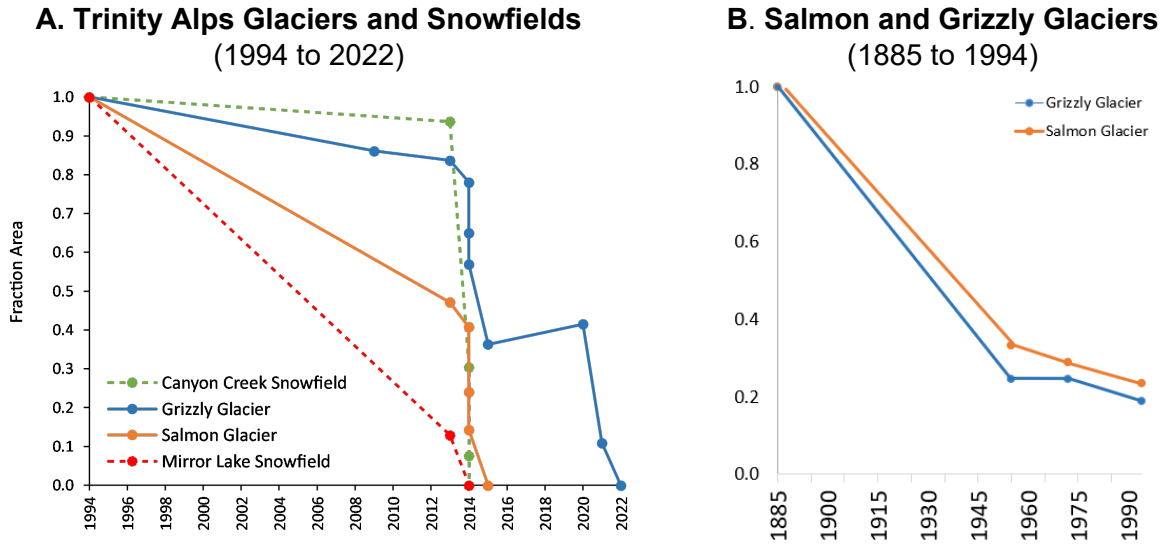
Regionally and globally, glacier retreat is intensifying due to increasing temperatures. California reflects this broader trend, with the complete disappearance of the Trinity Alps glaciers and the continued decline of the Sierra Nevada glaciers.

Figure 3.11.1. Change in Area of Sierra Nevada Glaciers.



The figure shows the change in area of Sierra Nevada glaciers as a fraction of the 1903 area.
Source: Basagic and Fountain (2011, updated to 2021 by H. Basagic, unpublished data)

Figure 3.11.2. Change in Area of Trinity Alps Glaciers and Snowfields.



The figure shows: **A.** the fractional glacier area remaining relative to 1994 for two glaciers and two perennial snowfields in the Trinity Alps from 1994 to 2015 and subsequent measurements of Grizzly Glacier until its extinction in 2022 **B.** the changes in the areas of the Grizzly and Salmon Glaciers relative to their estimated areas around 1885; data prior to 1994 are not available for the Canyon Creek and Mirror Lake Snowfields. In 2015, Salmon Glacier disappeared entirely and the lower half of Grizzly Glacier broke apart into large ice blocks, leaving only the upper portion of the glacier intact (see historical and contemporary photographs in Appendix A).

Sources: Garwood et al. (2020 and 2026)

What does the indicator show?

A glacier is defined as a mass of perennial snow or ice that moves (Cogley et al., 2011). California's glaciers provide a stark illustration of the accelerating impacts of climate change. Selected glaciers and snowfields have experienced substantial reductions in area (see **Figure 3.11.3** for locations). **Figure 3.11.1** shows large declines in the seven Sierra Nevada glaciers relative to 1903. By 2021, the Sierra Nevada glaciers lost 65 to 89% (an average of about 75%) of their 1903 area, after having lost approximately half of their area since the 1970s (Basagic, unpublished 2021 data; methodology described in Basagic and Fountain, 2011). These findings are consistent with those from a separate study of 769 glaciers and perennial snowfields that were identified within the

Sierra Nevada in the 1970s and 1980s based on the US Geological Survey's 1:24,000-scale, topographic maps (Fountain et al., 2017). The largest 39 glaciers, free of rock debris mantling the surface, covered an area of 2.74 ± 0.12 square kilometers (km^2) in the 1970s and 1980s. By 2014, overall, they lost approximately 50% of their area. Measurements in recent years have been hindered by extensive snow cover (personal comm, Basagic, 2025 and Stock, 2026), although recent photographs capture Lyell and Maclure glaciers (**Figure 3.11.4** and **Figure 3.11.5**). Researchers project that these glaciers will be completely gone by the beginning of the next century, a profound environmental change occurring within a relatively short period of time (Jones et al., 2025).

Figure 3.11.3. Glaciers and Perennial Snow Regions in California.



Source: Garwood et al. (2020)

Figure 3.11.4. Lyell and Maclure Glaciers, 2024 and 2025.

A. Lyell Glacier in September 2024



B. Maclure Glacier in September 2024



C. Lyell Glacier in September 2025



D. Maclure Glacier in September 2025



E. Lyell Glacier in September 2025

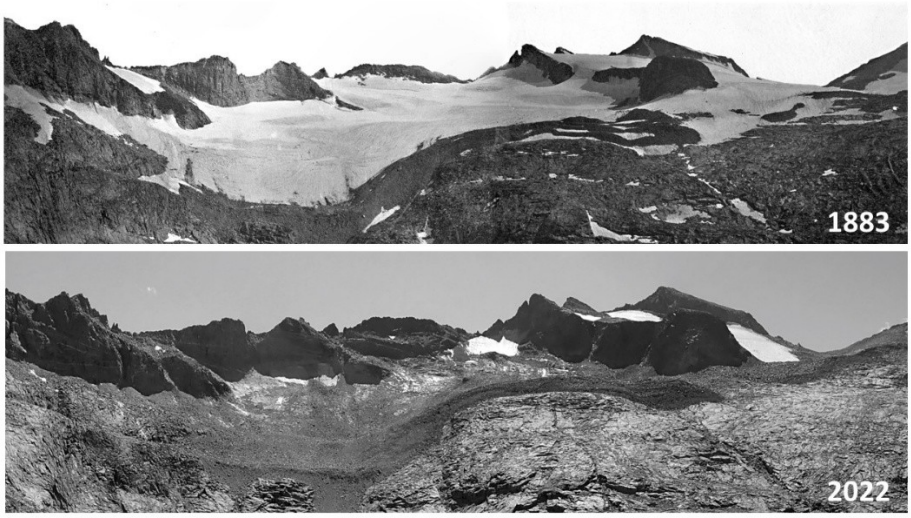


F. Maclure Glacier in September 2025



Source: Greg Stock (personal comm, 2025)

Figure 3.11.5. Lyell Glacier, 1883 and 2022.



Source: National Park Service

The Trinity Alps were a glaciated subrange of the Klamath Mountains in northwest California. Around 1885, at least nine Holocene glaciers existed in the Trinity Alps (Heermance et al., 2026). Grizzly and Salmon glaciers are the only two that persisted in the 21st century (Garwood et al., 2020). **Figure 3.11.2** shows substantial losses in the size of glaciers and snowfields in the Trinity Alps since 1994. All snowfields throughout the Trinity Alps and greater Klamath Mountains of southern Oregon and northern California disappeared by 2014 during an extended drought, and glaciers disappeared by 2022 (Garwood et al., 2020 and 2026; **Figure 3.11.2A**). Both glaciers had lost 70 to 75% of their area between 1885 and 1955; by 1994, approximately 20% of their 1885 area remained (**Figure 3.11.2B**). Between the fall of 2020 and the fall of 2021, Grizzly Glacier experienced a catastrophic 76% reduction in area. By the fall of 2022, after repeated annual drought conditions, the last remaining stagnant Grizzly Glacier ice had melted (Garwood et al., 2026) leaving the Klamath Mountains without glacial ice for the first time in centuries. This milestone marks the first time in nearly two decades of tracking California's climate change indicators that monitored glaciers from a distinct region have disappeared entirely.

Glacier loss in California reflects broader regional and global trends. Glaciers across the western United States have experienced rapid retreat in recent years (Abubakari and Ambinakudige, 2024), and glacier mass loss in North America has accelerated in response to rising air temperatures (Kääb and Røste, 2024; Williamson et al., 2025). On average, glaciers globally are projected to lose nearly 40% of their mass relative to 2020 by 2100, corresponding to a global mean sea-level rise of 113 mm, even if carbon emissions stop and temperatures stabilized at present-day conditions (Zekollari et al., 2025). The number of glaciers disappearing globally is projected to peak between 2041 and 2055, with up to approximately 4,000 glaciers disappearing annually (Van Tricht et al., 2026).

Why is this indicator important?

Tribal Connection 3.11.1

The loss and shrinking of these glaciers are grieved by California Tribes. Tribal Elder Dean Tonnenna explains the impacts the Mono Lake Kootzaduka'a experience from the shrinking glaciers in their territory including Conness, Lyell East and West, and Maclure: "*The glaciers in our area are an important component of our homeland. We are accustomed to looking up to the mountaintops no matter where we are along the Sierra Nevada and seeing the familiar glaciers. The glaciers have been around for countless generations, and they're mentioned in some of our traditional origin stories, especially the story of how pine nuts came to our region. The glaciers are also indicators of the future regarding water supply within our homeland and everything that's connected with water. We are concerned that if the glaciers dry up and vanish, that will correspondingly mean that our creeks and streams may no longer have enough water to last until the winter snows come again. With our streams and creeks drying up earlier in the year, that will have a cascading effect upon the vegetation community and our ability to gather plants for food, medicine, and cultural practices like basketry*" (Mono Lake Kootzaduka'a Tribe of California and Nevada, 2026).

Glaciers are important indicators of climate change. Because glaciers are sensitive to fluctuations in temperature, they provide visual evidence of warming. In addition, as warming causes snow and ice to melt, darker colored surfaces are exposed, albedo decreases, less solar energy is reflected out to space, and the planet warms even more. Deposition of black carbon from wildfire emissions can further darken snow and ice surfaces, contributing to additional albedo reductions (UCAR, 2026).

Glacier loss can also lead to cascading effects on hydrology and aquatic habitats, contribute to sea level rise, and impact recreation and tourism (USGS, 2021). Glacier shrinkage results in earlier peak runoff and drier summer conditions, affecting many aquatic species in alpine and subalpine environments that require cold water temperatures to survive. Species dependent on glacier environments are projected to face local extinction where glaciers disappear completely (Wilkes et al., 2023). Ice and persistent snow in the Trinity Alps create high-elevation cold-water habitats that support several endemic species, including the beetle, *Nebria praedicta*, and the coastal tailed frog (*Ascaphus truei;* see **Figure 3.11.6**), the latter of which is a California Species of Special Concern.

Three regional watersheds provide cold glacial and snowmelt flows to streams supporting small populations of spring Chinook salmon (*Oncorhynchus tshawytscha*) and summer steelhead (*Oncorhynchus mykiss*). Rapid declines in glacial ice and snowpack threaten these cold-adapted species and their resilience (Garwood et al., 2020). For information on increasing river water temperatures and impacts on Chinook salmon populations, see the *Salmon Water River* and *Chinook Salmon Abundance* chapters.

Figure 3.11.6. Coastal Tailed Frog.



The Coastal tailed frog (*Ascaphus truei*) ranges from British Columbia to northern California, from near sea level in Humboldt County up to elevations of 2150 meters in the Trinity Alps.

Source: CDFW (2016); Photo credit: Thompson et al. (2016)

What factors influence this indicator?

A glacier is a product of regional climate, responding to the combination of winter snow and spring/summer temperatures. Winter snowfall nourishes the glaciers; winter temperature determines whether precipitation falls as rain or snow, thus affecting snow accumulation and glacier mass gain. Spring and summer air temperatures affect the rate of snow and ice melt.

In recent years, increasing winter and spring temperatures across North America have led to less snowpack in spring and early summer (Mote et al., 2018). Based on their assessment of glacier studies in various parts of the world, the Intergovernmental Panel on Climate Change (IPCC, 2021) concluded that human-induced warming likely contributed substantially to widespread glacier retreat during the 20th century. Local variations in topography and climate either enhance or reduce the magnitude of change so that each glacier's response is somewhat unique.

Sierra Nevada

The glacier retreat in the Sierra Nevada occurred during extended periods of above average spring and summer temperatures; winter snowfall appeared to be a less important factor (Basagic and Fountain, 2011). Glacier area changes at East Lyell and

West Lyell glaciers were found to be significantly correlated with spring and summer air temperatures. In the past century, average annual temperatures in the Sierra Climate Region warmed by almost 3 degrees Fahrenheit (°F), or 1.7 degrees Celsius (°C) with summer and fall having warmed the most, at 3.6 (2°C) and 3.4°F (1.9°C), respectively (WRCC, 2026).

As seen in **Figure 3.11.1**, the seven glaciers studied have all decreased in area. However, the magnitude and rates of change are variable, suggesting that factors other than regional climate influenced these changes. One of these factors is glacier geometry. A thin glacier on a flat slope will lose more area compared to a thick glacier in a bowl-shaped depression, even if the rate of melting is the same. In addition, local topographic features, such as headwall cliffs, influence glacier response through shading solar radiation, and enhancing snow accumulation on the glacier through avalanching from the cliffs.

Trinity Alps

Grizzly and Salmon Glaciers and Canyon Creek and Mirror Lake Snowfields in the Trinity Alps occurred at 2,460 meters, an elevation far lower than other glaciated areas in California. The high latitude region has a particularly wet climate during the winter months due to its proximity to the Pacific Ocean (Garwood et al., 2020). Although a marginal climate for glaciers, these glaciers persisted into the 21st century due to topographic features where tall headwalls increase shading and enhance localized snow accumulation through avalanching and wind transport.

Although large data gaps exist, clearly the largest amount of ice loss in the Trinity Alps occurred during the first half of the 20th century with a combined area loss of 72% for Grizzly and Salmon glaciers (Garwood et al., 2020; see **Figure 3.11.2**). Since then, the glaciers receded at a much slower but steady rate and persisted even while winter precipitation in the Trinity Alps was below the long-term average (using 1895 to 2015 as baseline) in nine of 20 years from 1996 to 2015, and summer temperatures exceeded the long-term average in 18 years of the same period. Scientists attribute the recent glacial retreat in the Trinity Alps (see Appendix A, **Figure 3.11.A-1** and **Figure 3.11.A-2**) largely to unprecedented and consistently high summer temperatures

coincident with record low winter precipitation in the region during the 2012-2016 drought (Garwood et al., 2020) and persisted through 2021 (Garwood, unpublished data). During the severe drought, snowpack was at an all-time low—no other year since 1950 reported an April 1st snowpack of less than 34% of the historical average in the Klamath Mountains (Garwood et al., 2020).

Technical considerations

Data characteristics

Sierra Nevada

To quantify the change in glacier extent, seven glaciers in the Sierra Nevada were selected based on the availability of past data and location: Conness, East Lyell, West Lyell, Darwin, Goddard, Lilliput, and Picket glaciers (Basagic and Fountain, 2011). Glacier extents were reconstructed using historical photographs and field measurements. Only late summer photographs, largely snow free, were used in the interpretation of the ice boundary. Early 1900 extents were based on ground-based images and evidence from moraines (loose sediment and rock debris deposited by glacier ice). To obtain recent glacier areas, the extent of each glacier was recorded using a global positioning system (GPS) in 2004. The 2014 outlines were derived from aerial photographs acquired by the US Department of Agriculture National Agricultural Imagery Program, 1-meter ground resolution. The 2021 imagery was acquired from DigitalGlobe WorldView © 2021 Maxar, 0.5-meter ground resolution.

Trinity Alps

Long-term changes in glaciers and perennial snowfields were quantified using clearly defined moraines; vertical aerial orthophotos (photographs geometrically corrected such that the scale is uniform); high-resolution satellite images; and GPS mapping (Garwood et al., 2020; Garwood, unpublished data). The 1885 outlines were generated by mapping the ridgelines of prominent Holocene moraines coupled with mapping the near vertical bedrock headwalls at the upper extent of the glaciers.

To examine the response of glaciers and perennial snowfields in the Trinity Alps to variations in climate, changes in glacier area were compared to winter precipitation and summer air temperature from the PRISM re-analysis data (Daly et al., 2008; PRISM

Climate Group 2018), employing a similar analysis as Sitts et al. (2010), using data for the 4 km × 4 km PRISM grid cell centered on Thompson Peak for the period of January 1895 to September 2015.

Strengths and limitations of the data

This indicator relies on data on glacier change based on photographic records, which are limited by the availability and quality of historical photographs. The use of both aerial photographs and satellite images provides high-quality visual data for measuring changes in glacier area. Detailed information about uncertainties associated with mapping the area of glaciers can be found in the methods section of Garwood et al. (2020). A limitation in relying on satellite and photographic images is that change in glacial volume cannot be assessed.

Increasing the number of glaciers studied and the number of intervals between observations would provide a more robust data set for analyzing statistical relationships between glacier change and climatological and topographic parameters. Additionally, volume measurements would provide valuable information and quantify changes that area measurements alone may fail to reveal.

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Appendix A. Historical and Contemporary Glacier Photographs

Historical glacier responses preserved in photographs are important records of past climates in high alpine areas where few other climate records exist. Repeat photographs – paired historical and contemporary images – for selected glaciers are presented below. Additional photographs of the Sierra Nevada, Trinity Alps and other western glaciers can be viewed at the "Glaciers of the American West" web site (PSU, 2021).

Figure 3.11.A-1 Historical and Contemporary Late Summer Photographs of Two Sierra Nevada Glaciers

Dana Glacier



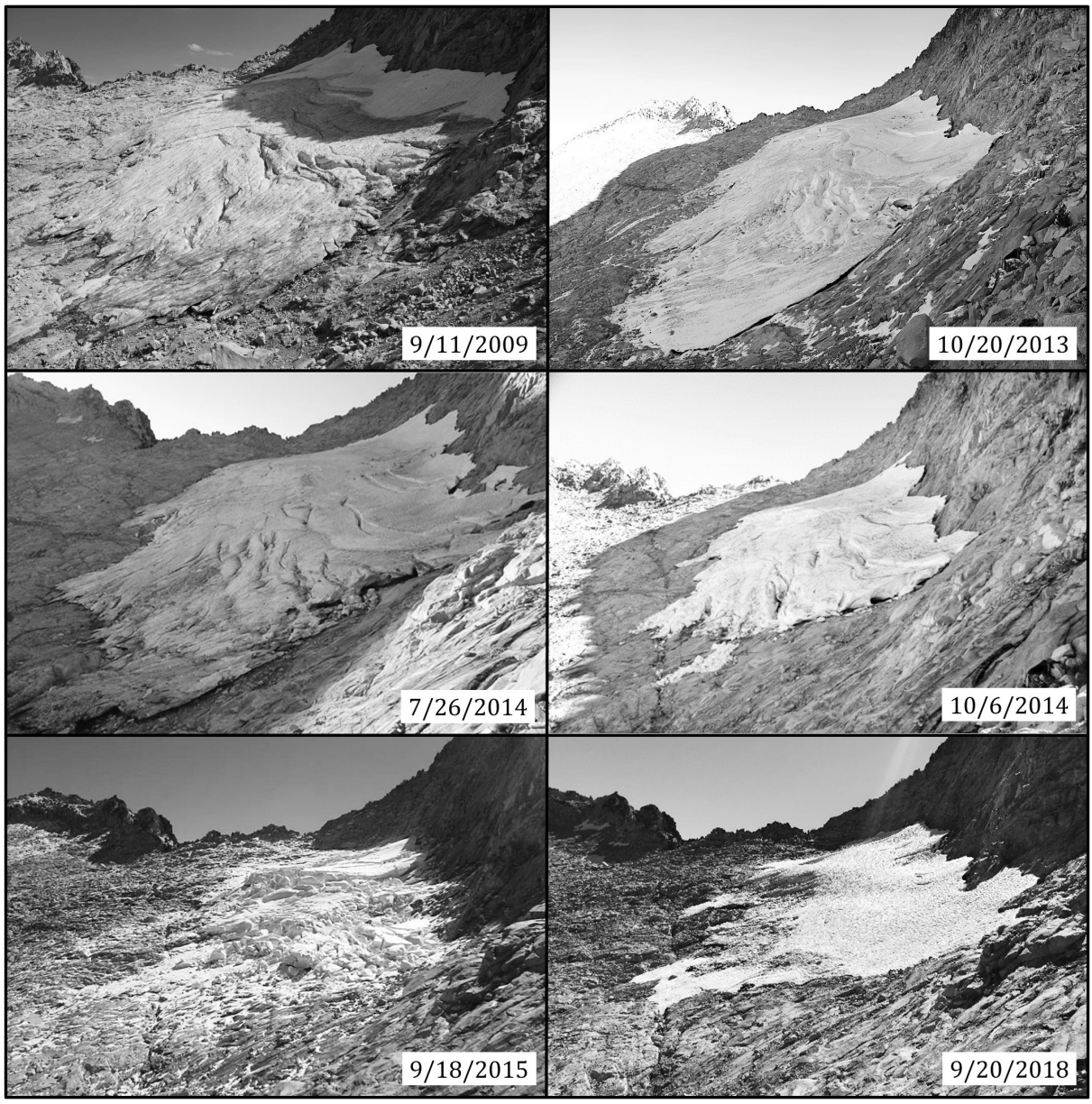
Credit: US Geological Service, photo station ric046: I.C. Russell, 1883 (left); R. Hallnan (right)

Conness Glacier



Credit: National Park Service, photo station Conness 5555 (left); H. Basagic (right)

Figure 3.11.A-2 Grizzly Glacier, repeat photographs



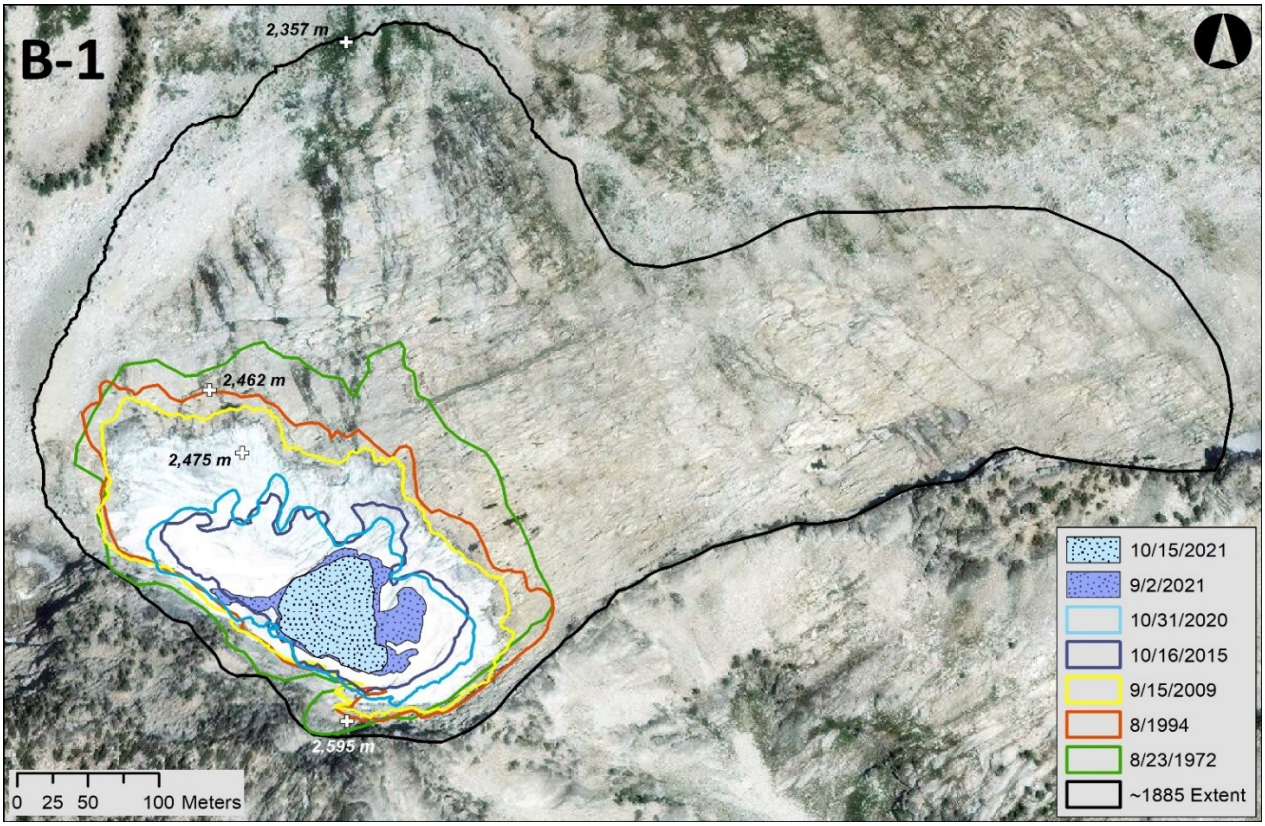
Credit: All photographs taken by J Garwood, with exception of October 2013 by K. Lindke and October 2014 by J. Barnes

Repeat photographs of Grizzly Glacier were taken between September 2009 and September 2018. The lower half of the glacier broke apart in the fall of 2015. A thin layer of fresh snow visible in the September 2015 image accumulated during a brief storm that occurred two days prior to the image date. This snow cover visually exaggerates the actual glacier size beyond the visible pile of scattered ice debris visible in the photo; a result of extreme calving, which is when chunks of ice break off at the

end of a glacier, in the lower half of the feature during the summer of 2015 (Garwood et al., 2020).

Appendix B. Glacier area loss for the Trinity Alps, California

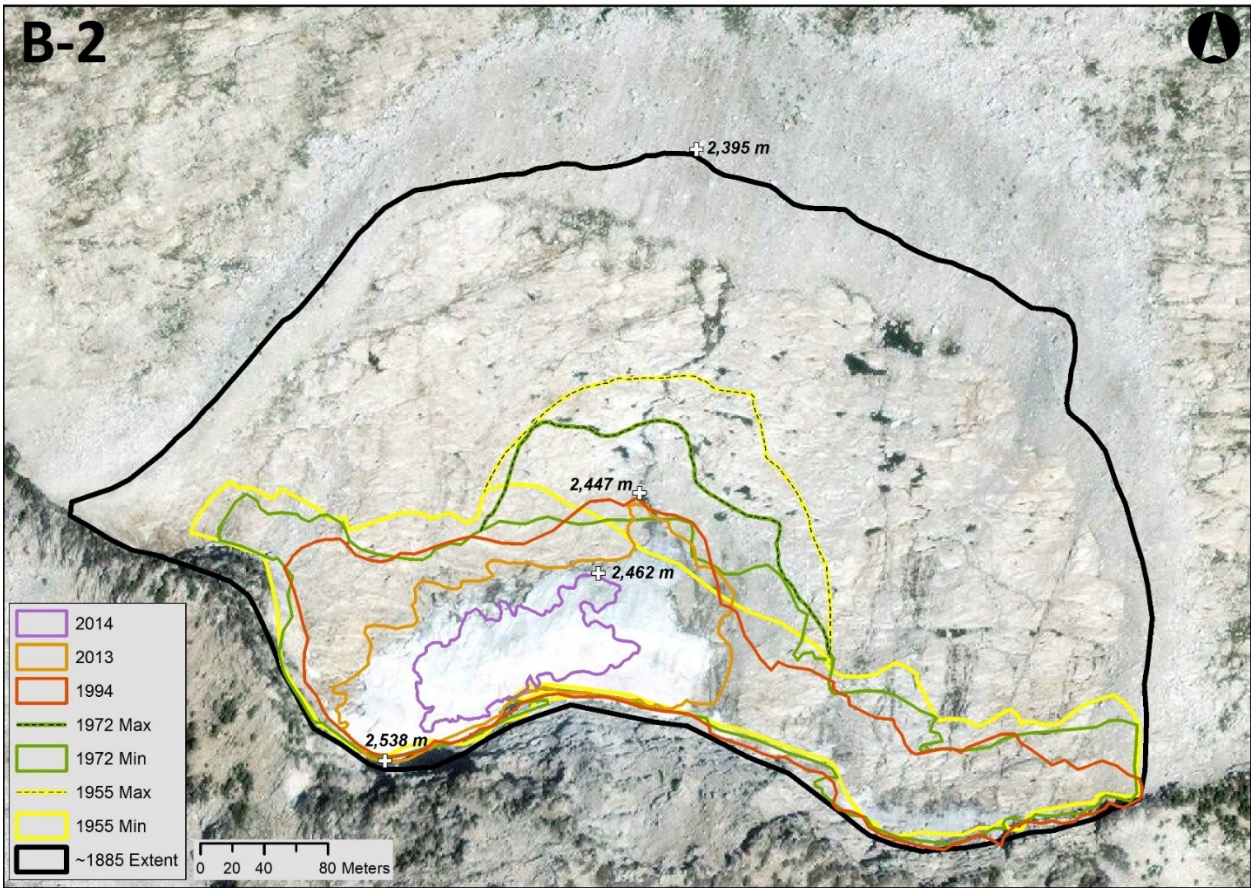
Figure 3.11.B-1 Grizzly Glacier, digitized outlines



Digitized outlines of Grizzly Glacier (B-1) and Salmon Glacier (B-2) from approximately 1885 to 2021. Salmon Glacier disappeared completely by the fall of 2015 while Grizzly Glacier maintained a similar area between 2015 and 2020 before losing 76% of its 2020 area during the summer and early fall of 2021. The 1885 outlines were generated by mapping the ridgelines of prominent Holocene moraines coupled with mapping the near vertical bedrock headwalls at the upper extent of the glaciers. The 1885 outlines represent the most recent Little Ice Age glacial advance. Due to extensive residual snow cover on Salmon Glacier in 1955 and 1972, outlines include a minimum estimated area (solid colors) and additional maximum estimated area (dotted regions). Satellite base image date is from 26 July 2014. Approximate surface elevations are noted at four locations at each glacier.

Source: Garwood et al., 2020 (updated 2021; J. Garwood, unpublished data)

Figure 3.11.B-2 Salmon Glacier, digitized outlines

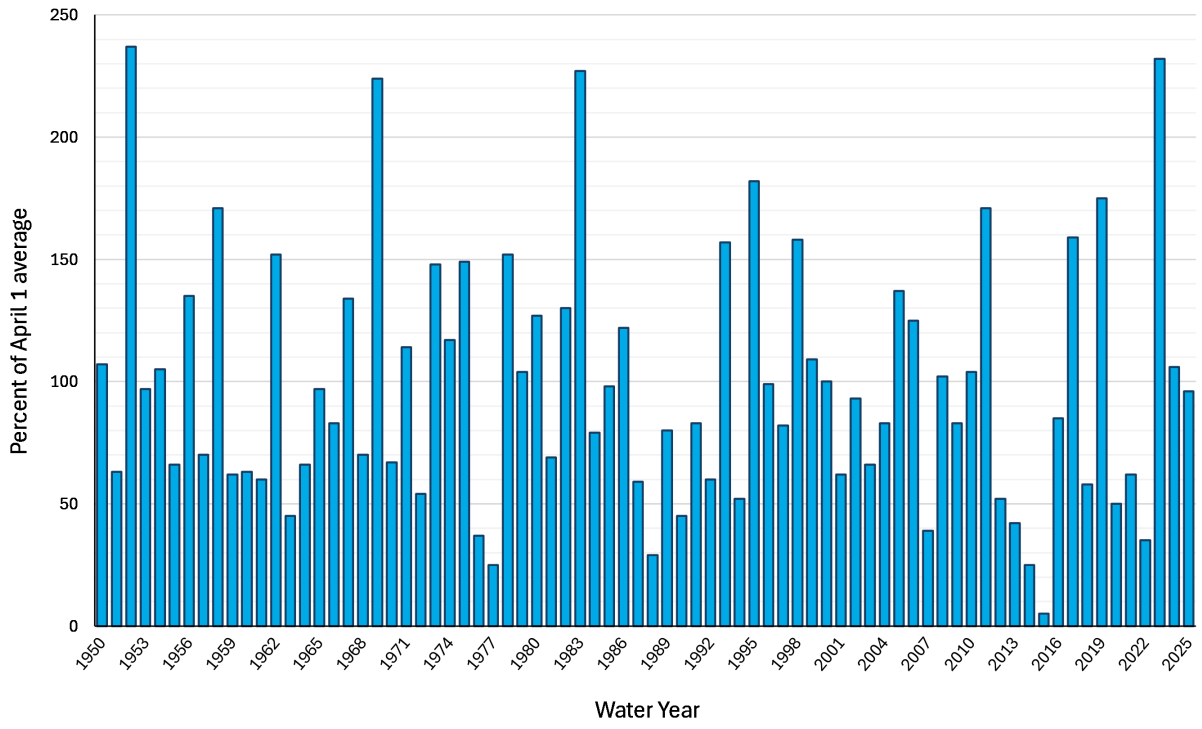


Source: Garwood et al., 2020

3.12 Snow-Water Content

The amount of water stored in the state's snowpack varies greatly from year to year, reflecting the variability in the amount and form of precipitation over California's mountain areas. There has been a small long-term decline across the state's snowpack since measurements began in the 1950s, as rising temperatures shift precipitation from snow to rain and cause earlier snowmelt. Significant, long-term declines in snow-water content occur in the Sierra Nevada and Cascade mountains at elevations below 2500m.

Figure 3.12.1. Statewide April 1 Snow-Water Equivalent (SWE).



This graph shows annual measurements of snow-water equivalent (SWE, also referred to as snow-water content) —the amount of water stored in the snow—on April 1, when California's snowpack typically reaches its peak. The historical average SWE on April 1, based on the water years 1991-2020, is about 28 inches. Source: DWR (2026a)

What does the indicator show?

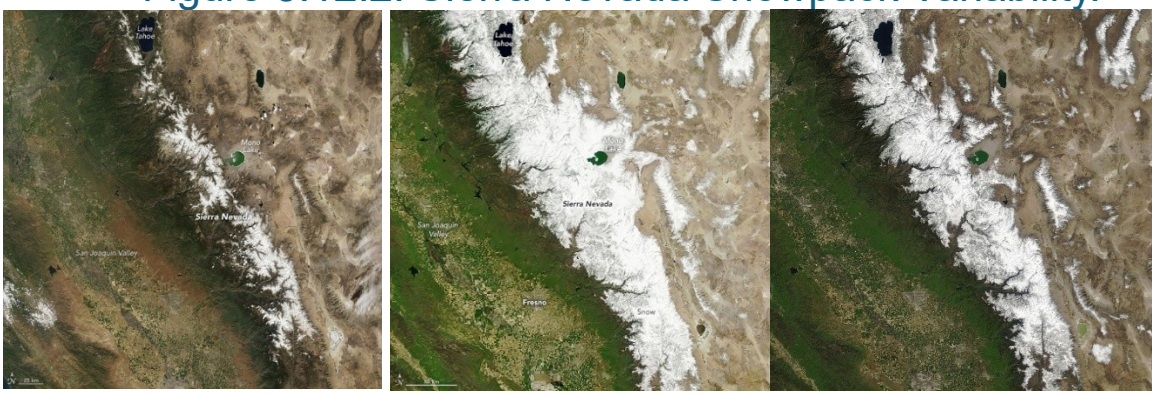
This indicator tracks the amount of water stored in California's snowpack, which typically accumulates from October to March in the Sierra Nevada and southern Cascade Mountains. Although some of this water will be lost to direct evaporation and transpiration, most will be available to percolate into the soil or runoff (see the *Snowmelt Runoff* chapter) into streams and rivers as temperatures rise in spring and summer. California's snowpack has historically stored up to 15 million acre-feet of water – about 35% of the state's reservoir capacity. Peak snow-water equivalent (SWE, the depth of water that would cover the ground if the snowpack were liquid) typically occurring between mid-March and mid-April. April 1 measurements are commonly used to estimate how much water will be released as snowmelt later in the year, though timing can vary by location and year (NRDC, 2014).

Figure 3.12.1 presents this amount of liquid water measured on April 1 each year based on snow course measurements. Snow courses are long-term monitoring locations where SWE is measured by weighing cores of snow pulled from the entire depth of the snowpack at a given location. The measurements represent snowpack conditions at a given elevation in each area. Statewide snowpack is highly variable, with extreme high and low snow years. There has been a small overall decline since snowpack data was first collected in the 1950s. SWE ranged from more than 200% of average in 1952, 1969, 1983, and 2023, to 5% in 2015 during the multi-year drought (2012 to 2016).

The past decade included years that were among the lowest (2013, 2014, 2015 and 2022) and the highest (2011, 2017, 2019, and 2023) on record. Maps of Sierra Nevada snowpack in low (2015), high (2023), and average (2024) snow years are shown in **Figure 3.12.2**. Snowpack in California can swing between "snow droughts" and "snow deluges". Snow droughts occur when SWE is unusually low (Cooper et al., 2016). It can result from either below-average winter precipitation ("dry" snow drought) or from near-normal precipitation when warmer temperatures limit snowpack accumulation ("warm" snow drought) (Harpold et al., 2017). A warm and wet snow drought occurred in the Sierra Nevada in 2026, when hot March temperatures and high-elevation rain

erased the Sierra Nevada snowpack months ahead of schedule (DWR, 2026c). Snow droughts are already more common across the western United States and are projected to become warmer and wetter in future years (Schmitt et al., 2024). On the other end of the spectrum are snow deluges - years of exceptionally heavy snowfall, such as 2023. These events require the unlikely pairing of both cool and wet conditions, and climate projections suggest they will become less frequent as the region warms (Marshall et al., 2024).

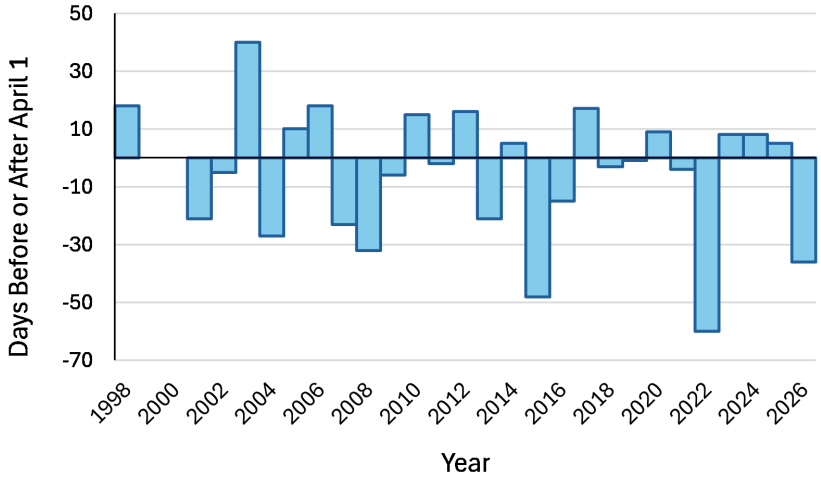
Figure 3.12.2. Sierra Nevada Snowpack Variability.



The following images are taken from satellite data that show the spatial extent of snowpack in late March and early April, around the time when snowpack in Sierra Nevada generally peaks: March 31, 2015 (left, the lowest snow year on record), April 6, 2023 (middle, a high snow year), and April 2, 2024 (right, an average snow year). Source: NASA Earth Observatory

As shown in **Figure 3.12.3**, the California Cooperative Snow Survey recently analyzed peak SWE through the 21st century and found that the average remains close to April 1, but with high variability and earlier peaks in 2015, 2022, and 2026.

Figure 3.12.3. Peak Statewide SWE Relative to April 1.



The figure shows the number of days before or after April 1, the peak statewide SWE occurred that year. Negative values represent number of days before April 1, and positive values represent number of days after April 1. Source: California Cooperative Snow Survey

Why is this indicator important?

California's snowpack acts as a natural reservoir, storing water in the form of snow during the colder months and gradually releasing it as water as it melts during the warmer months. This meltwater feeds into rivers and streams, providing a significant portion of the state's water supply for agricultural, urban, and industrial use (DWR, 2026b). Snowmelt gradually releases cold freshwater into lakes and rivers (see the *Lake Water Temperature* and *Salmon River Water Temperature* chapters), and many aquatic ecosystems in California depend on this seasonal influx (Sadro et al., 2019). In times of low precipitation or reduced water availability, the gradual melt of the snowpack ensures a relatively steady downstream flow, helping to mitigate the impact of drought on water availability (see the *Drought* chapter). Snowfall also creates opportunities for winter sports such as skiing, snowboarding, and snowshoeing, which

contribute significantly to the state's tourism industry, bringing in revenue and supporting local economies (DWR, 2026b).

Tracking SWE provides critical information for managing water supply, mitigating drought, preventing floods, and maintaining ecosystem health. To reduce flood risk, water managers keep space in reservoirs during winter to capture storm runoff. Around April 1, operations shift to storing streamflow for summer use, relying on the snowpack to release water gradually. In high-snow years like 2017 and 2019, early snowmelt in March or April can ease pressure on reservoirs. Whiplash between extreme wet and dry conditions, such as from extreme drought to a record-setting snowpack such as in 2022 to 2023, further complicates water management and flood risk (Jimenez Arellano et al., 2025). Forecasts based on SWE, such as the California Department of Water Resources (DWR)’s Bulletin 120, are critical for managing this balance. Tracking snowpack is also key to assessing drought risk. Low SWE in winter or spring can signal water shortages in summer (NRDC, 2014). Importantly, today’s managed water systems were designed for past climate conditions**.** Adapting to a warming climate will require improved monitoring, forecasting, and integrated water management approaches (Siirila-Woodburn et al., 2021).

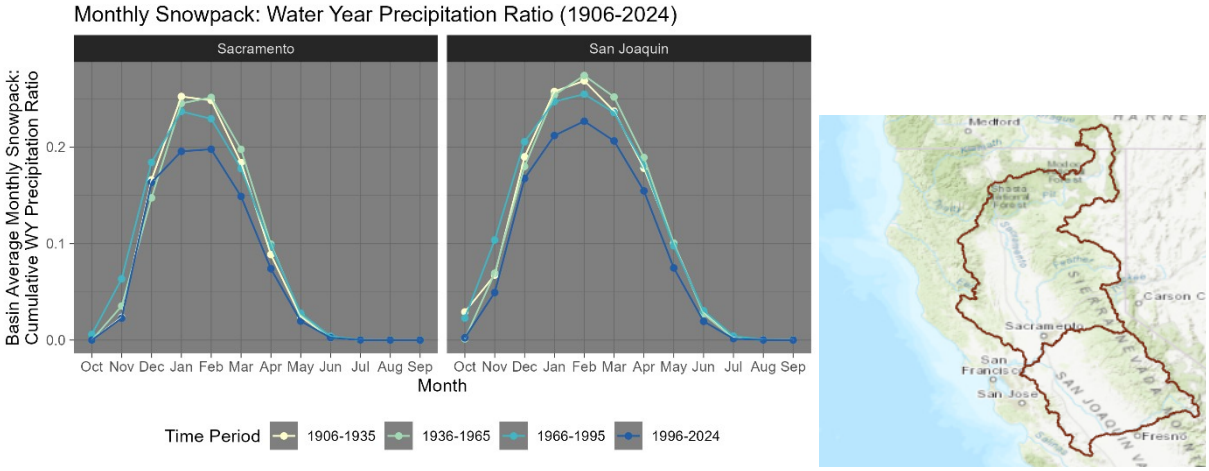
What factors influence this indicator?

Snow forms when air temperatures are near or below freezing (0°C or 32°F) and the ground is cold enough to support accumulation. Colder air produces lighter, drier snow with low water content, while slightly warmer conditions create heavier, wetter snow with more liquid water. Although warmer snow can hold more water, the overall number of days cold enough for snowfall is declining, ultimately reducing the total snow-water stored over a season (UC Davis, 2018).

Warmer temperatures accelerate snowmelt, reducing SWE by the end of the season, especially if precipitation falls as rain instead of snow. Late-season precipitation that falls as rain on snow accelerates snowmelt, resulting in rapid snowmelt that can lead to flooding (Katz et al., 2023; Reis et al., 2026). **Figure 3.12.4** shows that a smaller proportion of annual precipitation is stored as snowpack in recent decades compared with the early 20th century. This pattern is evident in both the Sacramento and San

Joaquin and reflects shift from snowfall toward rainfall as temperatures warm (see the *Precipitation* chapter).

Figure 3.12.4. Ratio of Monthly SWE to Total Precipitation.



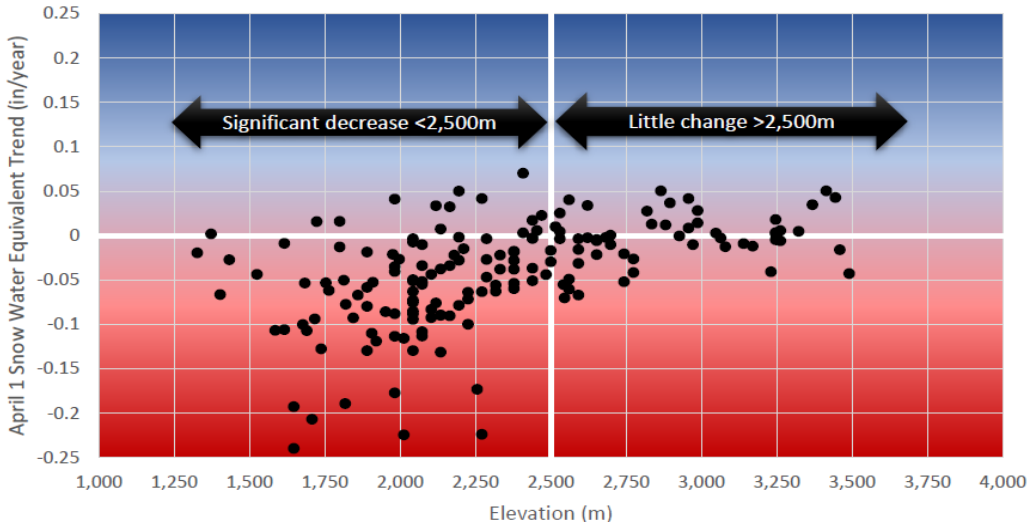
The graphs show the ratio of monthly SWE compared to cumulative water year precipitation for four time periods: 1906-1935, 1936-1965, 1966-1995, and 1996-2024. Values are spatial averages across the San Joaquin and Sacramento watersheds (outlined in map on the right). Monthly values represent the average annual fraction of water year (WY) precipitation stored as snow during each time period. Source: Analyses by Christine Albano (2026). Data is from the USGS ScienceBase-Catalog.

Across western North America, more than one-third of long-term snow monitoring stations show evidence of earlier snowmelt, often occurring before peak snow accumulation is reached (Musselman et al., 2021). In addition, with unabated warming, more than half of precipitation in the Sierra Nevada is projected to fall as rain instead of snow (Beltran-Peña et al., 2025). By late 21st century, snow accumulation in the Sierra Nevada is projected to decline to less than half of the historical average, with the greatest snow loss at mid elevations during fall and spring (Shulgina et al., 2023).

Local characteristics play a role in regional patterns of snowpack. Higher elevations are generally colder, so they often accumulate more snow than lower elevations. The influence of elevation is evident in an analysis of snowpack trends in the Sacramento River, San Joaquin River, and Tulare Lake Basins (**Figure 3.12.5**; Riddlebarger et al., 2021). The snow courses that make up the northern Sierra group in **Figure 3.12.5** are

at lower elevations (average 6,900 feet) compared to the southern group (average 8,900 feet). In the past 70 years, the proportion of precipitation as snow has decreased at the rate of 4% per decade over lower and middle elevation regions of the northern Sierra Nevada, while the highest elevations of the southern Sierra Nevada, where temperatures remain at or below 0°C during winter and spring, showed no declines (Lynn et al., 2020). Consistent with this pattern of lower (and thus warmer) elevations being more susceptible to warming impacts on snowpack, an analysis of April SWE and temperature from 1985 to 2016 found that the northern Sierra Nevada to be more vulnerable to warming than the southern region (Huning and AghaKouchak, 2018). Over the past decade, the average snow level (altitude where precipitation changes from snowfall to rain) along the western slope of the northern Sierra Nevada has risen over 1,200 feet (Hatchett et al., 2017).

Figure 3.12.5. Trends on April 1 SWE at Sierra Nevada and Cascade Mountains Snow Courses.



The figure shows 60-year trends in SWE at each snow course. Trends are represented by each dot. Snowpack has declined at 78% (129 of 166) of the snow courses: snow courses at elevations below 2,500 meters showed negative trends at an overall average of - 0.07 inch/year; at elevations higher than 2,500 meters, the trends clustered between -0.05 and +0.05 inch/year. Source: Riddlebarger et al. (2021)

Warming temperatures are driving snowpack losses across the western United States, beyond what would be expected from natural variability alone (Siler et al., 2019). Reduced snowpack is observed across all months, states, and climates, especially in the spring, in the Pacific states, and in locations with mild winter climate (Mote et al., 2018). California's snowpack trends are consistent with these declines (Mote et al., 2018; Musselman et al., 2021; Siirila-Woodburn et al., 2021). Warm daily maximum temperatures in March and April in the Sierra Nevada are associated with earlier peak snow mass of 0.6 days per decade since 1930, as well as earlier snowmelt and lower SWE (Kapnick and Hall, 2010). Continued warming will likely lead to less snowpack if precipitation does not significantly increase (Knowles and Cayan, 2004), while increased precipitation could partially offset snowpack losses in some higher-elevation areas.

To a lesser extent, SWE may be influenced by the amount of solar radiation reaching the snowpack in each season, which, in turn, depends on cloudiness and timing of the beginning of the snowmelt season (Lundquist and Flint, 2006). Cloudiness decreases solar radiation on the snowfields and would tend to result in less wintertime snowmelt and thus more SWE left by April 1 (the opposite would occur if cloudiness declined in the future).

A potential confounding factor in the variation and trends in snowpack is the effect of dust and air pollutants (including black carbon, a component of soot) on both the initial formation of mountain snowpack and on snowmelt timing. Field measurements and modeling have shown that the presence of dust in the atmosphere, including dust from Asia and the Sahara carried to California by high-altitude winds, may increase snowfall over the Sierra Nevada by serving as ice nuclei, which in turn could contribute to increased snowpack (Ault et al., 2011; Creamean et al., 2013). Recent studies in the Colorado River Basin have helped to quantify important influences on snowmelt timing and, ultimately, amounts that are due to springtime snow albedo (reflectivity) changes associated with dust (mostly from within the region) falling onto snow surfaces across the Western US (Painter et al., 2010). Light-absorbing particles such as black carbon, which in burned forests are deposited onto the snow surface, have been measured in

the Sierra Nevada snowpack at concentrations sufficient to increase surface temperatures and increase snowmelt (Hadley et al., 2010; Huang et al., 2022).

Technical considerations

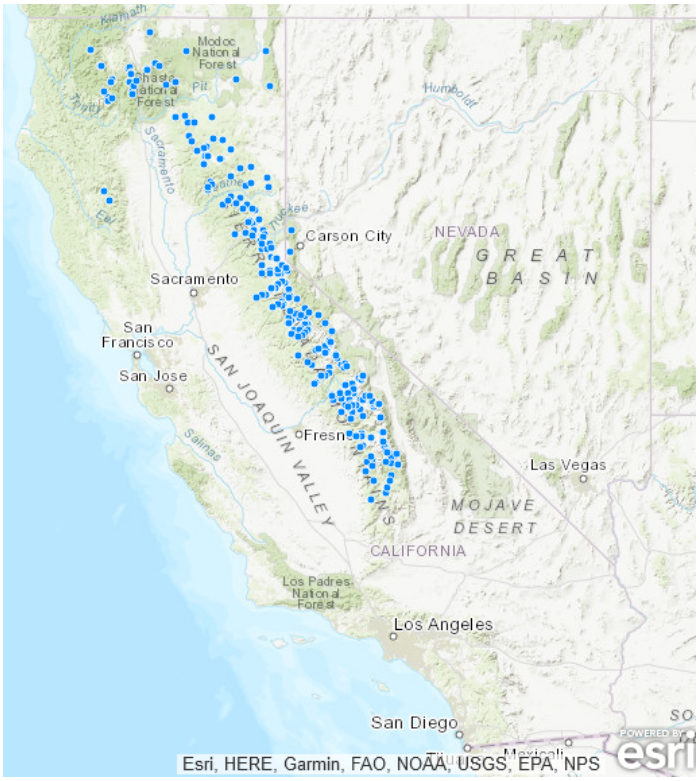
Data characteristics

Statewide SWE is based on observations from permanent snow courses. At these locations, observers collect and weigh snow cores that extend through the full depth of the snowpack. Since the 1930s, within a few days of the beginning of each winter and spring months, measurements have been taken along snow course locations that represent snowpack conditions at a given elevation in each area.

SWE represents the amount of water that would result if the snowpack melted completely. Manual measurements are typically collected near the first of each month from January through May. The April 1 survey is particularly important because it generally occurs near the seasonal maximum snowpack accumulation. The statewide values are based on measurements taken at about 260 snow course stations from the Trinity Alps and Mount Shasta in northern California, and throughout the Sierra Nevada down to the Kern River basin in the south (**Figure 3.12.6**).

Measurements are taken by skiing or flying to remote locations and extracting 10 or more cores of snow along ¼ mile-long pre-marked “snow course” lines on the ground. The depth of snow and the weight of snow on the cores are measured. The weights are converted to a depth of water that would result if snow melted completely, and the results from all the measurements at the snow course are averaged to arrive at estimates of the SWE at that site (Osterhuber, 2014). More than 50 state, federal and private entities have pooled their efforts in collecting snow data from over 250 snow courses in California (see **Figure 3.12.6** for locations).

Figure 3.12.6. Location of Snow Courses.



Map shows areas where SWE is measured during regular snow surveys. Source: California Cooperative Snow Survey

Data from monthly snow surveys are supplemented by daily information from an automatic snow sensor network (often called snow pillows), developed and deployed over the last 30 to 40 years. They serve as a valuable check on the representativeness and accuracy of the snow-course measurements. The snow sensors measure the accumulation and melting cycles in the snowpack, providing data on the effect of individual storms or hot spells. In addition to tracking changes during the snow accumulation season, snow sensor data help greatly in forecasting water volumes involved in the late-season filling of reservoirs.

SWE data for snow courses and snow sensors can be downloaded from the Department of Water Resources' California Data Exchange Center.

Strengths and limitations of the data

The measurements are relatively simple, and the methods have not changed since monitoring started. Averaging 10 or more measurements at each course yields relatively accurate and representative results for each survey. However, snow course measurements are collected at specific monitoring locations and may not fully capture variability across all elevations, terrain types, and snow conditions throughout California's mountain regions. Furthermore, averaging measurements from all sensors obscures localized changes occurring at specific locations.

OEHHA acknowledges the expert contribution of the following to this report:

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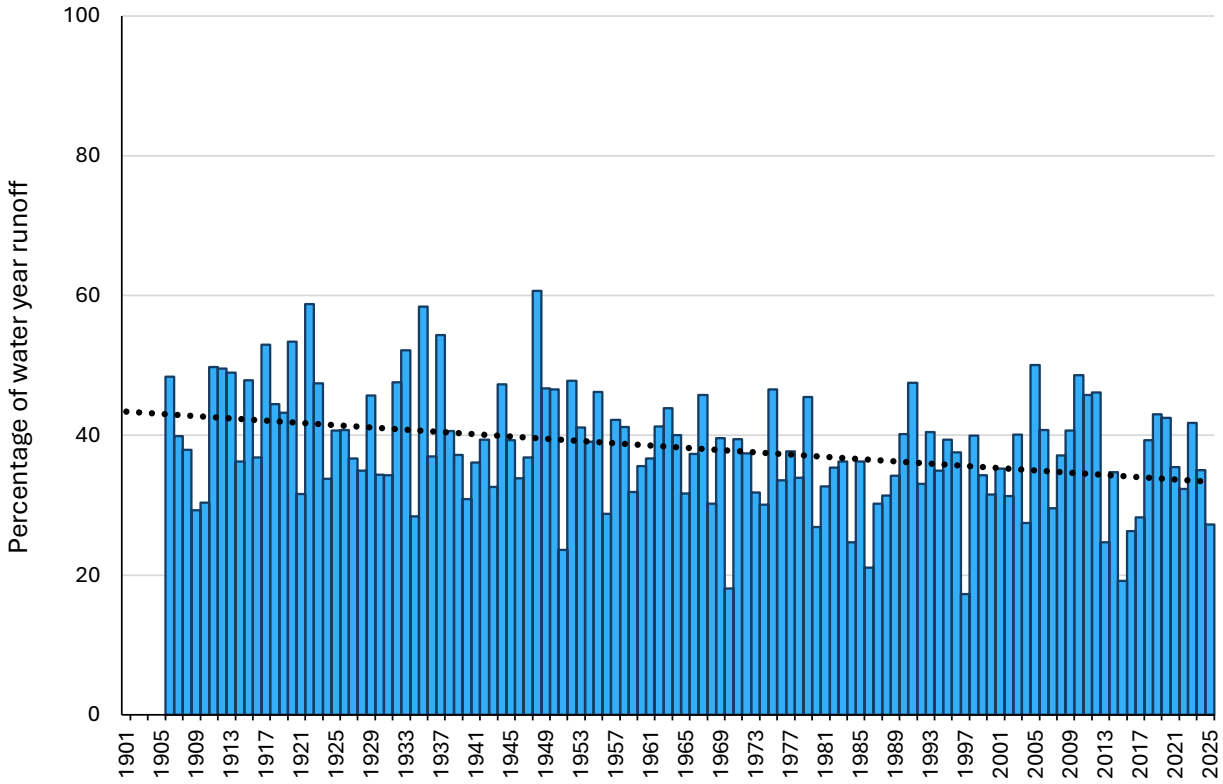
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3.13 Snowmelt Runoff

The fraction of spring (between April and July) snowmelt runoff from the Sierra Nevada into the Sacramento River and the San Joaquin River hydrologic regions has generally declined over the past century relative to total runoff for the water year (October 1 through September 30). The declines are about 20 percent in the Sacramento River and about 12 percent in the San Joaquin River.

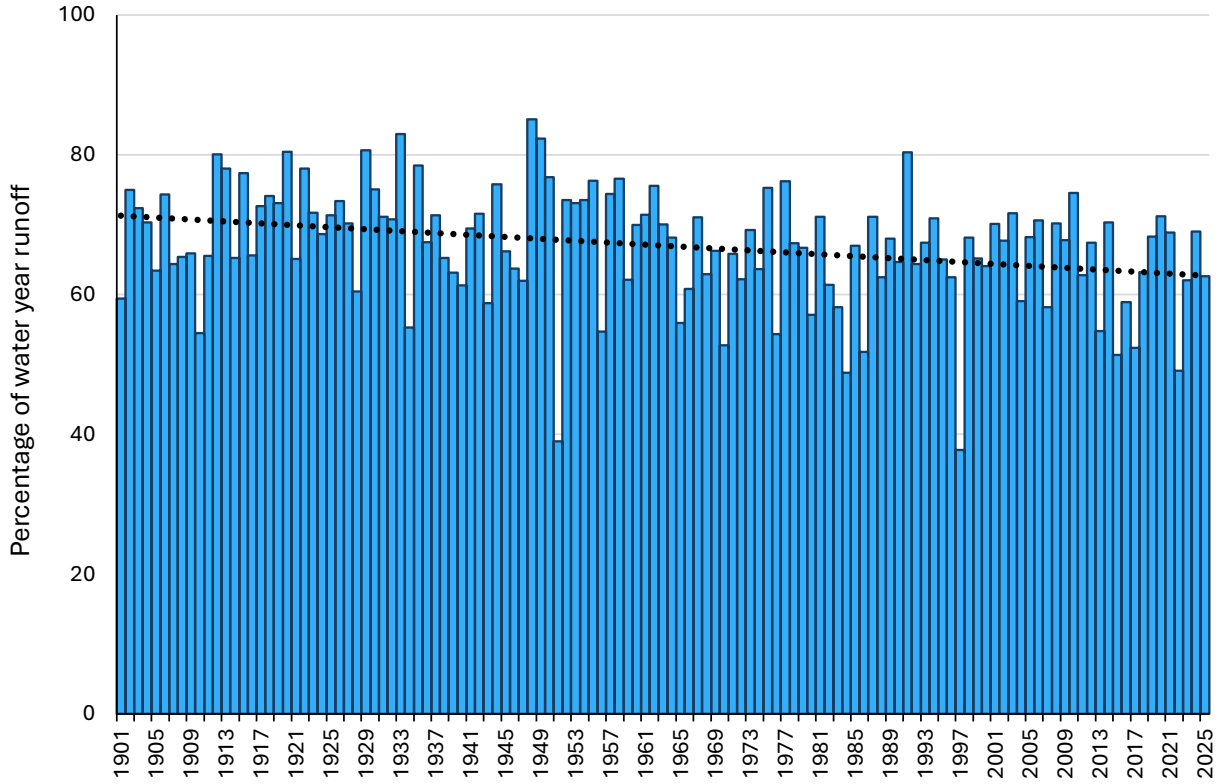
Figure 3.13.1. Sacramento River Spring Runoff.



The Sacramento River, California's longest, flows over 400 miles from the Cascades through the Central Valley, joining the San Joaquin to form the Delta before reaching the Pacific. This graph shows April–July runoff as a percentage of total water year runoff.

Source: DWR (2026)

Figure 3.13.2. San Joaquin River Spring Runoff.



The San Joaquin River, California's second longest, begins in the Sierra Nevada, flows 100 miles west, then turns north for 260 miles before joining the Sacramento River. This graph shows April-July runoff as a percentage of total water year runoff.

Source: DWR (2026)

What does the indicator show?

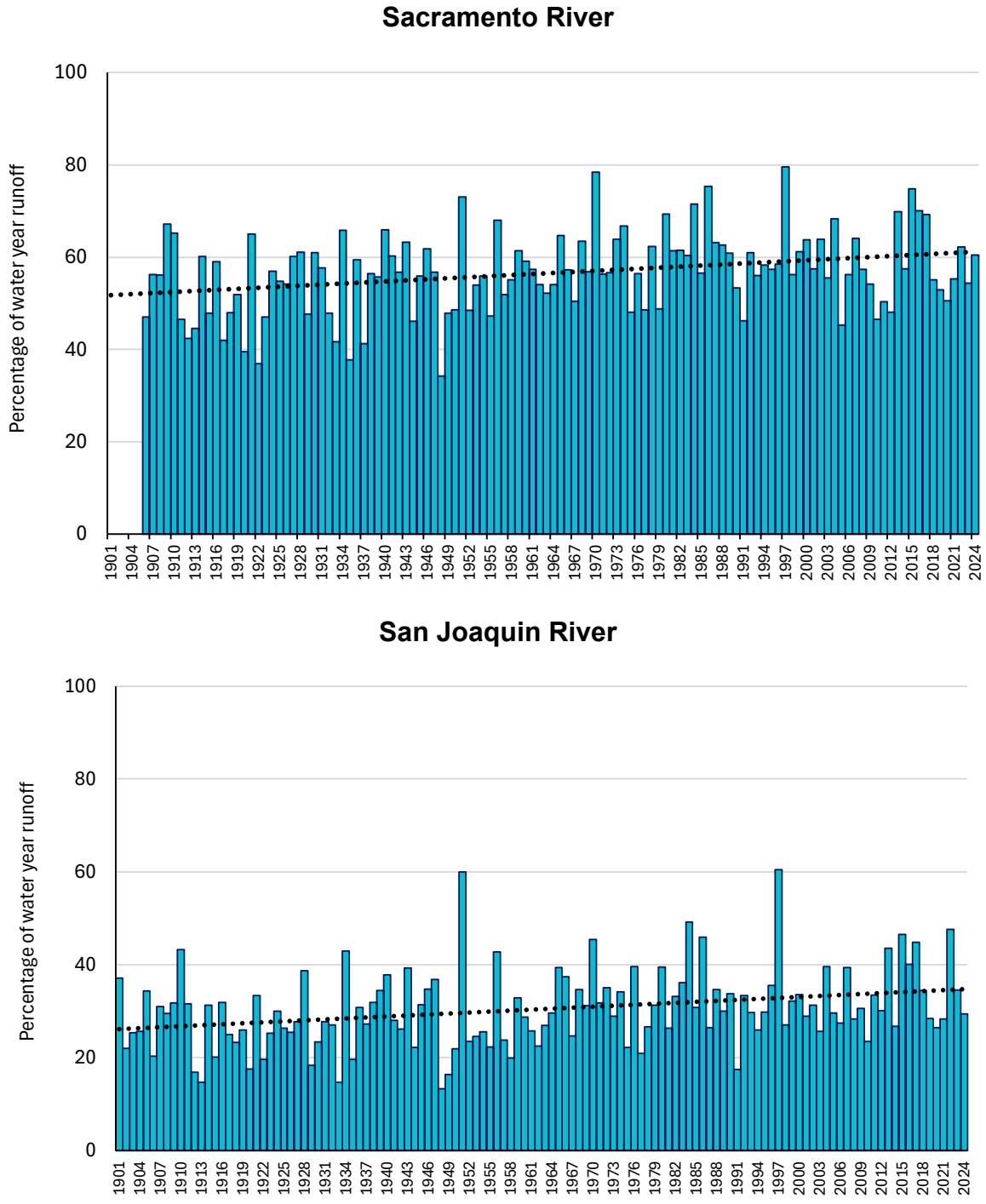
In the spring, snowpack in the Sierra Nevada melts and releases water as runoff. This snowmelt runoff — which typically occurs from April through July — feeds the Sacramento and San Joaquin Rivers, which serve as major sources of water for the state. The proportion of spring (April–July) unimpaired snowmelt runoff flowing into the Sacramento (**Figure 3.13.1**) and San Joaquin (**Figure 3.13.2**) Rivers has declined by ~20% and ~12% over the last century, respectively, with high year-to-year variability. Unimpaired runoff refers to the amount of water generated from melting snow that flows

into rivers and streams under natural conditions (i.e., without alterations from reservoirs, water diversions, etc.).

The earlier arrival of warmer temperatures in the spring causes snow to melt earlier in the year, leading to reduced water availability later in the summer and fall. **Figure 3.13.1** and **Figure 3.13.2** show the spring fraction as a percentage of total runoff for the entire water year, which spans from October through the following September.

In the Sacramento River, two of the last ten years (2015, 2016, and 2025) ranked among the ten lowest in the percentage of total water year runoff occurring in the spring. In the San Joaquin River, three of the last ten years (2015, 2021, and 2022) also had some of the lowest percentages of total runoff in the spring. The 2015 water year also saw the lowest snowpack on record. Winter runoff was exceptionally high in 2017 due to major storm events in January and February. As a result, the spring runoff contributed a smaller percentage of the total water year runoff, despite its volume being large. As the percentage of spring snowmelt runoff has declined over time, the percentage of winter runoff (October–March) has shown a general increase (**Figure 3.13.3**).

Figure 3.13.3. Sacramento and San Joaquin River Winter Runoff.



The graphs show October-March snowmelt runoff as a percentage of total water year runoff.

Source: DWR (2025)

Average values for the percentage of runoff in the spring are higher for the "snow-dominated" San Joaquin River, compared to the "rain-dominated" Sacramento River – about two-thirds and one-third of the total water year runoff, respectively (DWR, 2021). This difference is explained further in *What factors influence this indicator?*

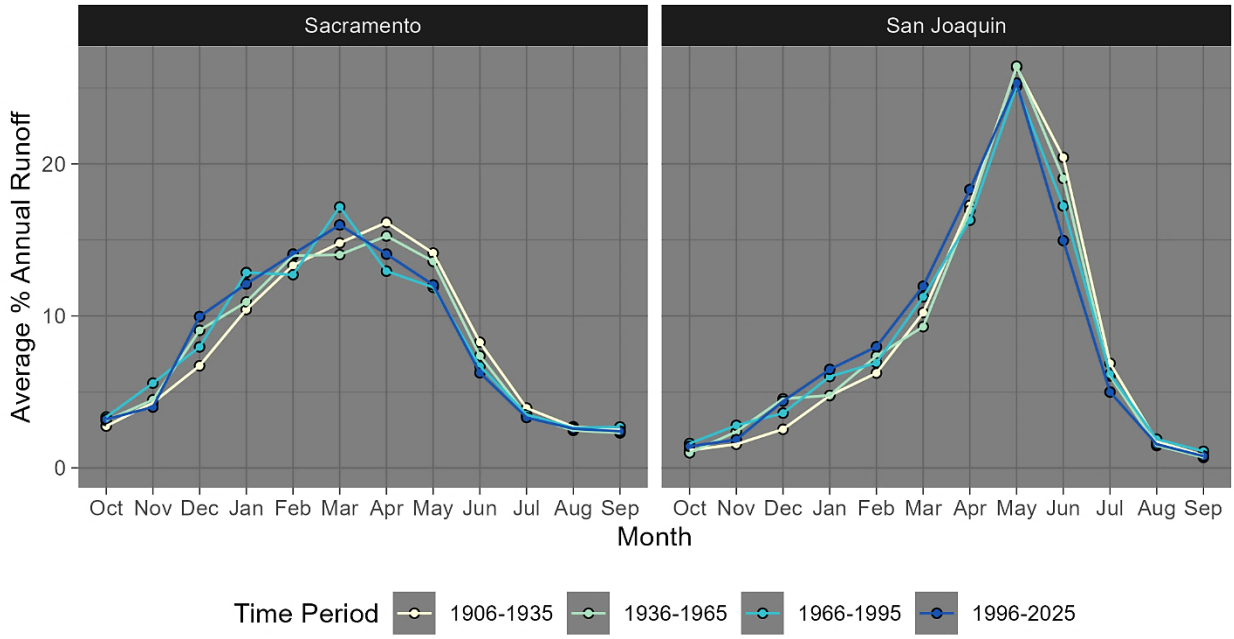
Why is this indicator important?

The Sacramento River and the San Joaquin River, the two largest river systems in California, serve as the major sources of water for the state. Snowmelt runoff into streams and rivers supplies water to meet human needs and to support ecosystems. In the Sierra Nevada and southern Cascade Mountains, snow accumulates from October through March, preserving much of California's water supply in cold storage. As temperatures rise in the spring and there is more daylight and solar radiation, the snowpack melts and releases runoff, typically from April through July.

Spring runoff in these two rivers averages around 14.1 million acre feet (18 billion cubic meters) of water, contributing to about 35% of the usable annual supply for agriculture and urban needs (DWR, 2021; Roos and Anderson, 2006). Spring runoff data, along with related snowpack information, are used for water supply and flood forecasting. (Forecasts of seasonal runoff are published weekly by the Department of Water Resources in Bulletin 120 typically from February through June).

Much of the state's flood protection and water supply infrastructure was optimized for historical conditions to capture high volumes during winter storms to prevent flooding. In the spring, as much streamflow as possible is captured and stored in reservoirs to be delivered for multiple uses during the drier summer and fall months. Changes to spring runoff patterns, such as the timing of peak monthly runoff, can strain the current water management system, requiring adjustments in water storage and flood strategies. In the last 60 years, peak runoff in the Sacramento River has shifted earlier by a month (March instead of April), compared to earlier years in the record (1906-1965); no such shift is seen in the San Joaquin River (**Figure 3.13.4**). Sacramento River watersheds are located at lower elevations and thus more vulnerable to changes in snowpack than the snow-dominated San Joaquin River watersheds.

Figure 3.13.4. Monthly Average Runoff as Percent of Annual (1906-2025).



A comparison between historical and current 30-year averages of the fraction of total water year runoff that occurs each month shows peak runoff occurring earlier in recent years in the Sacramento River, while the San Joaquin River is largely unchanged.

Source: DWR (2025), analysis by Christine Albano

The earlier onset of spring runoff generally results in less available water in warmer months for domestic and agricultural uses, hydroelectric power production, recreation and other uses. This results in lower soil moisture, which could stress vegetation, leading to tree deaths and increasing wildfire risk. Changes in the amount and timing of snowmelt runoff can alter streamflow and impair cold-water habitats, particularly for salmonid fishes (Halofsky, 2021; Roos, 2000). Runoff during rain-on-snow events – when rain falls on existing snowpack – has been associated with mass erosion of slopes, damage to riparian zones, and downstream flooding (Li et al., 2019). Warming temperatures increased runoff during the large storms of February 2017 by about 30% (Huang et al., 2018).

Tribal Connection 3.13.1

Earlier and more concentrated snowmelt runoff is also occurring east of the Sierra Nevada. A Tribal member from the Big Pine Paiute Tribe of the Owens Valley notes that this snowmelt runoff is less easily absorbed by drought-impacted land. "*In addition to wildfire and drought, the region has also faced climate extremes in the form of heavy snowmelt and runoff. In 2023, a season of significant snowfall in the Sierra Nevada was followed by a rapid and intense melt, forcing the community to prepare for possible flooding. This was not a new concern—Big Pine and the surrounding areas have experienced flash flooding before, particularly when the land becomes too saturated to absorb additional water. Historically, water flowing off the mountains during the spring melt was absorbed by the valley's meadows, wetlands, and creeks, but with shifts in precipitation timing, land development, and soil health, the ability of the land to buffer these events has weakened. Much of the land where one of our Tribal groups traditionally lived lies directly in a floodplain, placing areas of cultural and ancestral importance at continued risk. These patterns further underscore how the challenges we now face are not isolated or seasonal—they are cumulative, intersecting, and deeply tied to both climate and the long-term legacy of altered land management*" (Big Pine Paiute Tribe, 2026).

What factors influence this indicator?

Snowmelt is directly influenced by the amount of precipitation that falls as snow. The amount of water stored in the snow is known as the snow water equivalent and is highly variable from year to year. Lower water volumes of spring snowmelt runoff compared to the rest of the water year (**Figure 3.13.3**) indicate warmer winter temperatures or early onset of warm springtime temperatures. With warmer winter temperatures, a greater proportion of precipitation occurs as rain, and snow falls and accumulates less at lower elevations than in the past. Higher elevations of the snow line mean reduced snowpack and runoff in the spring.

Increased winter snowmelt was found to be highly sensitive to temperature, as indicated by long-term trends in temperature and snowmelt data at a significant percentage of

snow monitoring stations across western North America (Musselman et al., 2021). In the Sierra Nevada, the peak snow mass and snowmelt shifted earlier over the past 30 years, as daily maximum temperatures increased in March and April (Kapnick and Hall, 2010). Years of "snow drought"—defined as anomalously low snow-water content due to either a lack of winter precipitation (dry snow drought) or lack of snow accumulation despite normal winter precipitation (wet snow drought; Harpold et al. 2017; also see the *Snow-Water Content* chapter)—between 1951 and 2017 originated and evolved in various ways in the northern Sierra Nevada (Hatchett and McEvoy, 2018), including from extreme early season precipitation, frequent rain-on-snow events, lower fractions of precipitation falling as snow, and midwinter peak runoff events. These conditions are generally associated with earlier snowmelt runoff.

The characteristics of a watershed affect changes in runoff. As previously mentioned, due to being located at lower elevations, the Sacramento River watersheds are more vulnerable to reduced snowpack than the San Joaquin River watersheds. A study of projected changes in runoff in the 21st century found that the rain-dominated Sacramento watersheds will experience earlier and increased amounts of peak runoff; in contrast, in the snow-dominated San Joaquin watersheds, runoff peak timing and amounts are projected to remain relatively unchanged (He et al., 2019; He et al., 2021).

Technical Considerations

Data characteristics

Runoff for the Sacramento River system is the sum of the estimated unimpaired runoff of the Sacramento River and its major tributaries, the Feather, Yuba, and American Rivers. "Unimpaired" runoff refers to the amounts of water produced in a stream unaltered by upstream diversions, storage, or by export or import of water to or from other basins.

The California Cooperative Snow Surveys Program of the California Department of Water Resources (DWR) collects snow water data. Runoff forecasts are made systematically, based on historical relationships between the volume of April through July runoff and the measured snow water content, precipitation, and runoff in the preceding months (Roos, 1992).

Related snowpack information is used to predict how much spring runoff to expect for water supply purposes. Each spring, approximately 50 agencies, including the United States Departments of Agriculture and Interior, pool their efforts in collecting snow data at about 260 snow courses throughout California. A snow course is a transect along which snow depth and water equivalent observations are made, usually at ten points. The snow courses are located throughout the state from the Kern River in the south to Surprise Valley in the north. Courses range in elevation from 4,350 feet in the Mokelumne River Basin to 11,450 feet in the San Joaquin River Basin.

Since the relationships of runoff to precipitation, snow, and other hydrologic variables are natural, it is preferable to work with unimpaired runoff. To get unimpaired runoff, measured flow amounts have to be adjusted to remove the effect of infrastructure or water management operations such as reservoirs, diversions, or imports (Roos, 1992). The water supply forecasting procedures are based on multiple linear regression equations, which relate snow, precipitation, and previous runoff terms to April-July unimpaired runoff. Major rivers in the forecasting program include the Trinity, Pit, McCloud, Sacramento, Feather, Yuba, American, Cosumnes, Mokelumne, Stanislaus, Tuolumne, Merced, San Joaquin, Kings, Kaweah, Tule, Kern, Truckee, East and West Carson, East and West Walker, and Owens.

A Basin Characterization Model was used to determine historical and current 30-year averages of the fraction of total water year runoff that occurs each month in the Sacramento River and San Joaquin River. The Basin Characterization Model is a 270-meter resolution gridded model that uses weather variables from the PRISM dataset and information on terrain, geology, soil, and land cover to simulate monthly snowpack, soil moisture, runoff, and recharge dynamics across the state of California from 1896 to present. It does not account for water management and land use disturbances so is intended as an approximation of natural hydrologic conditions. Data are available from the US Geological Survey at: https://www.usgs.gov/data/basin-characterization-model-a-monthly-regional-water-balance-software-package-bcmv8-data

Strengths and limitations of the data

River runoff data have been collected for over a century for many monitoring sites. Stream flow data exist for most of the major Sierra Nevada watersheds because of California's dependence on their spring runoff for water resources and the need for flood forecasting. The April to July unimpaired flow information represents spring rainfall, snowmelt, as adjusted for upstream reservoir storage calculated depletions, and diversions into or out from the river basin. Raw data are collected through water flow monitoring procedures and used, along with other variables, in a model to calculate the unimpaired runoff of each watershed.

Instrumentation and measurement methods have generally improved over time, strengthening the reliability of monitoring data. However, some monitoring sites have been relocated short distances, and variations in streambed shape can affect the accuracy of flow measurements. Most foothill sites, though, have relatively stable streambeds that minimize this limitation.

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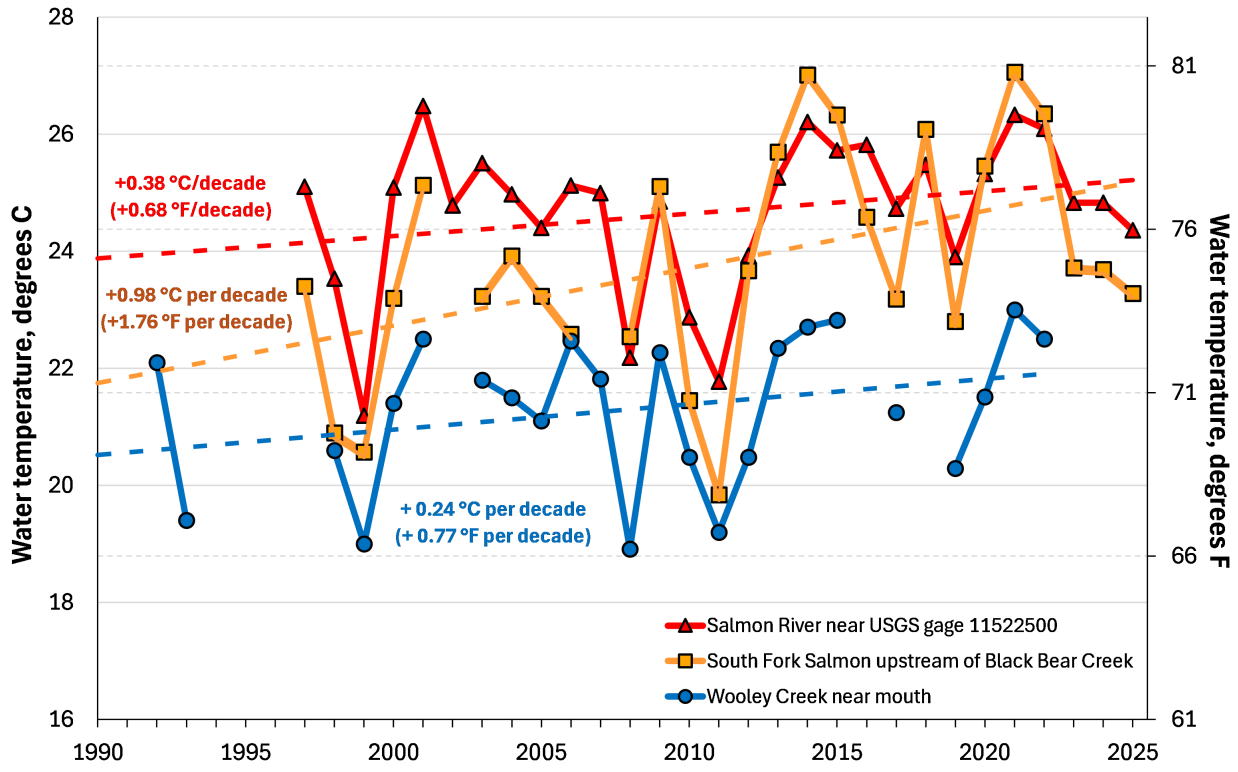
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3.14 Salmon River Water Temperature

Water temperatures in the Salmon River and its tributaries have been warming, coincident with warming air temperatures and decreasing snowpack. The watershed has been relatively little altered by human activities and has no dams. The river's aquatic life, including salmon, depends on cold-water conditions, making it suitable for tracking the ecological effects of climate change.

Figure 3.14.1. Salmon River Water Temperatures* (1992-2025).

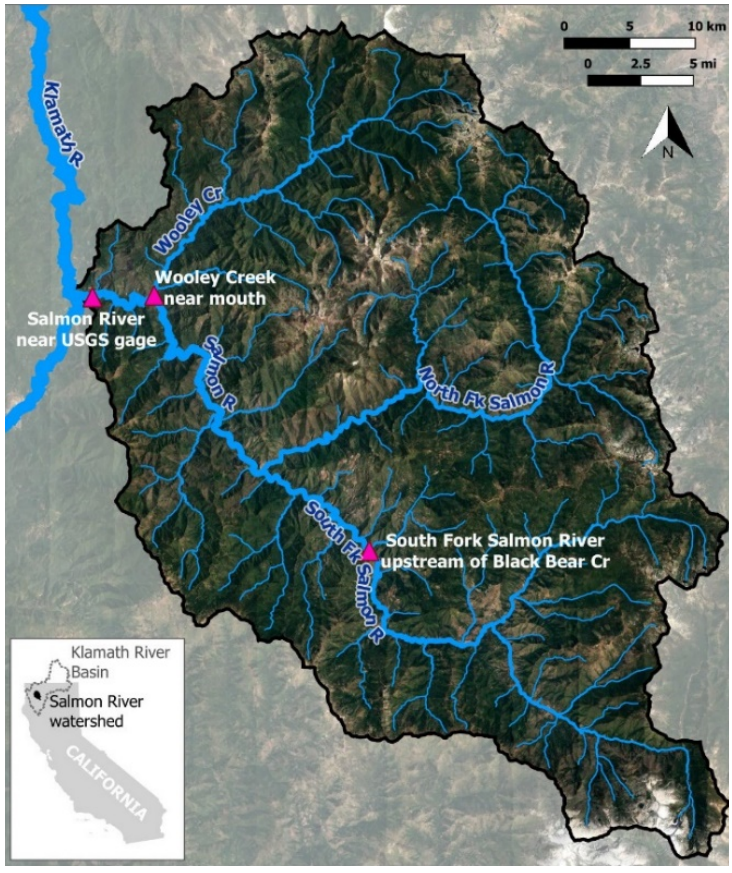


The figure above shows annual maximum temperatures -- i.e., the highest instantaneous temperature--during the summer, at three monitoring sites in the Salmon River watershed. Dashed lines denote linear trends. Source: SRRC, Karuk Tribe, and USFS (2026)

What does the indicator show?

From 1992 to 2025, water temperatures, measured as annual maximum temperature (AMT) at three sites in the Salmon River watershed (**Figure 3.14.1**) are trending higher. The Salmon River watershed is a 750 square mile sparsely populated area in Siskiyou County surrounded by subranges of the Klamath Mountains. Temperatures at the South Fork Salmon River site upstream from Black Bear Creek are increasing the fastest, with a rate of 1.8 degrees Fahrenheit (°F) per decade, or 0.98 degrees Celsius (°C) per decade. Water temperatures at the Wooley Creek and Salmon River at US Geological Survey (USGS) gage stations are increasing more slowly, with rates of 0.68°F (0.38°C) and 0.77°F (0.43°C) per decade, respectively.

Figure 3.14.2. Location of Three Temperature Monitoring Sites in the Salmon River Watershed.



Source: Riverbend Sciences

The three monitoring sites (shown in **Figure 3.14.2**) are a subset of many sites throughout the Salmon River and its tributaries where water temperatures are monitored. A previous analysis combined 27 long-term sites in the watershed to assess collective trends for the month of August during the period 1995 - 2017, finding that daily maximum temperatures warmed by 0.70°F per decade (0.39°C per decade) and daily mean temperatures warmed at a rate of 0.38°F per decade (0.21°C per decade) (Asarian et al., 2019). Years showing higher water temperatures generally coincided with low flows and high air temperatures; years reporting the lowest stream temperatures coincided with high flows and cool air temperatures (Asarian et al., 2019).

Why is this indicator important?

Water temperature is a fundamental regulator of river ecosystems. It influences species' metabolism, growth rates, reproduction and distributions (David et al., 2018). The Salmon River watershed provides cold water habitat for anadromous fish, notably steelhead and coho and Chinook salmon. Identified as a Key Watershed by the US Forest Service, it serves as a refugia for at-risk salmon and steelhead stocks in the Pacific Northwest (Elder et al., 2002). This river system still retains wild runs of salmonid species that have disappeared from much of their historic range within California (SRRC, 2020).

Although the Salmon River (**Figure 3.14.3**) is still affected by the legacy of historic mining that began in the mid-19th century during the California Gold Rush, and some of the watershed's forests have been logged, today's relatively modest human influences make it an excellent location for tracking the effect of climate change on water temperatures (Asarian et al., 2019). The river has no dams and much less water is diverted for human uses in the Salmon River watershed than in other areas of California due to the area's low population density.

Warming summer water temperatures threaten the production and health of culturally and economically important fish in the Salmon River watershed (Asarian et al., 2019). Higher temperatures can increase metabolic demands, susceptibility to disease and pose a threat to fish populations, especially to spring-run Chinook salmon. Fish live in these habitats through the entire summer. Under current conditions, temperatures in

portions of the river and its tributaries are likely to exceed thermal suitability for this species during the hottest periods in summer. The survival of the dwindling population of spring Chinook salmon, as well as coho salmon, hangs in the balance. These fish are critical to food security, cultural survival and well-being of the Karuk Tribe and other indigenous peoples in the Klamath Basin (Karuk Tribe, 2016) (see *Chinook Salmon Abundance* chapter for further discussion).

Figure 3.14.3. Salmon River.



The Salmon River flows from the high elevations of the Salmon Mountains, a sub-range of the Klamath Mountains, in Northern California. It is the second largest tributary to the Klamath River and joins the Klamath at Somes Bar, California, about 106 km (66 miles) upstream from the Pacific Ocean. Photo credit: USDA Forest Service

The Karuk Tribe's Ancestral Territory occupies 60% of the Salmon River watershed, a sub-basin of the larger Klamath River Basin (Elder et al., 2002). The Karuk consider the Salmon River sub-basin as one of the most culturally significant watersheds within the Klamath National Forest. There is a strong commitment for cooperative stewardship of the watershed among residents, the Salmon River Restoration Council (SRRC), the Karuk Tribe, the US Forest Service (USFS), and the California Department of Fish and Wildlife (CDFW) (Elder et al., 2002).

In 1994, the North Coast California Regional Water Quality Control Board and the US Environmental Protection Agency determined that beneficial uses in the Salmon River, including cold water salmonid fisheries, are impaired due to elevated water temperatures (NCRWQCB, 2005). Regulations intended to address those impairments were adopted in 2005. Coho salmon in the basin are state and federally listed as threatened (NCRWQCB, 2005). Spring Chinook salmon were listed as endangered by the state of California in June 2021 (Karuk Tribe, 2021). The removal of four dams on the mainstem Klamath River in 2024 provided spring Chinook salmon opportunities for re-establishing populations in their former habitats upstream of the Salmon River (ODFW and The Klamath Tribes, 2021).

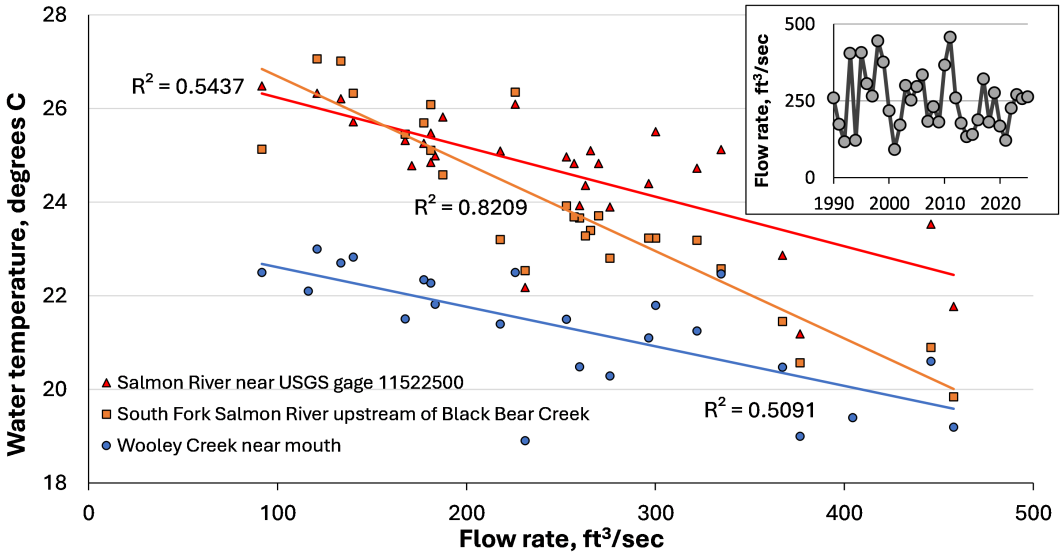
What factors influence this indicator?

Summer stream temperatures in the Salmon River and its tributaries are trending warmer due to warming air temperatures, decreased snowpack, earlier snowmelt and spring runoff, and decreases in water flow (Asarian et al., 2019; see the *Snow-Water Content* and *Snowmelt Runoff* chapters). Years of low snowpack and snow water runoff tend to yield decreases in stream and river flow in watersheds (Asarian, 2020). Since the 1940s, April 1 snowpack has been decreasing in the Salmon River watershed (CDEC, 2021; Van Kirk and Naman, 2008). Since summer river flow is strongly influenced by snowpack, temperatures at the South Fork Salmon River site are particularly sensitive to climate change and have warmed relatively rapidly since monitoring began in 1997. Water temperature has been increasing at the highest rate at this location (**Figure 3.14.1**). A symptom of warmer temperatures and less snow is the extinction of the Salmon Glacier in the Trinity Alps at the headwaters of the Salmon

River's South Fork in 2015 following a multi-year drought and many decades of ice loss (Garwood et al., 2020; also see *Glacier change* indicator). The nearby Grizzly Glacier has since gone extinct as well. In previous decades, these glaciers fed cold water to streams during the summer.

Streamflow is an important determinant of water temperature (Asarian et al., 2023a and b). River and stream temperatures are cooler when flows are high and warmer during years with diminished flows. **Figure 3.14.4** shows the relationship between stream flow rates during the month of August at the Salmon River monitoring station and maximum temperatures at the three stations shown in **Figure 3.14.1**. Low August flow rates coincided with warmer stream temperatures in 2001, 2014, and 2015. Conversely, higher flow rates in 1999, 2010, and 2011 corresponded with much cooler stream temperatures during those years.

Figure 3.14.4. River Water Temperatures and August Stream Flow.



Annual maximum water temperatures from 1992 to 2020 at the three monitoring sites are plotted against average August streamflow measured at the Salmon River monitoring station (at Somes Bar, USGS Gage 11522500). (R^2 values indicate the strength of the correlation; a value of 1 indicates a perfect correlation between the variables.) The inset graph presents annual average August streamflow over the past 30 years. Source: Water temperature data from SRRC, Karuk Tribe, and USFS (2026); Streamflow data from USGS (2026)

Other physical factors also influence water temperatures in streams and rivers, including solar radiation, heat radiated from objects (e.g., clouds and vegetation), evaporation, convection of heat from air to water, conduction of heat between the water and stream bed, and mixing of water from different sources (Dugdale et al., 2017). During the summer, water temperatures in streams and rivers with wider channels that are more exposed to solar radiation tend to be warmer than water upstream in small well-shaded streams. Water temperatures fluctuate over time in response to atmospheric conditions (air temperatures, clouds, and smoke), hydrologic conditions (snowmelt, rain, stream flow, and groundwater), and growth or loss of vegetation. Factors affecting spatial patterns in water temperature include elevation (cooler air temperatures at higher elevations), topography (mountainous terrain reduces solar exposure), and near-stream vegetation (cooler temperatures where trees provide shade). Wooley Creek flows through steep, mountainous terrain, which partially protects it from solar radiation and keeps its waters relatively cool for its size. Temperatures are increasing at a slower rate at Wooley Creek due to these characteristic features. Because near-stream vegetation helps regulate water temperature through shading, changes in vegetation resulting from wildfires can also affect stream temperatures. Fire plays an integral role in regulating vegetation in the Salmon River watershed. Prior to fire suppression that became effective in the early/mid-20th century, fires burned more frequently and typically in smaller patches compared to what is occurring today (Skinner et al., 2018). Approximately a century of fire suppression has dramatically altered forest structure and fuel continuity. As a result, when fires now occur and escape containment, the probability of high fire severity is increased, which can reduce stream shade and increase water temperature (Karuk Tribe, 2016).

Researchers have been studying the effects of wildfire smoke and its potential to cool water temperatures. David et al. (2018) analyzed ground-based measurements of air and water temperatures from 12 stations throughout the lower Klamath River Basin in correlation with atmospheric smoke data derived from satellite imagery during six years with widespread wildfires. The analysis indicated that wildfire smoke had a cooling effect on both air and water temperatures at all study locations. This smoke-induced cooling has the potential to benefit cold-water adapted species, particularly because

wildfires are more likely to occur during the warmest and driest years and seasons. A follow-up analysis of a larger number of stations showed the cooling effects of smoke were greater in August than in other months and were stronger in larger waterbodies than smaller waterbodies (Asarian et al., 2020). Wildfire smoke has limited the increases in August water temperatures but has not affected annual maximum water temperatures because in most years fires do not start until after the year's hottest water temperatures have already occurred. The Karuk Tribe has used fire to manage the mid-Klamath landscape since time immemorial and has proposed using prescribed fire smoke as an emergency measure to cool potentially lethal stream temperatures in fish habitat areas (Karuk Tribe, 2019).

Researchers conducted an analysis of both climate and non-climate factors and their comparative influence on August stream temperatures using statistical models (Asarian et al., 2019). Climate parameters evaluated were streamflow, air temperature, snowpack, and smoke; the non-climate parameters included landscape features such as riparian vegetation and river channel morphology. Results indicated that warming stream temperatures observed across the Salmon River watershed are largely attributed to climate conditions. The greatest amount of warming occurred at sites where temperatures are highly sensitive to river flow, including the South Fork of the Salmon River.

Technical considerations

Data characteristics

SRRC; the Karuk Tribe; and USFS [Klamath National Forest (KNF) and Six Rivers National Forest (SRNF)] have been monitoring water temperatures in the Salmon River watershed since 1990 using automated probes that record measurements every 15–60 minutes. Probes are placed in well-mixed flowing water and are intended to represent overall conditions (i.e., "stream temperature"), not isolated pockets of cold or warm water. At most sites, probes are deployed in late spring or early summer, remain through the summer, and are retrieved in the fall for data download (KNF, 2011). A few sites are monitored year-round.

Although many sites are monitored, a subset of three sites that have long, relatively complete records were selected for this indicator:

1) Salmon River at USGS gage 11522500, approximately 1 mile upstream from its confluence with the Klamath River. In addition to the seasonal temperature probes placed by the USFS at this site, the Karuk Tribe also operates a permanent monitoring station here that provides year-round multi-parameter water quality data available online in real-time at: https://waterquality.karuk.us/
2) Wooley Creek, approximately 0.3 miles upstream from its confluence with the Salmon River. Wooley Creek is one of the Salmon River's largest tributaries and its watershed is entirely protected within the Marble Mountain Wilderness, so human impacts are slight.
3) South Fork Salmon River upstream of Black Bear Creek. Long-term data analyses (Asarian et al., 2020) show that water temperatures at this site are highly sensitive to river flow, with temperatures being cool in high-flow years and warm in low-flow drought years.

Strengths and limitations of the data

There are many ways to summarize stream temperature data, and previous Salmon River analyses (Asarian et al., 2019, 2020) evaluated trends for multiple metrics of summer stream temperature. For this indicator, annual maximum temperature is the highest instantaneous maximum temperature recorded during the summer. This metric was chosen because it is simple to calculate, easy to understand, and biologically meaningful. This metric was calculated only for sites and years when there were enough data to be representative (i.e., complete measurements available during the hottest period of the summer) (Asarian et al., 2020). Equipment and techniques for monitoring these sites have improved over time.

Figure 3.14.1 shows data gaps for certain years at the Wooley Creek and South Fork monitoring sites. Reasons for data gaps include logistical constraints preventing site access (e.g., fires or staffing shortages), malfunctioning, loss of probes due to vandalism, or low water levels exposing probes to air.

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OEHHA respects the right of tribal nations to govern the collection, ownership, and application of their data. The Karuk Tribe has given OEHHA permission to use the water temperature data and related information presented in this indicator.

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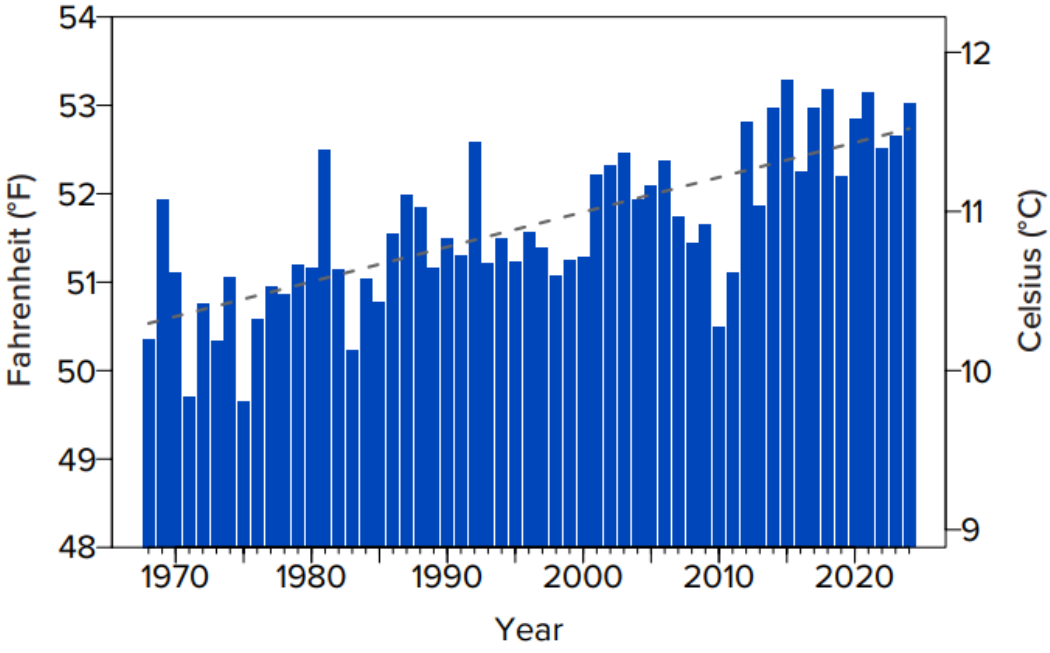
3.15 Lake Water Temperature

Lake Tahoe is a high mountain lake known for its clear, blue water and is often called a jewel of the Sierra. It is the third deepest lake in North America, at 1645 feet (501 meters). Lake Tahoe waters are warming in response to changing climate conditions in the Sierra Nevada.

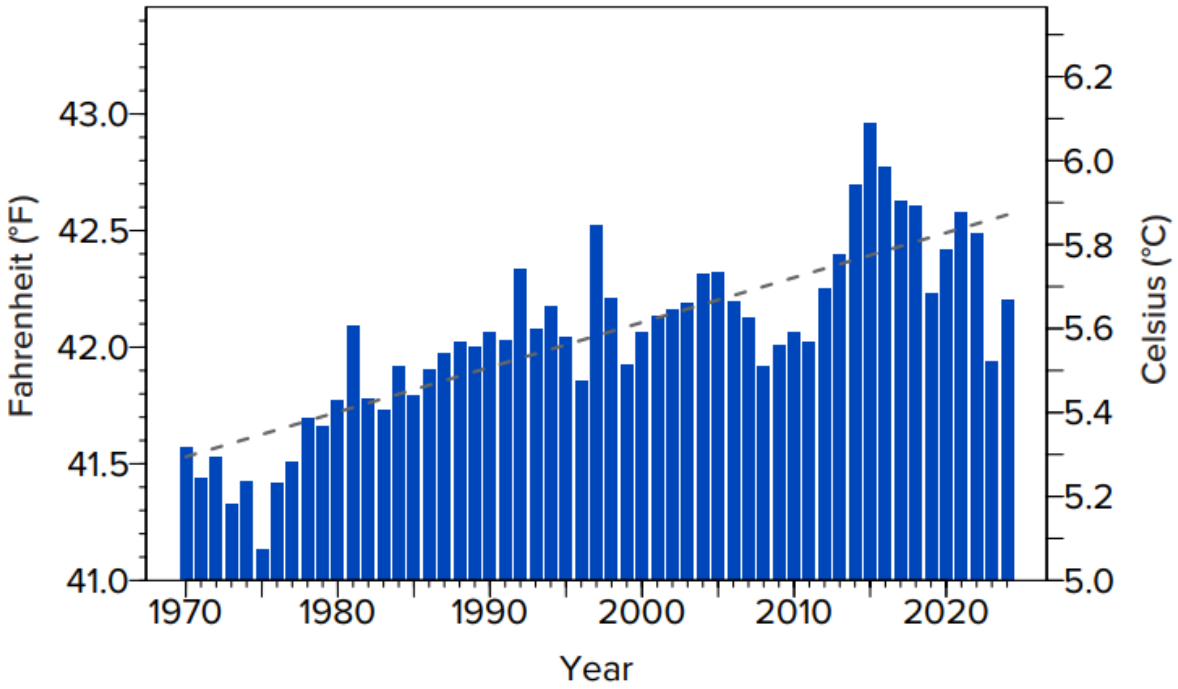


Figure 3.15.1. Annual Average Water Temperatures at Lake Tahoe.

A) Surface water temperature (1968–2024).



B) Volume-averaged temperature (1970–2024).



Source: Getty Images (photo) and UC Davis (2025a)

What does the indicator show?

Annual average surface water temperatures at Lake Tahoe, which vary greatly from year to year, have increased by 2.6 degrees Fahrenheit (°F) since 1968, or 1.4 degrees Celsius (°C), at a rate of 0.39°F (0.22°C) per decade (**Figure 3.15.1A**). Nine of the ten highest average surface temperatures were reported since 2010, and 2015 was the warmest year on record (53.29°F, or 11.8°C). Warming trends for water temperatures follow the overall warming trends for air temperatures at Lake Tahoe (warming air temperatures have also contributed to more rain and less snow and earlier snowmelt at Lake Tahoe).

Figure 3.15.1B shows annual average lake water temperatures across multiple depths ("volume-averaged"). Volume-averaged temperatures have warmed overall over the past fifty years by approximately 1.1°F (0.61°C), at a rate of 0.22°F (0.12°C) per decade, a smaller increase compared to surface water temperatures (**Figure 3.15.1A**). After peaking in 2015, volume-averaged temperatures trended downward until 2019, but

showed an uptick in 2020 and 2021, aligning with trends seen for air temperature in the area.

In addition to the surface and volume-averaged temperatures shown in **Figure 3.15.1**, it is worth noting that the maximum daily surface temperature (summer) for Lake Tahoe in 2024 was 74.9°F (23.8°C), recorded on July 22, the highest observed value since 2019 (UC Davis, 2025a).

While Lake Tahoe is unique, the physical, chemical and biological forces and processes that shape it are the same as those acting on most natural ecosystems. Thus, Lake Tahoe can serve as an indicator for other systems, both in California and worldwide (UC Davis, 2025a).

Warming has also been reported in other lakes in the western United States. Clear Lake water temperature has increased since measurements began in 1968 (De Palma-Dow, 2022). Temperature data derived from satellite observations show increasing summertime surface water temperatures in a 16-year study of four lakes in Northern California (Lake Tahoe, Mono Lake, Clear Lake, and Lake Almanor) and two in Nevada (Pyramid Lake and Walker Lake) (Schneider et al., 2009). From 1992 to 2008, these six lakes showed a significant warming trend for summer (July through September) nighttime surface temperatures, ranging from 0.09°F (0.05°C) per year at Clear Lake to 0.27°F (0.15°C) per year at Lake Almanor and Mono Lake. The lakes exhibited a similar rate of change, with the mean warming rate of 0.22 (± 0.05)°F, or 0.11 (± 0.03)°C, per year.

Why is this indicator important?

Lakes serve as good sentinels for climate change. They are sensitive to climate, respond rapidly to change, and integrate changes in the land areas that drain into them. Lakes in mountain regions may be particularly sensitive to ongoing changes in climate, in part because high-elevation ecosystems are warming among the fastest rates found globally (Pepin et al., 2015).

Warming lake water temperatures pose a significant threat to aquatic ecosystems (O'Reilly et al., 2015). Rates of freshwater biodiversity loss outpace those of other

environments (Parisek et al., 2025). Temperature is one of the most important factors influencing growth, metabolism, and survival of cold-blooded aquatic animals. High-altitude lakes like Lake Tahoe are especially vulnerable, as they are among the fastest-warming lakes in the world (O'Reilly et al., 2015). Even small temperature increases disrupt the physical and biological processes that sustain these ecosystems (Sadro et al., 2019). Approximately 19% of mountain lake environments in the United States are vulnerable to heat stress, and this number is expected to increase to 33% by 2100 (Parisek et al., 2025)

Tribal Connection 3.15.1

Lake warming can significantly disrupt tribal lifeways. Clear Lake in Lake County is the largest freshwater lake contained wholly in California, and one of the oldest lakes in North America. It has also been home to several tribes, including the Big Valley Band of Pomo Indians, since time immemorial. At one Lake monitoring site where many Tribal cultural activities take place*, "Notably warm temperatures were observed from February to April in 2013, in December 2014, in October 2015, and through the second half of 2024. The highest temperatures on record were observed during the July 2024 heatwave. […]. Even seemingly small increases in water temperature can significantly affect key physical and biological processes in lakes. Lake impacts have also affected the Tribe. Fish and other aquatic species often do best within a certain range of water temperatures. As water temperatures rise, native populations of fish and other species which are important to the Tribe might not thrive, while introduced species that previously would not survive in the lake are absent their natural predators. Balance is key for a healthy lake"* (Big Valley Band of Pomo Indians, 2026).

In the Sierra, interrelated factors such as the amount of snowpack, the timing and magnitude of snowmelt, and water temperature have important implications for growth of benthic algae and phytoplankton, primary productivity and food web dynamics. Elevated water temperatures, as well as other climate-driven stressors like exposure to wildfire smoke, disrupt metabolic rates of organisms, from plankton to fish (UC Davis, 2025a; Smits et al., 2024). Changing snowpack and winter conditions can also extend

plant growing seasons for lakes in the summer, enabling invasive aquatic plant species in lakes to expand their range.

One major consequence of rising temperatures is increased stratification — when water forms distinct layers based on temperature (O'Reilly et al., 2015). Normally, cooler surface water sinks in fall and winter, circulating oxygen and nutrients vital to aquatic life. As winters warm, this mixing becomes shallower (Sahoo et al., 2015). Since 1968, Tahoe's stratified summer period has lengthened by approximately a month (UC Davis, 2025a). These changes jeopardize the survival of native fish and invertebrates, already stressed by warming temperatures and competition of warmer-adapted invasive species like bass and blue gill (California Tahoe Conservancy, 2021a and 2020).

Stratification influences algal growth and water clarity. When mixing is limited, larger algae sink while smaller ones remain near the surface, scattering light and reducing clarity. This reduced clarity leads to greater surface warming, which strengthens stratification and further favors small algae—creating a feedback loop. Cyanobacteria is a type of freshwater bacteria that produces harmful algal blooms and thrives in warm, slow-moving water. In addition, limited mixing can trap fine particles from stream runoff in the lake's upper layers, keeping the water cloudy for longer (Coats et al., 2006).

Long-term monitoring shows a decline in summer clarity, reflecting changes in temperature, precipitation, and nutrient and sediment inputs. Because water clarity influences light penetration, it plays a key role in shaping the diversity and productivity of aquatic life. It also contributes to the lake's aesthetic and recreational value, making it an important indicator of ecological and economic health (UC Davis, 2025a and b).

Dissolved oxygen levels declined in 393 temperate lakes across the U.S. from 1941 to 2017 (Jane et al., 2021). In surface waters, the drop was mainly due to warmer temperatures reducing oxygen solubility. In deeper waters, stronger stratification and reduced clarity were the main causes. Deoxygenation can harm cold-water and oxygen-sensitive species, increase harmful algal blooms, and raise the risk of methane buildup and release.

A decline in the water clarity and ecosystem health of the lake jeopardizes future tourism. The scenic beauty of Lake Tahoe offers cultural and recreational opportunities,

such as hiking, skiing, camping and boating. The annual visitor population of approximately 15 million (California Tahoe Conservancy, 2021b) makes it a region of national economic significance, with estimated annual revenues of $4.7 billion (Mooney and Zavaleta, 2016).

What factors influence this indicator?

Key drivers controlling lake water temperature are solar radiation, air temperature (influenced by greenhouse gas concentrations), ice cover, cloud cover, humidity, and wind. In addition, suppressed lake mixing (discussed above) can enhance warming of surface waters. Landscape characteristics such as latitude, elevation, and catchment features or land cover can modulate climate effects on individual lakes (Schmid et al., 2014). The climate signal might be further modified by a lake's morphometric attributes, such as lake size and shape, or through differences in the source and magnitude of water inputs (Rose et al., 2016).

Summer air temperature is the single most consistent predictor of lake summer surface water temperature (O'Reilly et al., 2015), largely because so many of the factors that control lake temperature are correlated with air temperature. Lake summer surface water temperature is warming significantly, with a mean trend of 0.19°F (0.34°C) per decade across 235 globally distributed lakes between 1985 and 2009 (Woolway et al., 2020). This warming water surface rate is consistent with the annual average increase in air temperatures and ocean surface temperatures over a similar time period (1979–2012).

By 2100, average maximum air temperature is projected to increase by approximately 4°F to 9°F (2°C to 5°C) (California Tahoe Conservancy, 2020). By the end of the century, air and water temperatures could remain warm late enough into the season that water would be trapped at the surface for more than 60 days longer than in 1968 (Sahoo et al., 2015).

In California lakes that experience ice cover, the amount of snowpack, timing of snowmelt runoff, and ice formation and ice-off (date of ice thawing and breakup) influence lake water temperatures (Melack et al., 2021; Sadro et al., 2019; Smits et al., 2020). For example, Emerald Lake is a high-elevation lake in the southern

Sierra Nevada that is covered with ice six to nine months of the year. Despite a strong warming trend in regional air temperature over the past three decades, researchers found warming water temperatures occurred only during drought years, when snowpack was reduced (Sadro et al., 2019). Snowpack and lake temperature are strongly correlated in mountain systems likely due to tight coupling between snowpack and ice cover in lakes (Smits et al., 2020). Years with low snowpack at Emerald Lake were accompanied by a reduction in the duration of ice-cover, which acts to buffer lake water from exposure to solar radiation and warming.

Although year-to-year variability is high, the number of days when air temperatures averaged below-freezing has declined by 27 days since 1911. Snow has declined as a fraction of total precipitation, from an average of 51% in 1910 to 34% in 2024. A warming climate is affecting other physical changes at Lake Tahoe -- including a shift in snowmelt timing to earlier dates—that may have significant impacts on lake ecology and water quality (UC Davis, 2025a).

As snowpack declines in the Sierra Nevada and other mountain ranges, lake temperature will become increasingly sensitive to warming with reduced ice cover. This regional trend is especially significant given that lakes worldwide are rapidly losing winter ice cover in response to warming, and the rate of loss has accelerated over the past 25 years. Ice melting in parts of the Northern Hemisphere is occurring 45 days earlier per century, with many lakes showing more intermittent or even ice-free winters. While Lake Tahoe does not typically have ice in the winter, the smaller lakes and streams in the Tahoe basin and across the mountains of California rely on ice conditions as an important variable which drives the ecology in the ice-free, summer season (Hampton et al., 2024).

Technical considerations

Data characteristics

The University of California, Davis and its research collaborators collect the measurements used for monitoring Lake Tahoe. They have recorded water temperature measurements at two locations in Lake Tahoe since 1968:

(1) at the Index Station (approximately 0.6 kilometers off the California side west shore) at depth increments of 2 to 15 meters starting at the surface to a depth of about 100 meters, on an approximately weekly basis, and at 20-centimeter increments to a depth of 125 meters biweekly since 1996. It became continuous measurements at a rate of 8 times per second as it falls through the water at a velocity of 60 centimeters/sec of since 2005;

(2) at the Midlake Station, the exact location of which varied slightly over time, at nominal depths of 0, 50, 100, 200, 300 and 400 meters, at least once a month. History of depth resolution is similar to that of the index station above.

Strengths and limitations of the data

A variety of thermometers and digital thermographs have been used at the Index Station over the years. Although the sensitivity, accuracy, and calibrations of these instruments have varied over time, these data are adequate for characterizing the thermal structure of the epilimnion and thermocline. Temperatures at the Midlake Station were originally measured at 13 depths with mercury-reversing thermometers, as follows: a protected thermometer, unaffected by pressure, records the temperature at reversal depth; readings from this thermometer are corrected for glass expansion and, along with a second, unprotected thermometer affected by pressure in deep water, provide measure of the actual depth of the temperature reading (Coats et al., 2006). These instruments were accurate to 0.01°C. More recently, temperature has been measured using a high precision thermistor that is part of a suite of instruments on a Seabird SBE-25plus profiler. Accuracy of the thermistor is 0.001°C. Lake surface temperature data derived from thermal infrared satellite imagery (ATSR and MODIS), when validated against corresponding *in situ* data for Lake Tahoe, were found to agree very well over the entire range of temperatures. This, along with an additional assessment of inter-sensor bias between all ATSR sensors, indicates that accurate and

stable time series of lake surface temperature can be retrieved from ATSR and MODIS satellite data.

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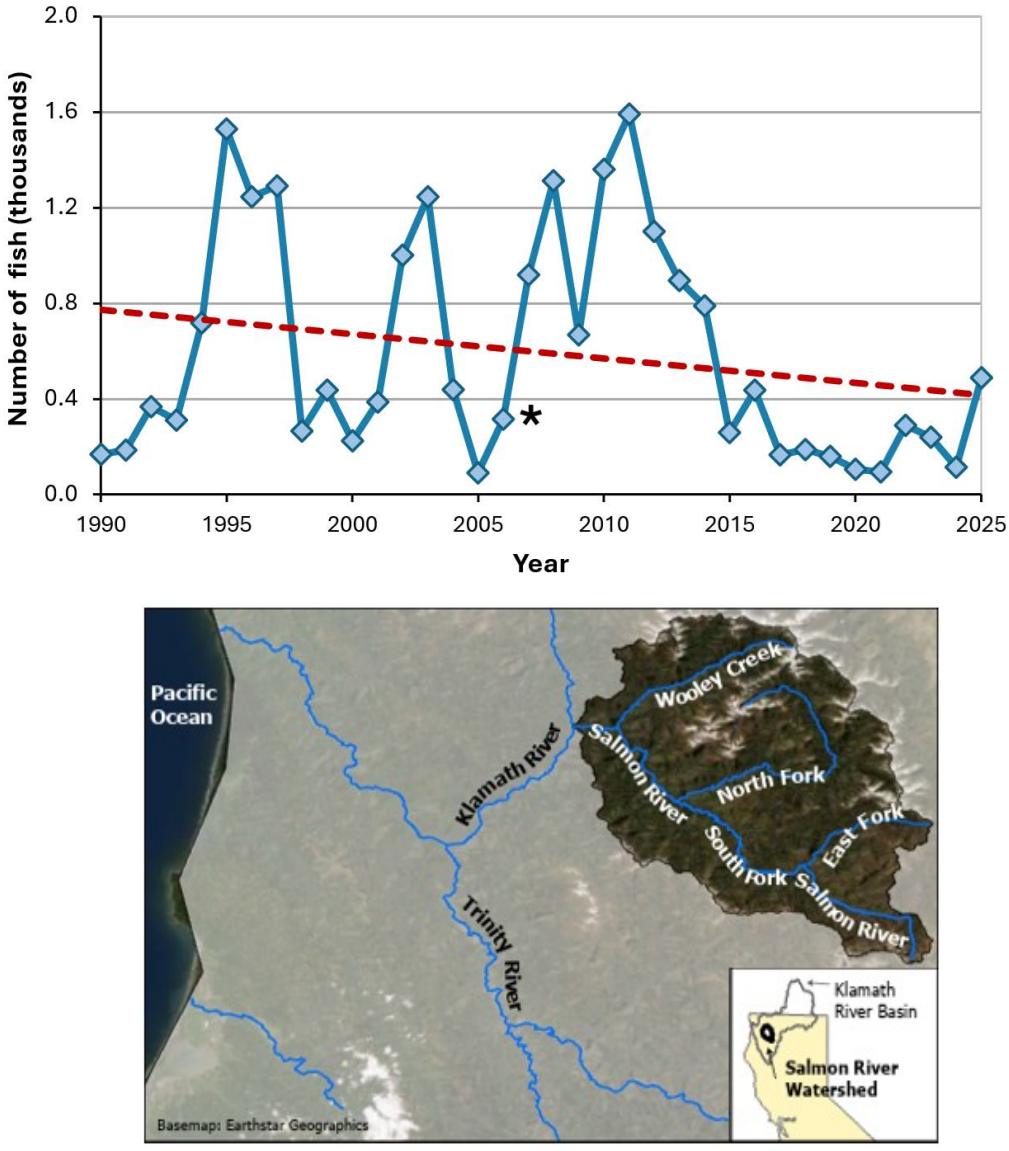


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3.16 Chinook Salmon Abundance

Chinook salmon (*Oncorhynchus tshawytscha*) are born in freshwater, grow in the ocean and return to rivers to spawn. California populations, while resilient, are increasingly unable to withstand the combination of long-standing habitat degradation and the accelerating pressures of climate change. The population decline is underscored by the closure of the state's commercial salmon fishery in 2025 for the third consecutive year, reopening in 2026.

Figure 3.16.1. Salmon River Spring-Run Chinook Salmon.



The counts show annual counts from 1950 to 2025 of total returns of adult and grilse, which are precociously mature Chinook that are 2 years old, reported from spawner escapement surveys, river harvests, and run-size estimates. *Fish surveys in 2006 were not conducted due to regional wildfires; instead, the value for 2006 is an estimate based on the historic average. Source: Salmon River Water Council (2025, top graph) and USGS (2019, map)

What does the indicator show?

This indicator tracks returning adult Chinook salmon abundance in two key systems: the Salmon River in the Klamath Basin and the Sacramento River in the Central Valley, which contains the Sacramento River and San Joaquin River basins. Together, these basins support most of California's remaining Chinook salmon runs.

Tribal Connection 3.16.1

The Eel River in Northern California historically supported one of the largest salmon runs in the state (CalTrout, 2025). Salmon or *malhuk* are culturally significant species for the Wiyot Tribe who inhabit the Eel River or *Wiya't* watershed. According to the Tribe: "*In Wiyot oral history, there were so many salmon before colonization that one could cross the river by walking on their backs. It is likely that nearly a million salmon returned to the river in a good year (Yoshiyama and Moyle, 2010). Post-colonization damming, logging, agriculture, and over-harvesting reduced salmon populations by as much as 99%, significantly reducing their ability to respond or adapt to climate change-related events. […]. The Wiya't, its tributaries, and the Baduwa't* [Mad River] *support ecologically distinct populations of California Coastal Chinook salmon (Oncorhynchus tshawytscha), which are currently listed as threatened under the Federal Endangered Species Act (ESA). Chinook counts have been below average for the past 6 years and the population shows no long-term trend for recovery, remaining at high risk of climate vulnerability*" (Wiyot Tribe, 2026).

Spring-run Chinook abundance in the Salmon River has declined sharply since 2011 (**Figure 3.16.1**), from almost 1,600 fish in 2011 to 489 fish in 2025. While 2025 count showed an uptick in abundance – the highest count since 2014 – the return remains below long-term average for the 11th consecutive year. The Salmon River supports the

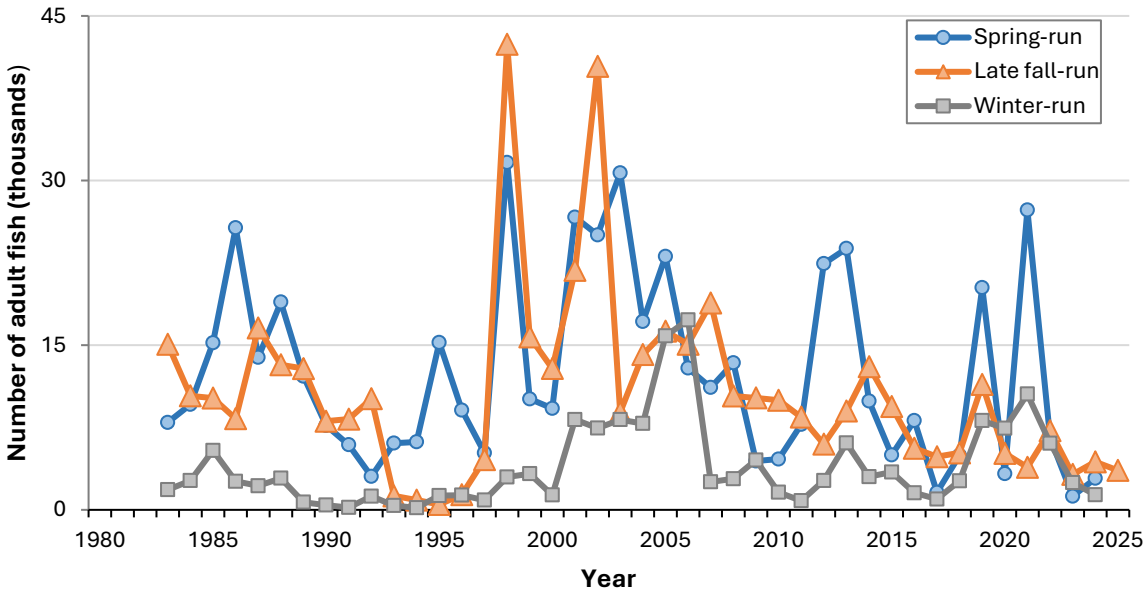
largest remaining wild spring-run Chinook population in the Klamath Basin and is largely free of dams, hatcheries, and major water diversions. The Upper Klamath-Trinity Rivers spring-run Chinook are listed as threatened under the California Endangered Species Act (CESA).

Unlike the Salmon River, Chinook populations in the Sacramento River are heavily influenced by dams, water diversions, and infrastructure (Michel et al., 2021). In the Sacramento River, all four Chinook runs—fall, late-fall, winter, and spring—have declined since about 2000 (**Figure 3.16.2** and **Figure 3.16.3**). The Sacramento River system supports the world's only winter-run Chinook salmon, which is listed as endangered at both the state and federal levels and frequently falls below 5,000 spawners annually, far below historical runs of 200,000 spawners per year. Winter-run Chinook salmon population had historical spawning habitat completely blocked with dam construction circa 1940 and now relies on managed cold-water releases from Shasta Reservoir for spawning and egg incubation. Fall-run Chinook, historically the most abundant run, peaked in the late 1990s and early 2000s but has declined and is now designated a Species of Special Concern by the California Department of Fish and Wildlife. The fall-run Chinook population is a fishery target, so the escapement numbers reported below in **Figure 3.16.3** represent only the fish that were not caught, except in years when the fishery was closed. Another factor to consider is that harvest levels tend to increase in years when larger runs are forecast. Spring-run Chinook, listed as threatened, shows high interannual variability but remains far below historical abundance.

Tribal Connection 3.16.2

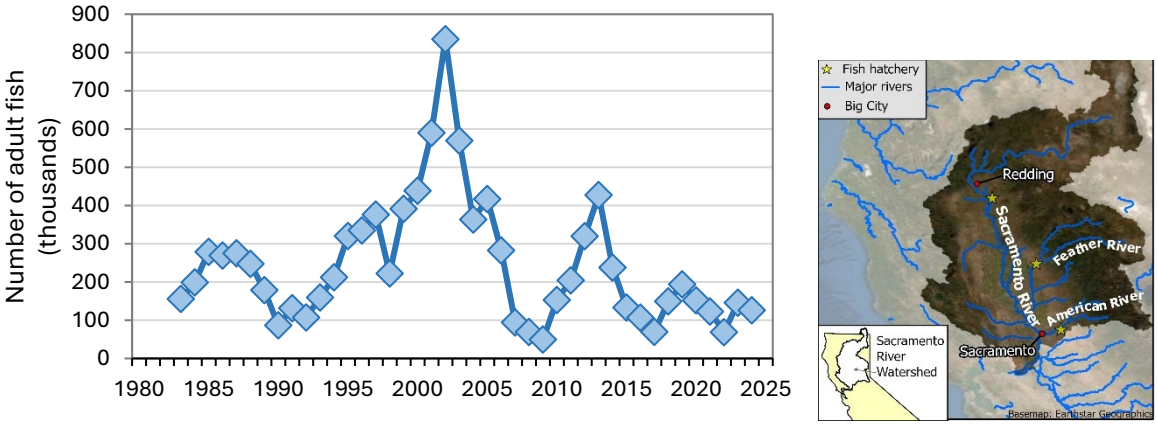
Chinook salmon used to run from the Sacramento River up the Yuba River and were a central part of the diet of Nisenan people living in the Yuba watershed. In Impacts of Climate Change on the Nevada City Rancheria Nisenan Tribe, the author writes: “Populations were drastically reduced by mining, dam construction, and overfishing throughout California’s colonization and mining period, and now face additional threats from heat and drought. Chinook salmon […] have access to less than a third of their historic spawning range in the Yuba River (The Nature Conservancy, 2025). The accessible portion is in the lowest and hottest part of the watershed and suffers from ongoing gravel loss and poor water quality. The numbers of Chinook returning to the Yuba River continue to decline” (Nisenan, 2026).

Figure 3.16.2. Sacramento River Chinook Salmon Abundance: Winter-, Spring-, Late-fall- Runs.



The figure above shows Sacramento River Chinook salmon abundance for the spring, late-fall, and winter runs, which are much smaller than the fall-run population. Source: CDFW (2025a)

Figure 3.16.3. Sacramento River Fall-Run Chinook Salmon Abundance.



The figure above shows the number of returning adult Sacramento River fall-run Chinook from 1983 to 2024. These data show returns, including hatchery returns, to the Sacramento River and its tributaries. The San Joaquin system, which meets the Sacramento River at the delta, is not included. Source: CDFW (2025) (left) and USGS (2019) (map, right)

Why is the indicator important?

California salmon populations are increasingly vulnerable to climate change. Historically, millions of salmon returned annually to California rivers; today, populations are a fraction of those levels and increasingly dependent on hatcheries (CDFW, 2024a). If current climate trends and human stressors persist, nearly all of California's salmon populations face a high risk of extinction within the next century (Moyle et al., 2017; UC Davis, 2017). From 1995 to 2020, abundance trends across 28 distinct populations of Pacific salmon (*Oncorhynchus spp.*) that were listed under the US Endangered Species Act (ESA) showed that populations in California had lower median trends than those in the Pacific Northwest, likely due in part to climatic and hydrologic stressors such as extended drought, declining snowpack, increasing stream temperatures, decreasing minimum and maximum flows (Ford et al., 2025).

Salmon are among California's most valued natural resources. As a keystone species, they have a disproportionately large effect on the broader natural environment relative to their abundance. Salmon are one of nature's "force multipliers," super-charging

benefits across entire ecological communities (Schindler et al., 2003). Their health influences the whole ecosystem. They are food for other species. Their bodies enrich habitats through cycling of nutrients from ocean to rivers (CDFW, 2024a).

Chinook salmon historically supported healthy ecosystems and local economies and jobs in California. Chinook ocean fisheries generated approximately $17.5 million in commercial revenue in 2021, declining to $16.3 million in 2022 (CDFW, 2026a) before closing from 2023–2025 due to extremely low adult returns (CDFW, 2025a), reopening in 2026 (CDFW, 2026b). Fishery closures have cascading economic impacts on fishing communities and related industries.

Tribal Connection 3.16.3

Salmon is celebrated in many aspects of Tribal culture, not only as a food source, but also as a species of cultural significance. For example, the Karuk Tribe's First Salmon Ceremony invokes the spring salmon run in the Klamath River; the Karuk also use the presence of salmon as an indicator of both riverine and forest habitat quality to guide traditional land management practices (Karuk Tribe, 2026). Prior to European contact, different runs of fish entering the Klamath River (of which the Salmon River is a tributary) provided for the needs of several tribes, including the Yurok, Karuk and Hoopa, with the spring-run Chinook as the only salmon available between late spring and early summer. Today, due to the greatly diminished abundance of the spring-run salmon, tribal harvest is limited in the Salmon River and sport fishing is prohibited (SRRC, 2022).

The Salmon River is the second largest tributary to the much larger Klamath River system (SRRC, 2020). The Salmon/Mid-Klamath watershed is considered one of the few salmon strongholds in the world, which means it resides within a major salmon ecoregion with historically high levels of wild salmon abundance, productivity, and diversity, and habitat quality capable of sustaining resilient wild salmon populations (Rahr III et al., 2025). Spring-run Chinook salmon were once widely dispersed throughout tributaries of the Klamath River upstream of the Trinity River confluence. Mining activities beginning in the late 1800s and dams built between 1918 and 1962

severely impacted the fish population in the Klamath region. The loss of beavers in California, including the Klamath watershed, due to hunting during the 1800s, has also impacted salmon populations. Beaver dams help create wetlands upstream of the structures which prevent silt from traveling downstream into the gravel streambeds where salmon spawn, create ponds of deeper, cooler water, and attract more insects for salmon to eat (Pollock et al., 2004). Beaver dams, unlike man-made dams, do not hinder the movement of salmon upstream (Pollock et al., 2022).

These fish are critical to the food security, cultural survival and well-being of indigenous people in the Klamath Basin including the Karuk Tribe (Karuk Tribe, 2016). The Salmon River does not have a hatchery, making this a unique refuge for wild salmon. Efforts to restore the Salmon River from mining, logging and other past land management practices have left it a remaining stronghold tributary in the Upper Klamath-Trinity River system for wild spring-run Chinook salmon. (Very low numbers of spring-run salmon are also found in the South Fork Trinity River and the New River, a tributary to the Trinity River).

Estimates of spawning escapement are extremely important to salmon management as an indication of the actual reproductive population size (Wells et al., 2014). The number of adults reproducing is important in defining population viability, as a measure of both demographic and genetic risks. It is equally important to manage harvest in the fisheries, which typically aims at meeting escapement goals such that the population remains viable (for ESA-listed populations) or near the biomass that produces maximum recruitment (for stocks covered by a fisheries management plan).

What factors influence this indicator?

Changes in climate can alter freshwater, estuarine, and marine habitats, putting salmon populations at risk. California Chinook salmon now encounters more stressful climatic conditions in freshwater bodies than those in which they evolved (Herbold et al., 2018; Moyle et al., 2013; Wells et al., 2014). As air temperatures rise, river and stream temperatures have increased and will likely continue to increase (see the *Salmon River Water Temperature chapter*). Warmer waters and lower flows increase juvenile salmon's exposure time to predators. Non-native predators in the Sacramento-San

Joaquin Delta consume more juvenile salmon when waters are warmer (Michel et al., 2021). High water temperatures can also increase Chinook salmon susceptibility to disease (Bergendorf, 2002). With warming air temperatures, more precipitation falls as rain instead of snow in the mountains (see the *Precipitation*, *Snowmelt Runoff* and *Snow-water Content* chapters), reducing the amount of snowmelt that provides cold water year-round to rivers and streams. During droughts, wetlands habitat availability and connections between salmon habitat areas are reduced and water quality is compromised (Crozier et al., 2019). Wildfires can also impact Chinook salmon in complex ways. In the short term, fires can cause deadly water temperatures spikes, reduce stream cover which further drives up water temperatures, increase runoff and erosion, and release toxic ash and fire retardants into the water. Over the long term, charred debris and fallen trees enrich river ecosystems, creating slow-water habitats that are beneficial for juvenile rearing (Becker, 2024; Flitcroft et al., 2016).

Streamflow is an important determinant of water temperature (Asarian et al., 2023; Moyle et al., 2017; Wells et al., 2014). River and stream temperatures are cooler when flows are high and warmer during years with diminished flows. Low summertime flows from lack of snowmelt together with warmer temperatures in salmon freshwater habitats can alter prey composition, riparian vegetation, and stream morphology. These changes in habitat affect salmon physiology and behavior in freshwater, which can in turn have consequences for growth and survival in the marine life stage. Significant reductions in cold-water river and stream flows in the summer may directly affect spawning, egg viability, rearing conditions and juvenile and adult migration (Martin et al., 2017, Munsch et al., 2019; Wells et al., 2014). Temperature and flow constraints on seaward migration timing may result in premature migrations when fish are small and vulnerable or before ocean conditions are favorable (Satterthwaite et al., 2014, Munsch et al., 2019, Goertler et al., 2024). Scientists have identified threshold levels of flow that are necessary for juvenile salmon survival and habitat use that could be used to assist in watershed restoration efforts (Michel et al., 2021; Munsch et al., 2020).

Ocean conditions strongly influence salmon survival. Because Chinook salmon spends two to three years in the ocean before returning to freshwater to spawn, the number of salmon observed in rivers in any given year partly reflects marine conditions in

preceding years (CCEIA, 2025). Ocean habitat compression and shifts in ocean forage have created difficult conditions for California's Chinook Salmon in recent years (CDFW, 2024b). Prey availability, driven by ocean temperature and upwelling strength, is a key determinant of juvenile growth and survival (Wells et al., 2014). Warm ocean temperatures, weak upwelling, and altered food webs have been linked to poor survival and sharp declines in Sacramento River fall-run Chinook (Lindley et al., 2009). Shifting food availability in the ocean has also led to anchovy-dominant diets for Chinook salmon. Anchovies carry an enzyme (thiaminase) that degrades thiamine, and Chinook dietary shift to anchovy has caused thiamine deficiency in spawning females' eggs. Offspring impacted by thiamine deficiency can have abnormal swimming patterns and low survival (Mantua et al., 2025).

Additional ocean stressors include increasing acidification, which threatens key invertebrate prey species, and sea-level rise, which may degrade estuarine habitats critical for salmon transitioning from freshwater to marine environments (Crozier et al., 2019). Along the Pacific coast, rising sea levels can lead to inundation of low-lying lands and increased salinity, thereby transforming estuarine habitats for migrating salmon (Wells et al., 2014). Because the success of salmon rearing in coastal estuaries strongly influences later survival in the ocean, the physical and biological conditions of estuaries are very important.

In freshwater streams and rivers, California salmon abundance is influenced by dynamic interactions between natural landscape features (e.g., climate and topography) and human activities. Anthropogenic influences on salmon populations include urban and agricultural runoffs, dams, water diversion for agricultural and domestic uses, and mining (Moyle et al., 2013; Wells et al., 2014, Moore et al., 2025). Land and water use changes over the past century have eliminated or blocked access to important habitats, limited habitat diversity, and constrained salmon distribution (CDFW, 2025b; Herbold et al., 2018; Munsch et al., 2022). Dams may contribute to water quality issues in freshwater such as the Klamath River (NOAA, 2024), which may impact fish during migration. Fishing also affects the abundances of adults that return to spawn. While the fishery targets the fall-run Chinook, it can incidentally capture protected stocks (Satterhwaite et al., 2023). State and federal water projects can also lead to declines in

salmon abundance. Juvenile winter-run Chinook entering the Delta can be entrained, or drawn into, the water export facilities that pump out large volumes of water for use in agriculture and municipalities. These facilities can also change hydrodynamics, delay salmon outmigration and consequently increase predation risk. In 2024 and 2025, the annual loss thresholds (maximum number of juvenile winter-run salmon that can be entrained by water projects) exceeded 100% by late March (Sturrock et al., 2026).

Technical considerations

Sacramento River Chinook Salmon Abundance

Data characteristics

Total spawning escapement values for the four salmon runs were taken from the California Central Valley Chinook Population Database Report (Azat and Killam, 2025). The report, also known as "GrandTab," is a compilation of sources estimating the late-fall, winter, spring, and fall-run Chinook salmon total populations for streams surveyed. Estimates are provided by the California Department of Fish and Wildlife, the US Fish and Wildlife Service, the California Department of Water Resources, the East Bay Municipal Utilities District, the US Bureau of Reclamation, the Lower Yuba River Management Team, and the Fisheries Foundation of California.

The *Central Valley Chinook Salmon In-river Escapement Monitoring Plan* is used by fisheries resource managers across the basin for estimating numbers of adult Chinook salmon returning to spawn (Bergman et al., 2013). After completing the ocean stage, hatchery-origin fish generally return to tributaries concurrently with natural salmon and are part of abundance counts. Escapement estimates are based on counts of fish entering hatcheries and migrating past dams, carcass surveys, live fish counts (snorkel surveys and video monitoring), and ground and aerial redd counts. This comprehensive plan includes a spatially and temporally balanced sampling protocol that when implemented allows for statistically defensible estimates of population status.

Strengths and limitations of the data

Chinook salmon monitoring has been conducted on the Sacramento River since 1950; however, abundance data in the early decades were lacking in precision and consistency (Bergman et al., 2013). The National Oceanic and Atmospheric

Administration (NOAA) Northwest Fisheries Science Center in their salmon indicator report present Chinook salmon abundance trends beginning in 1985, citing lower data quality and consistency prior to this year (Wells et al., 2014).

While methodology varies by river/tributary, the escapement estimates are useful for trend analysis, particularly in the years we assessed.

Salmon River Spring-run Chinook Salmon Abundance

Data characteristics

Spring-run Chinook salmon estimates for the Salmon River are collected during an annual cooperative spawning survey. Since 1995, the Salmon River Restoration Council (SRRC) has helped coordinate with the US Forest Service the annual Spring Chinook and Summer Steelhead Cooperative Fish Dive. The dive event covers the upper mainstem and the North, South and East forks of the river in a single day. The lower mainstem and Wooley Creek (a large tributary) are surveyed separately in the same week. The survey area is approximately 89 miles measured in intervals or “reaches” of two to four miles. The dive takes place in late July when fish are holed up in deep pools and near cool side streams, allowing direct counts of individual fish (SRRC, 2022).

Strengths and limitations of the data

Both the methodology and effort made when conducting the summer dive events have been consistent over the years except for 2006, 2020, and 2025. Wildfire closures in 2006 prevented the mainstem Salmon River and Wooley Creek from being surveyed. An expansion equation was developed to estimate the number of spring-run Chinook salmon that would have been counted on those reaches based on the historic average. In 2020, the COVID-19 pandemic restricted divers to a core number of individuals and the survey was spread out over two days instead of one. The entire survey area was covered except for two lower priority reaches and was not expected to significantly affect the count (Personal communication, Sophie Price, SRRC, April 2022). In 2025, the survey team was limited to a smaller number of local fisheries professionals due to wildfire activity in the area, but survey procedures were otherwise relatively unchanged.

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Introduction

Anthropogenic warming has disrupted terrestrial ecosystem dynamics across the planet and contributed to a global reduction in biodiversity and ecological stability (IPCC, 2022). Observations from California's changing ecosystems provide critical insight into the harmful impacts of human-driven climate change on terrestrial plants and animals.

Changes in climate and land use have increased wildfire severity and magnitude, leading to widespread habitat loss. The minimal reliance on tribal knowledge and decades of fire suppression have systematically weakened terrestrial resilience, fueling catastrophic burns. Fire suppression, drought, pest infestations and higher temperatures have also led to a surge in tree mortality across California (Harrison et al., 2024). The reduction in forest biomass strains ecological and cultural resources and threatens some of California's most iconic tree species, including the giant sequoia and coastal redwood. As demonstrated by elevational shifts and declines in the Sonoran and Deep Canyon Deserts, even vegetation thought to be tolerant to drought and heat stress is vulnerable to climate change. Changes in species composition and altered

migration patterns among small mammals, birds, and butterflies further reflect biological shifts in response to habitat loss and changing climate conditions.

Downward trends in winter chill and increased pest abundance also jeopardize the production of high-value nuts and fruits. Given that California is the largest agricultural producer for the United States, accounting for 13.5% of total national agricultural exports in 2024 (CDFA, 2025), altered maturation times and pest infestations are critical to prevent, but control methods can have costly consequences for human and environmental health.

The following chapters – Wildfires, Forest Tree Mortality, Changes in Forests and Woodlands Composition, Vegetation Distribution Shifts, Winter Chill, Fruit and Nut Pest Abundances, Fruit and Nut Maturation Time, Spring Flight of California Central Valley Butterflies, Changes in Small Mammal and Avian Distributions, Bird Wintering Ranges, and Migratory Bird Arrivals – highlighting the impacts of climate change on California's terrestrial ecosystems.

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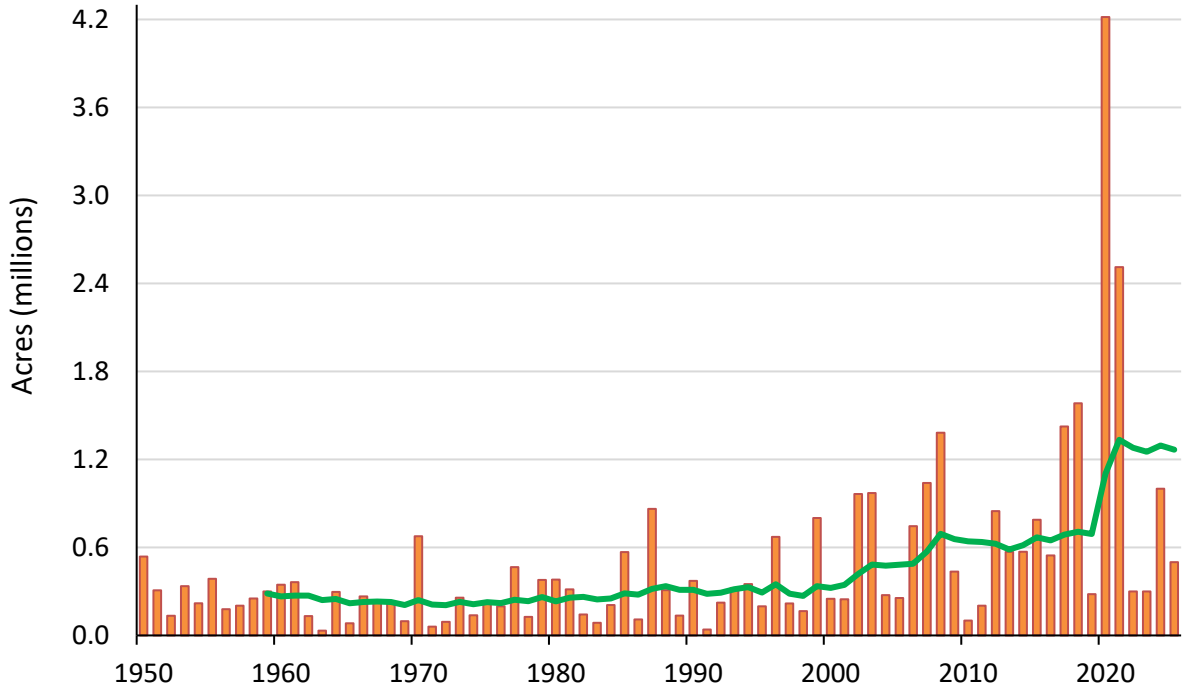
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4.1 Wildfires

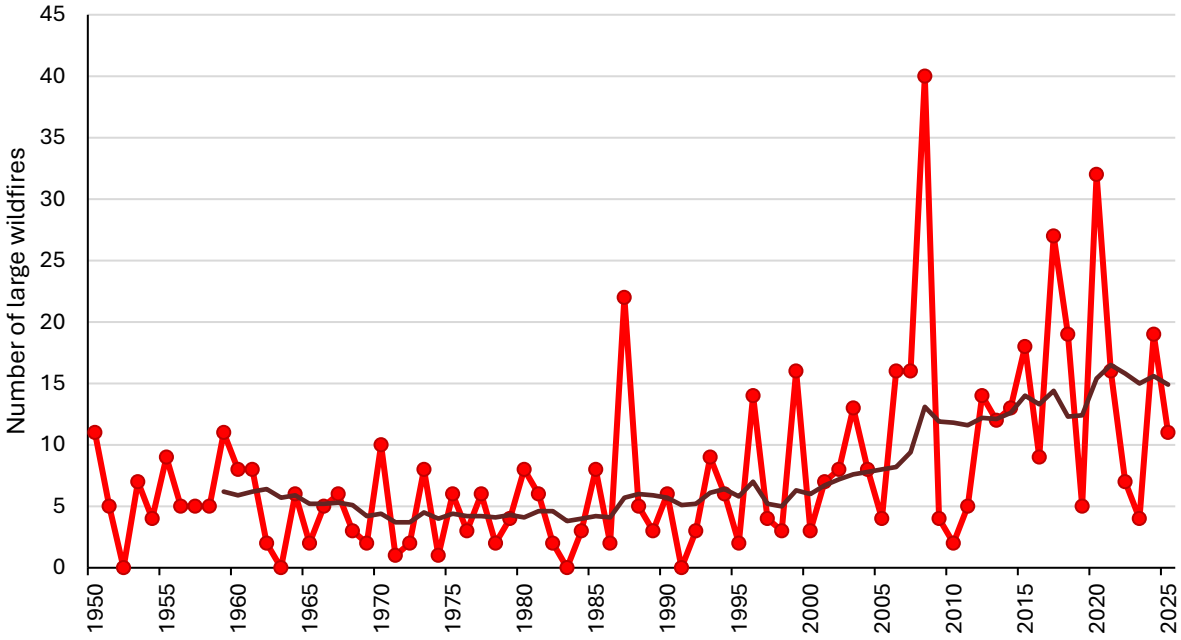
Wildfires now burn more acreage, and large fires are occurring more often, fueled by dry conditions, high winds, and dense vegetation. Fast-moving wildfires have left entire neighborhoods in ruins, and the increasing extent of high-severity wildfire damage to natural landscapes limits recovery. Although fire is an essential and often beneficial component of California's ecosystems, the undesirable impacts from modern wildfires challenge people and ecosystems to adapt to each increasingly dangerous fire season.

Figure 4.1.1. Statewide Annual Acres Burned.



The graph shows annual number of acres burned in California from 1950 to 2025. Source: CAL FIRE (2026a)

Figure 4.1.2. Statewide Number of Large Wildfires.



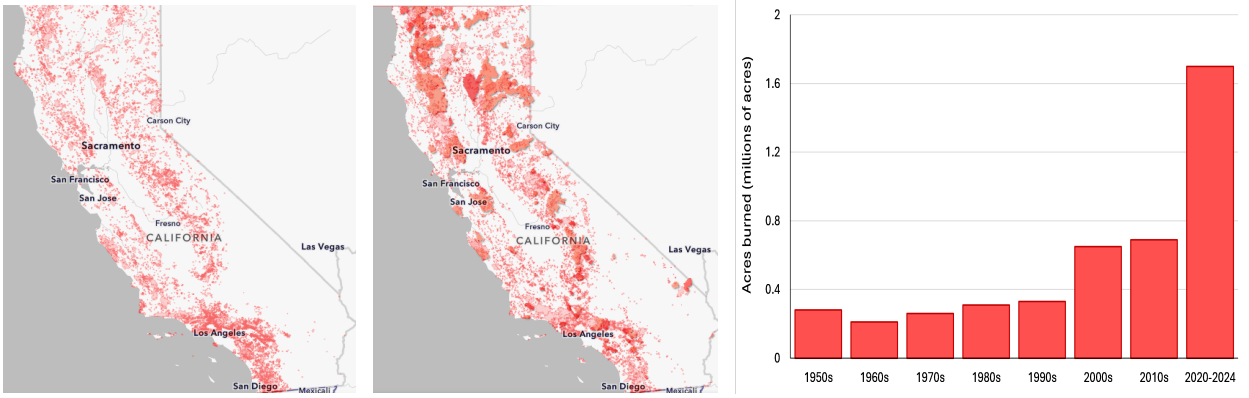
The graph shows the number of large wildfires larger than 10,000 acres from 1950 to 2025 (the dark line represents the 10-year running average). Source: CAL FIRE (2026a)

What does the indicator show?

Figure 4.1.1 shows the number of acres burned by wildfires each year. The total annual area burned since 1950 ranged from a low of 32,000 acres in 1963 to a record high of 4.2 million acres in 2020 – more than 4 percent of the state's roughly 100 million acres of land. 2021 was the second highest year in acreage burned by a wide margin: wildfires consumed about 2.6 million acres, compared to about 1.6 million in 2018, the third highest year. 2024 ranks seventh highest. In addition, large wildfires are becoming increasingly common: the total area burned by wildfires and the number of large fires (over 10,000 acres) in California has risen substantially (**Figure 4.1.2**). The average (mean) area burned each year in the last two full decades (2000s and 2010s) is at least double the acreage of earlier decades (**Figure 4.1.3**).

Figure 4.1.3. Areas Burned in California.

A) 1950s-1990s 2000s- 2024 B) Average annual acreage burned by decade

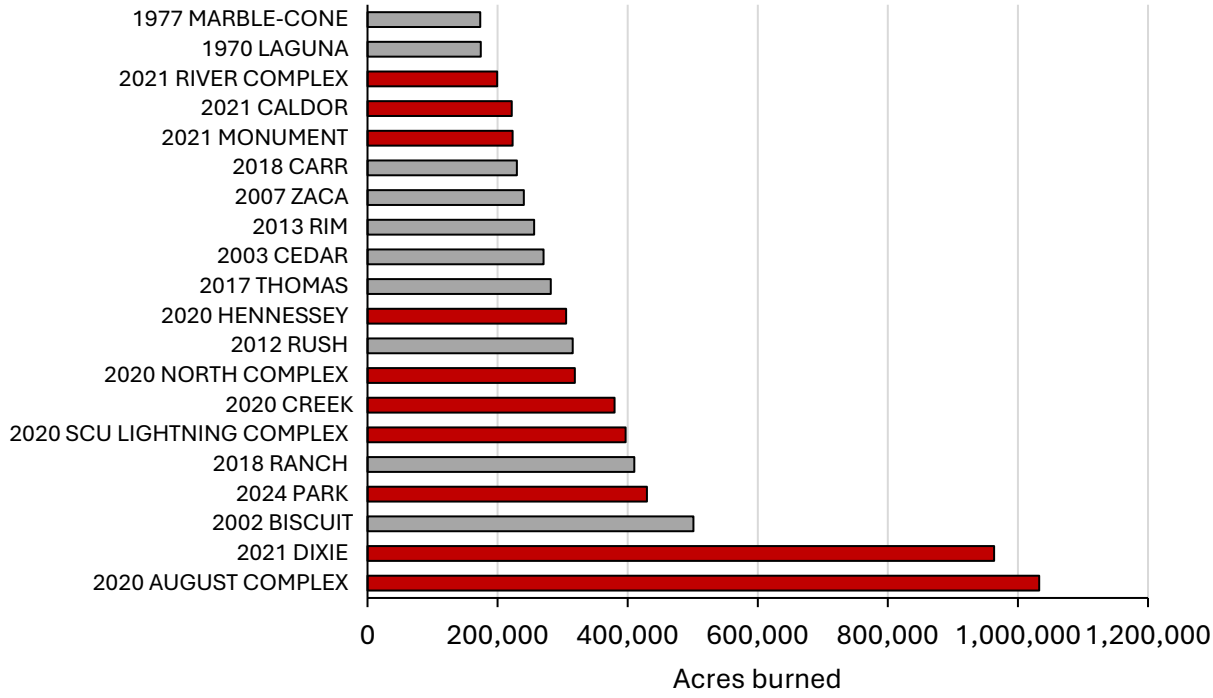


The maps above show areas burned in 1950s-1990s (A) and in 2000s-2024 (B). The graph shows the average annual acreage burned by decade.

Source: CAL FIRE (2025)

From 1950 through 1999, about 0.3 million acres burned on average each year. From 2000 to 2019, about 0.7 million acres burned on average each year. From 2020 to 2024, about 1.7 million acres burned on average each year (more than double the annual average from 2000 to 2019). In addition, until the 2010s, the largest fires occurred in Southern California. In the past several years, most of the largest fires have occurred in the north, including the August Complex fires in 2020 (in Mendocino, Humboldt, Trinity Tehama, Glenn, Lake and Colusa Counties) and the Dixie Fire in 2021 (in Butte, Plumas, Lassen, Shasta and Tehama counties), which surpassed previous fire size records with all but two of the largest wildfires have occurred since 2000 (**Figure 4.1.4**), including nine that burned in 2020 and 2021 (CAL FIRE, 2025). The increasing prevalence of very large fires (>10,000 acres) in California and across the West has led some researchers and agencies to describe the US as entering an era of “mega-fires” or, when also considering recent large-scale tree mortality events, an era of “mega-disturbances” (CAL FIRE, 2018; also see the *Forest Tree Mortality* chapter and *Changes in Forests and Woodland Composition* chapter).

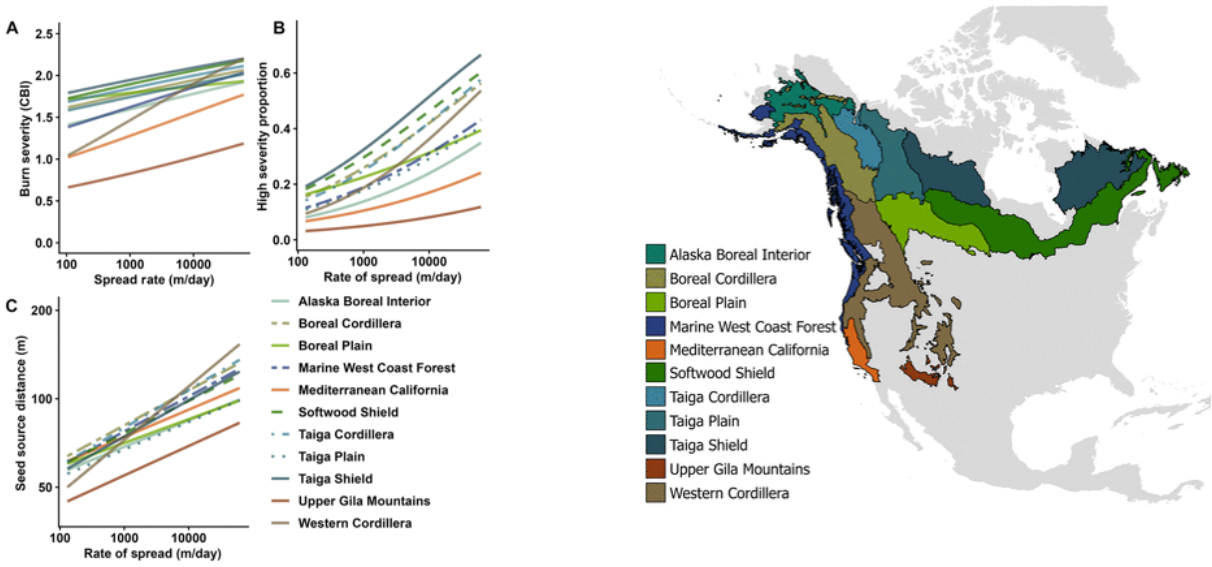
Figure 4.1.4. Top Twenty California Fires, by Size, Since 1950.



Red bars denote fires that occurred in 2020 through 2024. Source: CAL FIRE (2025)

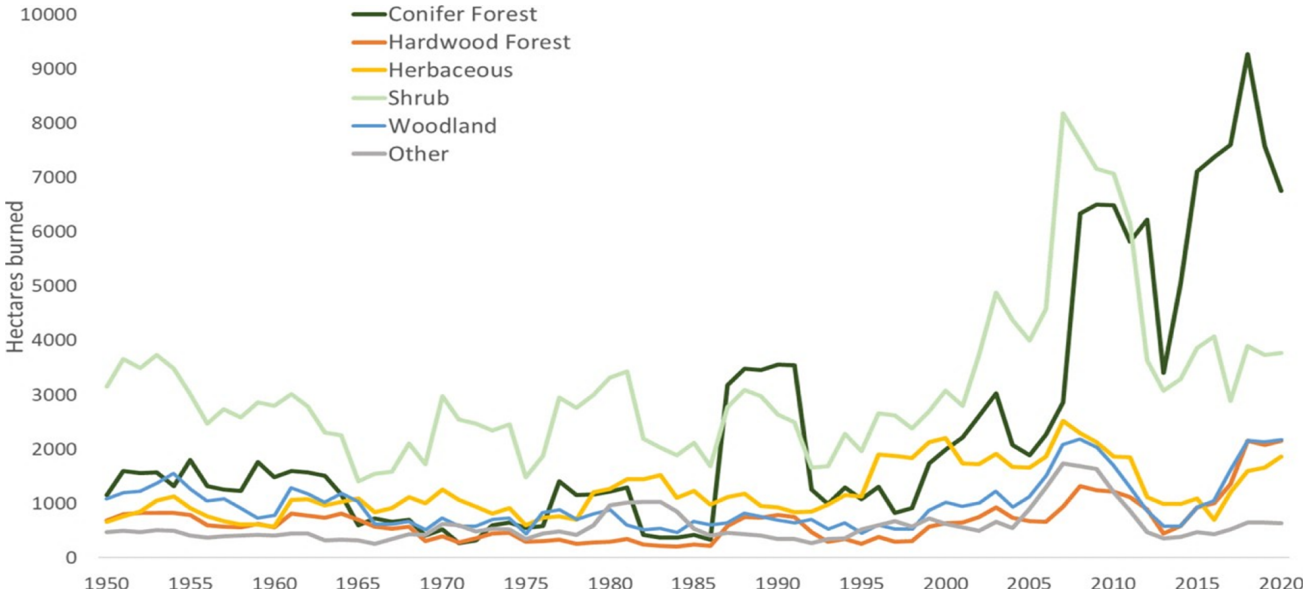
In addition to increasing acreage burned and increasing numbers of large wildfires, the speed at which a fire burns is an important metric relevant to the impacts of wildfires. A study of 3,499 wildfires occurring between 2012 and 2023 in conifer-dominated forests of Canada and the western United States found that the fastest fires burned outsized areas and had more severe ecological impacts (**Figure 4.1.5**; Coop et al., 2026). As described in more detail in *"What factors influence this indicator?*", evidence suggests that a changing climate, combined with land-use patterns, is creating conditions that favor faster-moving, larger, and more severe wildfires across the state and may have significant ecological impacts. Further research on wildfire spread rates in California could provide valuable insights into how climate change is influencing fire behavior. This need is underscored by the fact that 16 of the 20 most destructive wildfires in the state's recorded history, as measured by structural damage and human mortality, occurred after 2010 (CAL FIRE, 2026b).

Figure 4.1.5. Rate of Spread of Wildfires in Conifer-Dominated Forests of Western United States and Canada and Ecological Impacts.



The increasing speed of wildfires is directly proportional to A) burn severity, B) the proportion of area burned at high severity, and C) the distance from live tree seed sources. The map on the right shows the ecoregions studied. Source: Adapted from Coop et al. (2026)

Figure 4.1.6. Area Burned by Vegetation Type.



The graph above shows area burned in California from 1950 to 2020 in hectares (1 hectare equals 2.47 acres). Area burned is smoothed over a five-year window for five vegetation types: coniferous forest; hardwood forest; woodland (consisting of hardwood and coniferous woodland); shrub; herbaceous vegetation; and "other," which includes lower flammability and partially vegetated areas. Source: Schwartz and Syphard (2021)

Why is this indicator important?

Wildfires are a natural part of California's landscape and play an important role in shaping the state's ecosystems. More beneficial fire is needed to restore ecosystem structure and function. At the same time, wildfires can pose serious risks to public health, safety, property, and infrastructure. In the worst instances they take a heavy toll on individuals and communities across the state—causing the loss of lives, homes, livelihoods, and cherished places—and beyond in terms of smoke-related health impacts and negative economic impacts.

"It was nuclear winter. It was like Armageddon. It looked like the end of the world."

- San Diego city firefighter Mitch Mendler, on southern California wildfires in 2007

(Reported by the Associated Press)

Large, high-severity wildfires threaten California's diverse ecosystems. While many of these ecosystems—and iconic species like giant sequoias and redwoods—are adapted to fire, the scale, frequency, or intensity of recent wildfires (such as the CZU Complex Fire that devastated the Big Basin Redwoods State Park (**Figure 4.1.7**) are unprecedented**.** Severe wildfires can transform forests into shrubland or grassland, diminishing soil health, water quality, wildlife habitat, and carbon storage (CAL FIRE, 2018). They degrade soils, increase erosion and flood risk (Oakley, 2021; Neary et al., 2008), and kill wildlife that might otherwise evade smaller fires (CAL FIRE, 2018).

Figure 4.1.7. Coastal Redwood Regrowth.



The CZU Complex Fire severely damaged ancient coastal redwoods of Big Basin Redwoods State Park in 2020, burning even upper branches despite fire-resistant bark (Potter, 2023). The redwoods mobilized old carbohydrate stores to resprout a few months after (sprouts formed a ring around the burned tree in the photo above), but it is uncertain whether they can fully recover or withstand future extreme fires (Peltier et al., 2023). Photo credit: Lissy Enright/US Forest Service

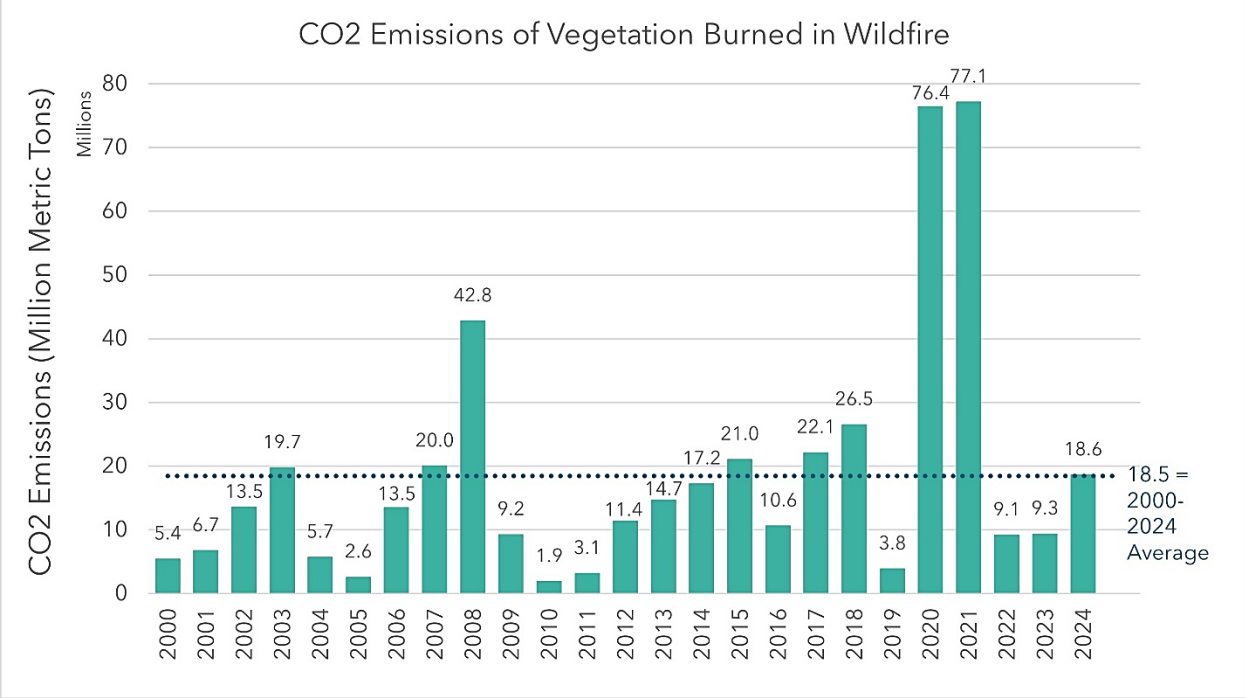
Severe wildfires also can disrupt aquatic ecosystems by altering streamflow, increasing sediment, and introducing pollutants like ash, fire retardants, and heavy metals—threatening species such as Chinook salmon (Alizadeh et al., 2021: Neary et al., 2008). Runoff from burned areas can carry such contaminants to the ocean, harming marine ecosystems for years (OPC, 2026). At the same time, wildfire smoke can provide a benefit to cold-water adapted species like Chinook salmon by reducing solar radiation and cooling air temperatures, which in turn cools freshwater temperatures (David et al., 2018; also see the *Chinook Salmon Abundance* chapter for the complex ways in which wildfires impact Chinook salmon populations in California).

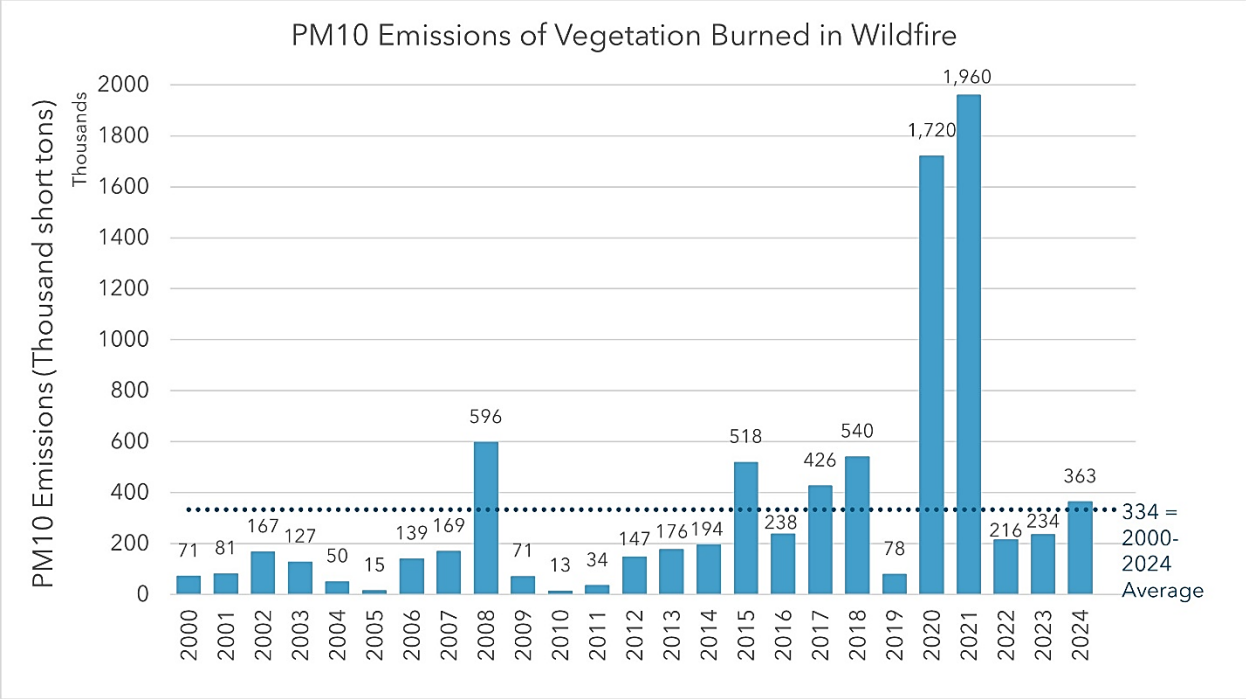
Smoke and toxic gases released by wildfires can impact the health of wildlife and ecosystems. Adverse health impacts of wildfire smoke have been reported to contribute to changes in behavior, movement and vocalization in a vast assemblage of terrestrial and aquatic mammals (primates, marsupials, bats, etc.), birds (raptors, woodpeckers, etc.), insects (butterflies, beetles, etc.) and reptiles (lizards, snakes, etc.) (Sanderfoot et al., 2021). Smoke is known to damage the lungs of birds and increase their susceptibility to respiratory infection. Wildfires have increasingly coincided with fall bird migration, where low visibility caused by smoke can disrupt the navigation for migratory species and create difficulties in finding food sources (Overton et al., 2021; Sanderfoot and Holloway, 2017; see the *Migratory Bird Arrivals* chapter and the *Spring Flight of California Central Valley Butterflies* chapter for other ways that climate change is impacting these species). Wildfire smoke can also negatively impact watersheds, where deposition of smoke and ash in streams can result in dramatic increases in nutrient concentrations and fluctuations of pH, potentially harming aquatic organisms (David et al., 2018).

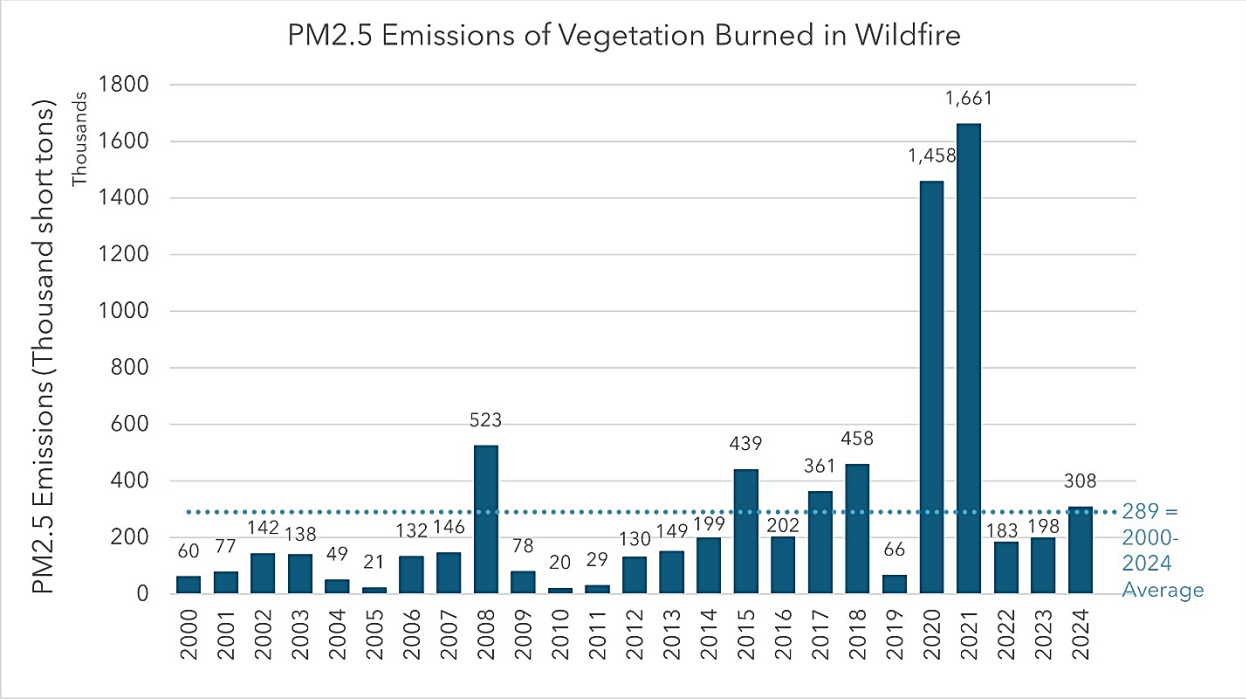
Wildfires have severe impacts on public health, primarily through exposure to wildfire smoke, which is often transported to local and regional population centers and can worsen air quality across the state. When human-made structures burn (as increasingly occur in the wildland-urban interface (WUI), communities are also exposed to diverse

and largely uncharacterized air toxins from building materials and household products. The chemical composition of WUI fire smoke — which may include combustion products of plastics, synthetic polymers, treated wood, paints, coatings, insulation, and electronics — can differ substantially from vegetation-only wildfire smoke, meaning PM (2.5) mass alone does not fully characterize the health hazard in structure-fire events. Wildfire also releases carbon dioxide (CO_2) and other greenhouse gases that contribute to climate change, though quantifying the net contribution is complex given that fire is part of the terrestrial carbon cycle and can bolster carbon sequestration in healthy fire regimes. **Figure 4.1.8** shows CO_2 and particulate matter ($PM_{2.5}$) emissions from California wildfires since 2004; 2020 and 2021 represent the two highest years on record. For a detailed assessment of wildfire smoke trends and health impacts, see the *Wildfire Smoke* chapter. Hazardous chemicals from fires can be both emitted into the air and deposited in the surrounding soil (Cornwall, 2025). Long after air emissions from the wildfires dissipate, potential exposure to deposited ash, soot, and debris in and around the burn areas, particularly during periods of high winds, may still occur.

Figure 4.1.8 Annual Wildfire CO_2, PM_{10}, and $PM_{2.5}$ Emissions.







Source: CARB (2026)

Larger and more severe wildfires are increasingly affecting people across all racial and socioeconomic groups in California (Yadav et al., 2023). Specific demographics especially vulnerable to wildfire impacts include older adults and children, as well as

people with disabilities. These individuals often face greater health risks and barriers to evacuation, protection, and recovery during wildfire events.

Historically marginalized populations also face systemic barriers that make it more difficult for them to access and participate in federal wildfire prevention programs. Certain racial and ethnic groups may also be more vulnerable to wildfire impacts. For example, the January 2025 Los Angeles wildfires, the worst in the city's history, exposed stark racial disparities in their impacts. Nearly half of Black homes in Altadena were destroyed or majorly damaged by the Eaton Fire, versus 37% of non-Black homes (Ong et al., 2025; **Figure 4.1.9**). While Latino neighborhoods were less directly affected by the fires, they faced greater health risks from wildfire smoke due to co-occurring pollution burdens (Pech et al., 2025).

Figure 4.1.9. Burned homes in Altadena from the Eaton Fire.



In January 2025, the Eaton Fire in Los Angeles County severely affected Altadena, a historically Black, middle-class community, where 61% of the community's Black households fell within the fire perimeter compared to 50% of non-Black households. This photo shows at least three burned-down homes and charred trees in Altadena from the Eaton Fire. Source: Ong et al.

(2025). Photo credit: Mayra Beltran/Los Angeles County.

Lower-income communities experience wildfires more frequently and with greater impact (Hino and Field, 2023; Masri et al., 2021). In addition, rural and low-income residents - especially older adults and people who live in isolated areas - often have limited capacity to protect their homes and are more likely to experience property loss during large, hard-to-contain fires (CAL FIRE, 2018; Syphard, 2012).

Access to adequate housing can offer protection from wildfire smoke, yet fire-prone communities increasingly face housing challenges. Wildfires reduce available housing stock, drive up prices, and create uncertainty around where new housing should be built. These pressures limit access to affordable, safe housing, particularly for already vulnerable populations—and increase the risks faced by those living in wildfire-prone areas (Lappe & Vargo, 2022). Low-income communities are also being pushed to the WUI and wildfire-prone areas because of limited affordable housing closer to cities.

Notably, wildfires are also a serious threat to California's tribal nations. Wildfires on or near native lands threaten the health, safety, and economy of those tribes, culturally important species, medicinal plants, traditional foods, and cultural sites (Jantarasami et al., 2018). More information specific to each tribe is presented in the *Impacts on Tribes* section. For example, the number of acres burned annually in the Eastern Sierra within a hundred miles of the Bishop Paiute Tribe's Reservation has increased by approximately 500% from 1950 to 2025 (Bishop Paiute Tribe, 2026). The number of wildfires per year has also been increasing since 1950, impacting the Bishop Paiute Tribe and others in the region. Although a historically fire-adapted system, large high-severity wildfires in this region threaten many species, alter the habitat, and disrupt ecosystem dynamics. Post-fire, shallow-rooted invasive plants are outcompeting slow-growing native plants in the Owens Valley, further contributing to future fire risk due to their flammability and weakening the soil (Big Pine, 2026).

The Pala Band of Mission Indians in the Palomar range of southern California has likewise noted ecological as well as social and cultural impacts from increasing wildfire frequency and severity (Pala Band of Mission Indians, 2026). They have observed fire-driven conversion from native woody shrublands to more flammable, invasive annual

grasses, increased soil erosion, siltation and channelization of surface water, which contributed to the severity of floods that impact the Tribe during the rainy season. Along with the downstream effects of flooding and habitat loss, wildfires have caused significant economic and cultural losses for the Tribe and continue to threaten their sacred sites and lifeways.

In terms of dollars, the Palisades and Eaton Fires of 2025 inflicted more damage than the five previous fire seasons combined (NOAA, 2025a). During several days in early January, LA County—with a population approaching 10 million people—was encircled by fire. The fires killed at least 29 people, destroyed at least 16,251 structures, and caused "between $76 billion and $131 billion" in capital losses and property damages. LA County's gross domestic product (GDP) is expected to contract by 0.48%, or $4.6 billion (Li, 2025).

In recent years, wildfires have deterred visitors from popular destinations like California's wine country and the Sierra Nevada (Bauman et al., 2020; Wilson et al., 2020). Smoke, poor air quality, and reduced visibility can create a sense of fear, force people indoors, and lead to travel restrictions to support firefighting efforts—all of which contribute to canceled plans and reduced tourism revenue. These disruptions also impact local workers, particularly those in outdoor service roles, who may face reduced hours and unpredictable conditions on smoky days.

Additionally, wildfire smoke can affect local energy production. Reduced solar output due to smoke and haze can place added stress on the power grid, with downstream effects for businesses and households alike (Gilletly et al., 2023).

What factors influence this indicator?

Changes to historical fire regimes

Before Euro-American settlement, 4.5 to 12 million acres burned annually in California through lightning strikes and intentional burns by Native Americans to steward the land (Stephens et al., 2007). These low-intensity fires reduced small trees and underbrush (which otherwise serve as fuel for larger fires), supported native species, and enhanced ecosystem resilience. Tribes like the Karuk and Amah Mutsun use fire to protect cultural and ecological resources (Amah Mutsun, 2022; Karuk, 2026). This natural fire regime

was disrupted by the depopulation of Native communities and over a century of fire suppression, leading to fuel buildup in forests (Taylor et al., 2016). Today's catastrophic burns are partly due to strict fire suppression dating back to 1910, which excluded tribal knowledge. Today, there is clear consensus among fire ecologists that dry, western pine forests depend on frequent, low severity fires to reduce fuels and maintain the open, park-like conditions with low tree density that these ecosystems evolved under. Without these fires, tree density increases, with smaller trees and heavy surface fuel loads enabling understory fires to spread into tree canopies that cause high severity fires. After decades of fire suppression, California forests have become significantly denser and prone to larger, high severity fires (Hagmann et al., 2021; Scharffenberger, 2021).

Tribal cultural burns differ from prescribed fire in that they are smaller in scale, timed to seasonal and ecological cues, and based on thousands of years of traditional knowledge. The small, patchy scale of cultural burns likely prevents heavy smoke from being delivered to large populations (Long et al., 2021). Prescribed fire (controlled burns) are intentionally managed fires conducted by trained forest and land management agencies, nonprofits, or private landowners or contractors under strict permitting and regulatory practices, potentially leading to more frequent but lower-intensity smoke exposures (Rosenberg et al., 2024). Prescribed burns offer a significant overall reduction in smoke emissions and health impacts compared to wildfire, even when factoring smoke from the prescribed fires (Kelp et al., 2025; US EPA, 2021c). Wildfires can produce up to 20 times more $PM_{2.5}$ per unit area burned than prescribed fires, and even in aggressive prescribed burning scenarios smoke levels only surpassed baseline smoke levels in 4% of California zip codes (Kramer et al., 2023). Areas in California which had been recently treated with prescribed fire and then burned during the 2020 wildfire season had 14% lower smoke emissions than adjacent, untreated areas. Prescribed burns were less effective at reducing smoke impacts in areas near human populations (Kelp et al., 2025).

Tribal Connection 4.1.1

A Big Pine Paiute Tribal member comments on the longstanding relationship between California Native American tribes and fire, and the current context: "*I want to note that while tribal leadership is increasingly being asked by state, local, and federal agencies how they can support and incorporate traditional fire practices, the reality is far more complex. From an indigenous perspective, the conditions we now face—the result of decades of fire suppression, ecological disruption, and land mismanagement—have pushed the landscape into a state that traditional practices were never meant to navigate alone. Cultural burning was never intended to act as crisis response or large-scale wildfire suppression. It was a preventative practice, rooted in the rhythm of the seasons, the relationship to the environment we were actively living in, and the long-term care of a landscape we'd been inhabiting from the start of our people's history. Now, many areas are so overgrown or overtaken by invasive species that cultural burning is no longer viable without first undergoing major ecological reset—often through the very wildfires we seek to prevent. Paradoxically, it sometimes takes a catastrophic event to clear the ground enough for traditional methods to become possible again, though by that point the damage is already done. This is not a failure of indigenous knowledge, but a reflection of just how far the land has been pushed beyond its natural systems of balance*" (Big Pine, 2026.)

Ignition sources and development patterns

Humans are the leading cause of wildfires in the US, with over 8,000 human-caused fires in California alone in 2024 (NIFC, 2025). Population growth and land use changes—such as housing expansion into wildland areas—have increased ignition sources and fuel availability (Li et al., 2021; Mass et al., 2019; Syphard, 2012). The expansion of electrical infrastructure (much of it vulnerable to strong winds) has further raised wildfire hazard (Mass et al., 2019). From 2013 to 2024, nearly 55,000 buildings were completely or partially damaged by wildfire in California, and 86% of these structures were in areas where development occurred on or near wildland areas (Bar et al., 2026).

Climate change

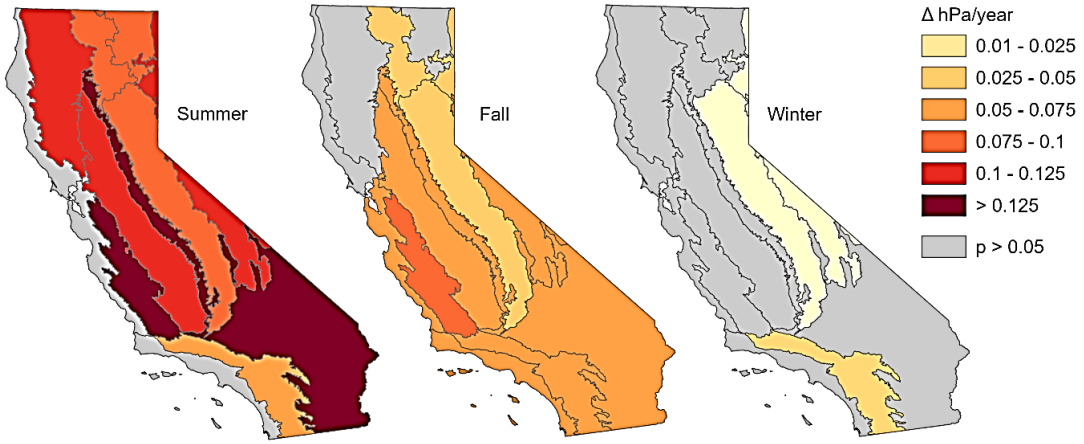
The size, severity, onset, and duration of wildfires are greatly influenced by climate change. Anthropogenic warming is estimated to have enhanced the frequency of extreme daily wildfire growth in California (whether wildfire area burned reached 10,000 acres or more in a day) by 25% on average, relative to pre-industrial conditions**.** For some fires, there was almost no change, and for other fires, the enhancement has been as much as 461% (Brown et al., 2023). The area burned by high-severity fires from 1985 to 2017 in western US forests showed an eightfold increase, corresponding with warmer and drier fire seasons (Parks and Abatzoglou, 2020). A recent study shows that anthropogenic warming (warming caused by human activity) significantly influences the onset of wildfire seasons in California (Madakumbura et al., 2025). Warmer spring and summer temperatures, reduced snowpack and earlier spring snowmelt have been associated with increased wildfire activity in western US forests beginning in the mid-1980s: more frequent large wildfires, longer wildfire durations, and longer wildfire seasons (Westerling et al., 2006; Westerling, 2016; Williams et al., 2019). Climate change contributed an estimated 33 to 82% of total burned area of wildfires in the western US from 1992 to 2020 (Feng et al., 2025).

Lightning-initiated wildfires have driven most of the recent increase in large wildfires in the forests of western US, including California (Li et al., 2020; NIFC, 2022). The relative importance of lightning versus human ignitions varies by ecosystem type, geographic region, fire-size threshold, and season with human ignitions remaining the leading overall cause of California wildfires (NIFC, 2025), while lightning plays a larger role in forest fire occurrence in certain regions and years. Lightning activity is sensitive to surface air temperature changes (Price, 2013). The atmosphere over the Northern Hemisphere has become increasingly unstable due to increased moisture content and warmer air temperature which may result in more lightning activity in the future (Chen and Dai, 2023). The number of days that the western US may experience cloud-to-ground lightning (a type of lightning caused by a discharge between opposite charges in the cloud and on the ground) could increase by the mid-21st century, driven by rises in moisture and atmospheric instability (Kalashnikov et al., 2025). Lightning can amplify climate-related impacts by igniting wildfires, which release greenhouse gases

through smoke, and by producing nitrogen oxides that lead to the production of tropospheric ozone, a potent greenhouse gas (Schumann and Huntrieser, 2007). At the same time, a large portion of global warming is due to positive feedback from increasing upper tropospheric water vapor influenced by global thunderstorm activity (Price, 2023)

Climate change-linked increases in temperature and in vapor pressure deficit (VPD) have significantly enhanced fuel aridity over the past several decades, creating a more conducive fire environment (Abatzoglou and Williams, 2016). VPD is a measure of atmospheric demand for water, i.e., the difference between the amount of water vapor in the air and the maximum amount that could exist in the vapor phase at that temperature. As summertime temperatures increased by approximately 1.4°C in California since the early 1970s, VPD has likewise increased (Williams et al., 2019; **Figure 4.1.10**). The warming-driven increase in VPD has been found to be the strongest climatic driver of wildfires in the summer and of increased wildfire activity across the Sierra Nevada (Chen et al., 2021).

Figure 4.1.10. Vapor Pressure Deficit (1984 to 2022).



The maps above show seasonal changes in vapor pressure deficit by ecoregion across California. Changes are expressed as rates of change over time, with gray shading indicating areas where trends were not statistically significant.

Source: CAL FIRE

High-precipitation years boost vegetation growth, which then dries out the following spring or summer under warm, dry conditions (Keeley and Syphard, 2017). Over the

past four decades, warm fall temperatures and declining precipitation have driven a rise in fire-favorable weather conditions across California (Goss et al., 2020). California is also experiencing "hotter droughts" – droughts that are intensified by unusually warm temperatures leading to reduced snowpack and streamflow, dry soils, and widespread tree mortality. These conditions heighten the risk of fast-spreading, high-severity wildfires that are ecologically damaging and costly to control (Crockett and Westerling, 2017). The 2012–2016 drought significantly reshaped forests in the central and southern Sierra Nevada, with tree mortality drastically increasing the amount of large woody fuels (Stephens et al., 2018). These studies represent an important step toward overall accountability of the impacts of climate change. The current state of knowledge and results strongly support action to mitigate the impacts of climate change, alongside proactive land management practices that enhance the resilience of forested landscapes to wildfire.

Higher-altitude forests are partly buffered against the effects of warming by the availability of moisture from climatologically colder and wetter conditions. Deep snowpacks and abundant spring runoff provide moisture to soil and vegetation, reducing the overall flammability of these forests by limiting the window when fuels are receptive to ignition and fire spread. However, fire is increasing disproportionately at high-elevation forests in the Sierra Nevada and, more broadly, the western United States (Alizadeh et al., 2021; Schwartz et al., 2015).

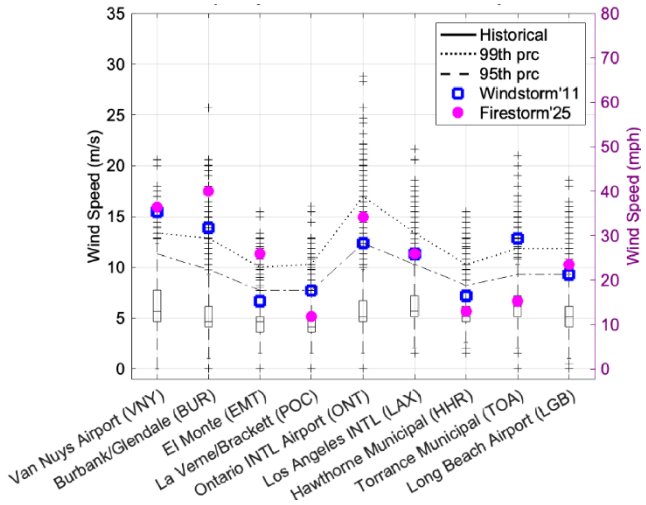
In California's seasonal and ephemeral snowpacks, which provide key water supplies throughout the state, a trend of increasing wildfire activity has been observed since 2001, peaking in 2020 and 2021 (Hatchett et al. 2023). This trend of increasing wildfire activity across major snow zones throughout California can strain the state's current water management system. Wildfire leads to earlier snowmelt due to increased exposure of snow to solar radiation by removing the canopy and by reducing the snowpack's albedo (ability to reflect sunlight) by the deposition of black carbon (Koshkin et al. 2022). Changes to spring runoff patterns requires adjustments in water storage and flood strategies, as much of the state's flood protection and water supply infrastructure was designed and optimized for historical conditions (see the *Snowmelt Runoff* chapter). Changes in fire management (such as reduced fire suppression at high

elevations), climate (including warming temperatures, especially at night, and earlier snowpack melt), fuels (resulting from increasing tree densities), and ignitions (from both lightning and human-caused sources) are recognized as factors influencing the trend. These factors are not mutually exclusive and may have synergistic effects.

Wind-driven wildfires

Large wildfires in California are often associated with strong wind, especially fast-moving downslope winds such as the Santa Ana winds (in Southern California) and Diablo winds (in Northern California) (Abatzaglou et al., 2021). In Southern California, Santa Ana fires, which occur mostly in September through December, spread three times faster than non-Santa Ana fires and occurred closer to urban areas (Jin et al., 2015). Santa Ana winds played a critical role in the magnitude of both the Palisades Fire and the Eaton Fire (Woolcott, 2025), just as they have in many of southern California's largest and most destructive fires (Gershunov et al., 2021). A trifecta of fire-conducive climate conditions set the stage for the 2025 fires: back-to-back wet winters that boosted herbaceous vegetation, the third driest start to the wet season, and an extremely strong and dry Santa Ana wind event (**Figure 4.1.11** and **Figure 4.1.12**; Guirguis et al., 2025). The evidence presented primarily addresses whether climate change has increased the frequency or severity of conditions conducive to fire, such as those in January 2025. Whether climate change made the specific January 2025 wind event more likely or intense is a separate attribution question. The 2018 Camp and Woolsey Fires occurred during periods of extreme fire weather that coincided with strong offshore winds. As the start of California's rainy season has steadily shifted later (Luković et al., 2021; Swain, 2021), wildfire risk has increased due to the overlap of dry fuels and fire-promoting winds in late autumn. In a study of 70 years of atmospheric conditions over California and the Northern Pacific, Guirguis et al. (2023) found conditions favoring hot Santa Ana winds to be increasing in frequency, a trend that is expected to continue in a warming climate.

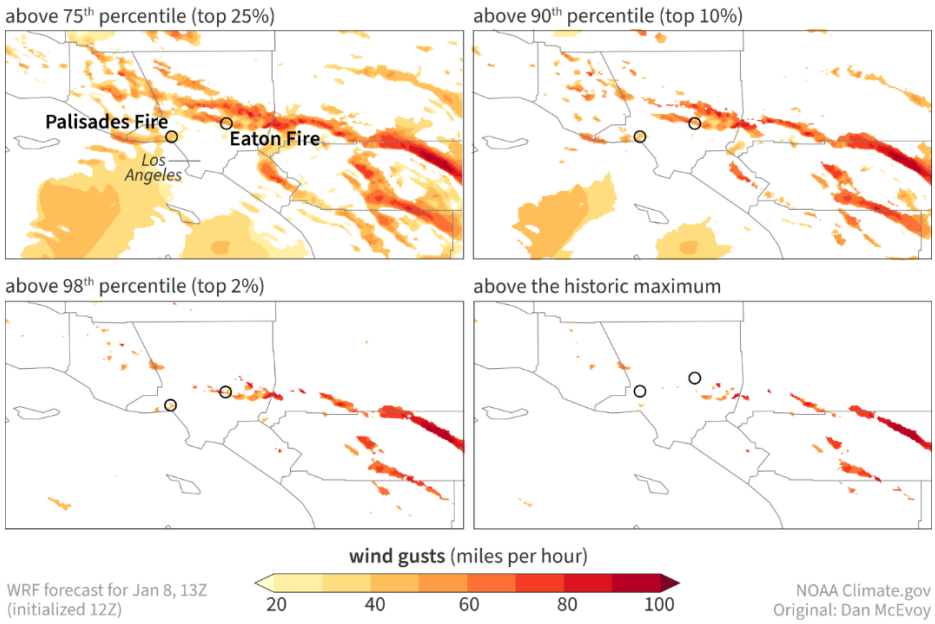
Figure 4.1.11. Observed Wind Speeds in Los Angeles County.



Daily peak sustained wind speeds at weather stations across Los Angeles County during the December 1, 2011 (Windstorm'11) and January 7, 2025 (Firestorm'25) events. Both events exceeded the local 95th percentiles at most weather stations.

Source: Guirguis et al. (2025)

Figure 4.1.12. Forecast Wind Gusts in the Los Angeles Mountains.



Maps show forecasted wind gusts above the 75th percentile (top left), more limited areas above the 90th (top right), and above the 98th over the Palisades and Eaton fires (bottom left) on January 8, 2025. Some gusts were forecasted to exceed historic maximums (bottom right).

Source: NOAA (2025b), adapted from Dan McEvoy.

Similarly, catastrophic wildfires in Northern California, including the series of “Wine Country” fires in Napa and Sonoma Counties in October 2017 and the 2018 Camp Fire in Butte County, were driven by downslope Diablo winds (Smith et al., 2018). These fires burned through both forested and non-forested landscapes of shrubs, grasses, and oak woodlands (Keeley and Syphard, 2019), many of which had not experienced fire in over 50 years.

In 2020, following a heatwave and amidst severe drought and extremely dry fuels, elevated moisture from a developing Pacific tropical storm moved northwards across California in mid-August, leading to a widespread dry lightning outbreak that ignited hundreds of fires (Hatchett et al., 2024). With suppression resources limited due to both high national resource commitment (US Department of Interior, 2020), and COVID-

related impacts on resource availability (Wells et al., 2024), many of these large complexes (e.g., the August Complex, the North Complex, the SCU, LNU, and CZU Complexes) contributed to the record burned area during 2020 as well as substantial structure losses.

Technical considerations

Data characteristics

Data on statewide annual acres burned (**Figure 4.1.1**) were downloaded from a fire perimeter database spanning 1950-2025 made publicly available online through CAL FIRE. CAL FIRE works with the USDA Forest Service (USFS) Region 5, the Bureau of Land Management (BLM), and the National Park Service (NPS) to track fires on public and private lands throughout California. The data for the period 1950 to 2001 include USFS wildland fires 10 acres and greater, and CAL FIRE fires 300 acres and greater, with data for smaller fires and other jurisdictions included when available. In 2002, standard practice additionally included BLM and NPS fires of 10 acres and greater, as well as CAL FIRE timber fires of 10 acres and greater, brush fires of 50 acres and greater, grass fires of 300 acres and greater, wildland fires destroying three or more structures, and wildland fires causing $300,000 or more in damage. Further details are available at the CAL FIRE fire perimeters webpage.

Strengths and limitations of the data

The CAL FIRE database represents the most comprehensive digital record of wildfires in California. However, some fires may be missing for a variety of reasons (e.g., lost historical records, and/or inadequate documentation). The containment date for many of the fires is missing, but a large majority of the fires have alarm dates, which reasonably approximates the ignition time. In addition, although every attempt is made to remove duplicate fires, some duplicates may still exist. In addition, overgeneralization may occur, such as unburned islands within old, large fires may be classified as burned.

OEHHA acknowledges the expert contribution of the following to this report:

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David Sapsis
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CAL FIRE

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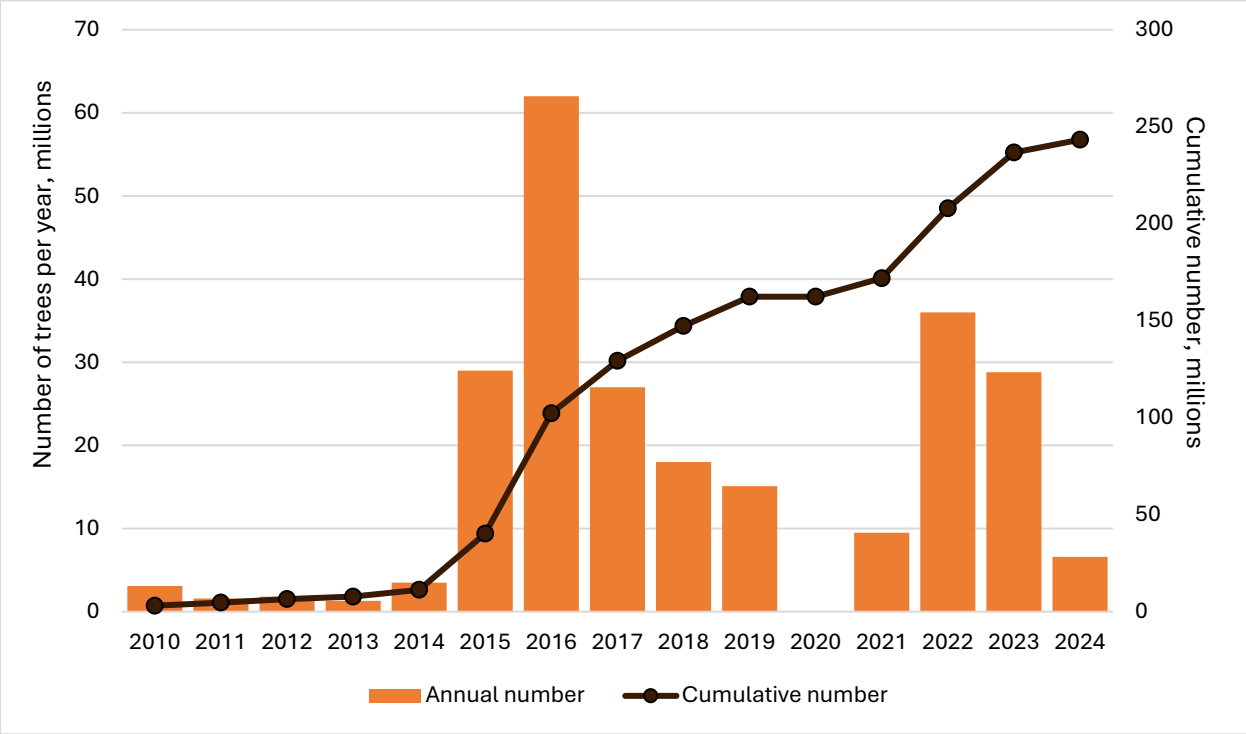
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4.2 Forest Tree Mortality

Since the unprecedented 2012–2016 drought, tree deaths in California forest lands have increased dramatically. An estimated 243 million trees in forest lands died between 2010 and 2024. Most of these trees were stressed from higher temperatures and decreased water availability, making them more vulnerable to insects and pathogens.

Figure 4.2.1. Estimated Number of Dead Trees in California.



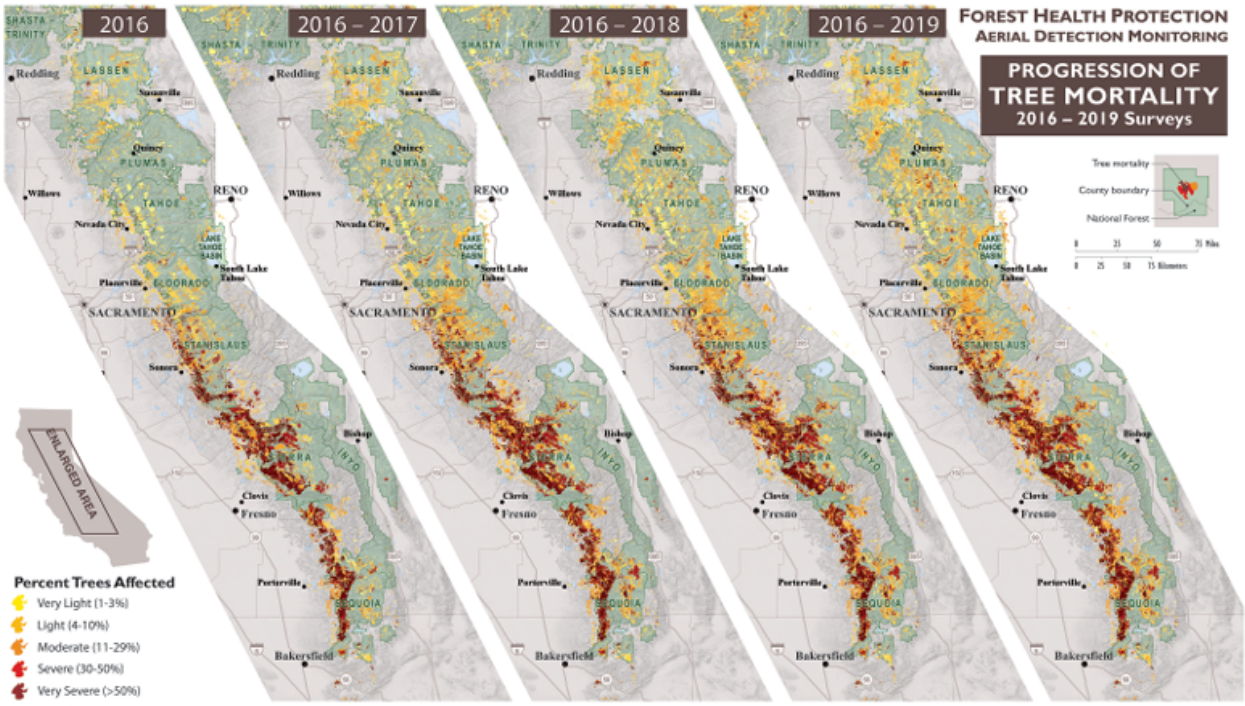
The figure shows the number of dead trees per year as detected by aerial surveys by the US Forest Service. The estimates include trees killed by a variety of agents including drought and drought-related insect activity, but exclude trees killed by wildfire. Surveys were suspended in 2020 due to the pandemic and stopped in 2025 due to federal budget cuts. The cumulative number of dead trees in forested areas between 2010 and 2024 exceeds an estimated 243 million. Source: USFS (2025)

What does the indicator show?

California's forests have experienced persistently high tree mortality since 2015. A sharp rise in tree deaths was first observed during the 2015 survey, coinciding with the

progression of the extreme 2012–2016 drought. The highest recorded tree mortality occurred in 2016, when an estimated 62 million trees died—more than double the number reported the previous year (**Figure 4.2.1**). During this drought, mortality dramatically increased first in the lower-elevation forests of the southern Sierra Nevada, where drought conditions were both most severe and prolonged. By 2016, widespread tree death also became apparent farther north and at higher elevations (**Figure 4.2.2**).

Figure 4.2.2. Tree Mortality in the Sierra Nevada from 2016 to 2019.

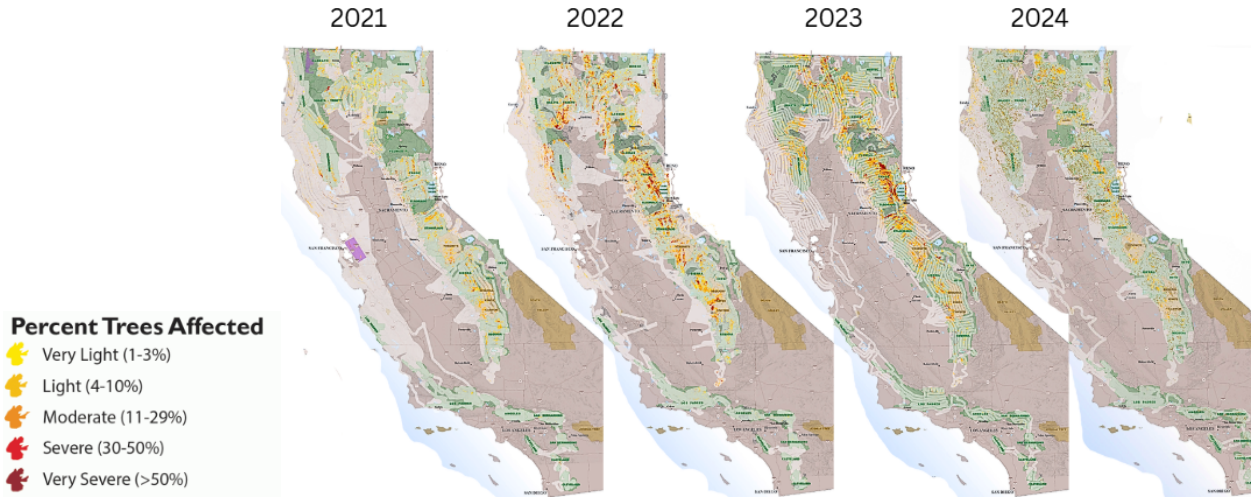


The maps show percent of dead trees recorded in the Sierra Nevada mountains from 2016 to 2019 from aerial surveys. Source: USFS (2025)

Relatively high tree mortality throughout the Sierra Nevada was apparent again in the 2022 and 2023 aerial surveys, to a lesser degree than what was observed during the 2012–2016 drought (**Figure 4.2.3**). The 2020–2022 drought was centered in north-central California, with the highest tree mortality in the central Sierra Nevada and the northern interior (Siskiyou, Shasta, Trinity, Tehama, and Glenn Counties). Also, unlike

the first exceptional drought, where the early mass die-off occurred primarily in low elevation species of pine, mortality primarily affected fir species (USFS, 2025).

Figure 4.2.3. Yearly Tree Mortality in California from 2021 to 2024.



The maps show the percent of dead trees recorded in California forests for each year based on US Forest Service aerial detection surveys. Source: USFS (2025)

The overall increase in tree mortality observed by aerial surveys aligns with satellite-based findings of an upward trend of annual tree cover loss from 1986 to 2019. Tree cover loss rapidly surged later in the study period and appeared to be driven by climate stress and wildfires (Dwomoh et al., 2023). California's pattern of tree mortality also corresponds with global trends: increasing tree mortality has been documented on all vegetated continents and in most bioregions over the past two decades. Tree mortality has been linked to increasingly dry and hot climatic conditions (Allen et al., 2010).

Notably, tree mortality estimates from these surveys may be underestimates: a recent study that mapped individual dead trees in California in 2020 at sub-meter resolution found that the majority of dead trees are isolated or scattered, therefore are likely missed by conventional monitoring methods (Cheng et al. 2024).

As noted in *Impacts on California Tribes*, many tribes have noticed an increase in tree mortality. In 2020 and 2021, OEHHA co-hosted three regional listening sessions with

the Bishop Paiute Tribe, the Pala Band of Mission Indians, the Santa Ynez Band of Chumash Indians, the Big Valley Band of Pomo Indians, and the Middletown Rancheria of Pomo Indians of California. Tribes participating in the Eastern Sierra and Southern California listening sessions including Bishop, Big Pine, Mono Lake Kootzaduka'a, Santa Ynez, Pala, Barona, and others have witnessed increased tree mortality of conifers, oaks as well as pinyon pines and other conifer species. During the Lake, Sonoma and Mendocino listening session, the Middletown Rancheria shared this image of local trees (**Figure 4.2.4**) that are dead or dying. The Kashia Band of Pomo Indians are also experiencing tree mortality and now refer to these stands or dead and dying trees as "match sticks".

Figure 4.2.4. Dead and Dying Trees at Middletown Rancheria.



Photo credit: Mike Shaver, Water Resources Manager, Potter Valley Tribe

Why is this indicator important?

Forests occupy almost one-third of California and are a vital resource for the state, providing important ecosystem services, including water and air purification, carbon sequestration, building materials, renewable energy, cultural resources, wildlife habitat,

and recreational opportunities (CNRA, 2016). Accelerating tree mortality and the increasing frequency of large-scale and high mortality events (known as forest dieback) could have profound effects on these ecosystem services. The loss of large trees represents a significant reduction in the capacity of forests to store carbon, further exacerbating climate change. The unprecedented scale of tree mortality and the increased fuel load present increased risks of large, severe fires in the coming decades (Stephens et al., 2018).

Tribal Connection 4.2.1

Pinyon pine nuts and acorns from a variety of oaks are culturally important foods for Tribal Nations across the state. One impact of climate change that tribes have observed is that drought weakens these trees' defenses, making them more susceptible to invasive insect pests and/or pathogens. For example, the Mono Lake Kootzaduka'a Tribe has observed higher mortality of pinyon trees, lower pinyon nut production and size, and less pinyon sap which is an important cultural medicine (Mono Lake Kootzaduka'a Tribe of California and Nevada, 2026). Similar observations of pinyon mortality have been made by other tribes in the Eastern Sierra, including the Big Pine Paiute Tribe and Bishop Paiute Tribe (Big Pine Paiute Tribe, 2026; Bishop Paiute Tribe, 2026), and the Big Valley Band of Pomo Indians in northern California (Big Valley Band of Pomo Indians, 2026). Likewise, the Big Valley Band of Pomo Indians, Big Pine Paiute Tribe, Bishop Paiute Tribe, and Pala Band of Mission Indians (Pala Band of Mission Indians, 2026) have all reported increased oak death and reduction in acorn availability and quality.

Examples of how increased tree mortality is impacting different tribes:

Tribe: region	Tree: pest	Driver	Cultural impact
Big Pine Paiute Tribe: Owens Valley	• Pinyon pine: Mountain pine beetle • Oaks	• Drought • Drought	• Decreased pine nut yield and size • Fewer acorns, stronger acorn tannins
Big Valley Band of Pomo Indians: Clear Lake	• Ponderosa pine: western pine beetle • Pinyon pine: Ips pine bark beetle • Valley oaks: Mediterranean oak borer	• Drought • Drought • Drought	• Wildfire fuel hazard • Decreased pine nut yield and size • Fewer acorns for Tribe and animals; fire fuels hazard; loss of habitat and cultural landscape
Bishop Paiute Tribe: Bishop	• Pinyon pine: Mountain pine beetle • Oaks	• Drought • Drought	• Decreased pine nut yield and size • Fewer acorns, change in taste
Karuk Tribe: mid-Klamath River	• Tanoak: Sudden Oak pathogen • Black oak: Sudden Oak pathogen • Sugar pine: fungal pathogen	• Drought • Warming temperatures • Warming temperatures	• Fewer acorns and tanoak mushrooms • Fewer acorns • Fewer pine nuts (Karuk Tribe, 2026)
Mono Lake Kootzaduka'a Tribe: Mono Lake	• Pinyon pine: Mountain pine beetle	• Drought	• Decreased pine nut yield and size • Less sap for medicine • Loss of critical habitat
Pala Band of Mission Indians: Pala	• Oaks: Gold spotted oak borer	• Drought	• Fewer acorns for Tribe and animals; fire fuels hazard; loss of habitat and cultural landscape
Wiyot Tribe: *Wigi* (Humboldt Bay)	• Sitka spruce: green spruce aphid	• Flooding, saturated soil	• Reduced critical habitat type (Wiyot Tribe, 2026)

There is also evidence that increased tree mortality amplifies other climate change-related phenomena such as forest type conversion (a change in tree species or group of species present, for example, from conifers to hardwood; see the *Changes in Forests and Woodlands Composition* chapter) and increased wildfire risk (see the *Wildfires*

chapter). Shifts in dominant tree species can alter ecosystem structure and function, including water use and availability, carbon storage, habitat suitability for wildlife, and fuel characteristics that influence fire behavior. If high tree mortality persists, California's forests may shift in species composition, convert to less forested vegetation, or disappear altogether (Larvie et al., 2019; Lenihan et al., 2003; Millar and Stephenson, 2015; Thorne et al., 2008).

What factors influence this indicator?

Tree mortality in California reflects the complex interplay of wildfire, rising temperatures, prolonged drought, and pest outbreaks (Dwomoh et al., 2023; Young et al., 2023). Decades of fire suppression have led to unnaturally dense forests, intensifying competition for water and other resources and leaving trees increasingly vulnerable to drought stress, pest infestations, and a surge of large and severe wildfires (Harrison et al., 2024; McIntyre et al., 2015; Stephens et al., 2018; Young et al., 2017). Recovery is threatened by habitat loss, conversion to different dominant species in response to changing environmental conditions, poor tree regeneration, and rising moisture deficits (Davis et al., 2023).

The extreme 2012–2016 drought, part of a larger "megadrought" from 2000 to at least 2021 in the U.S. southwest, was an example of the increasingly common "hot droughts", when anomalously high temperatures coincide with very dry conditions. The broader megadrought was the driest in over 1,200 years, with up to 42% of its severity linked to climate change (Williams et al., 2022). Using tree ring data from California, researchers estimated 2014 to be the worst single drought year in at least the last 1,200 years in the state, as seen in the tree rings of blue oak — the result of unusually low (but not unprecedented) precipitation and record high temperatures (Griffin and Anchukaitis, 2014). Hot droughts increase the physiological stress in trees (Diffenbaugh et al., 2015; Young et al., 2017). In fact, rising global temperatures have contributed to droughts of a severity that is unprecedented in the last century (Millar and Stephenson, 2015). Regional warming and drought change the hydrology at landscape scales (Thorne et al. 2015). Less precipitation falling as snow, declining snowpack water content, and earlier spring snowmelt and runoff have impacted old growth western forests (van Mantgem et

al., 2009). The 2012–2016 drought occurred at a time of record warmth — 2014 was, at that time, the warmest year on record, followed by 2015 — and was accompanied by record low snowpack (DWR, 2017; also see the *Air Temperature, Drought,* and *Snow-Water Content* chapters).

The 2012–2016 drought triggered widespread tree dieback in the Sierra Nevada, driven by pests thriving in dense, fire-suppressed forests. Meanwhile, rising precipitation variability—including record wet years—has amplified disease outbreaks linked to moisture, also increasing tree mortality (Harrison et al., 2024). Tree mortality during drought is linked to rising climatic water deficit (CWD), a measure of plant water stress that increases with warming, reduced precipitation, and earlier snowmelt. High CWD impairs water transport in trees, a key driver of drought-induced mortality (Flint et al., 2013; Thorne et al., 2015). Prolonged depletion of soil moisture, compounded by high tree density and warm temperatures, substantially increased tree mortality in the Sierra Nevada during the 2012–2016 drought (Goulden and Bales, 2019). Statewide, approximately 10.6 million hectares (ha) of forest containing up to 888 million large trees in California experienced measurable loss in canopy water content during this drought (Asner et al., 2016).

Notably, hot droughts may be beneficial for some tree species growing at high elevations. Tree growth of *Pinus jeffreyi*, *P. lambertiana*, and *P. contorta* in the San Jacinto Mountains from 2000 to 2020 fared better with warmer temperatures and lower precipitation. Warmer temperatures in these historically cooler elevations may be extending growing season while remaining within the temperature range needed for growth (Knapp et al., 2023).

Large scale, drought-induced tree mortality events create feedbacks that exacerbate the threat of wildfires (Stephens et al., 2018). Across the west, drier conditions have also amplified the occurrence and extent of wildfires (Abatzoglou and Williams, 2016) that directly kill trees and also burn trees that previously died due to other factors. Longer fire seasons—due to reduced snowpack, earlier melt, and rising temperatures—are pushing wildfires into higher elevations. In northern montane forests, climate's influence on fire size and area burned has increased by two- to four-times over the past century.

At lower elevations, hotter, drier conditions fuel more destructive, wind-driven autumn fires (Goss et al., 2020). Since 1985, forest cover has declined nearly 7%, largely due to fire (Wang et al., 2022). Another study found yearly statewide forest spatial loss to fire in 2021–2023 averaged about 150 km^2/year (Safford and Stewart, 2026).

Warming temperatures favor pest growth, heightening risks of tree infestations and disease (van Mantgem et al., 2009). Most conifer deaths result from drought-weakened trees succumbing to beetle attacks rather than direct drought stress (Moore et al., 2016). Recent decades have seen widespread forest dieback and mortality across western North America as warmer winters fueled insect outbreaks (Bentz et al., 2010). Pathogens are also expanding, for example, the range of white pine blister rust has shifted upslope with warming, so that high-elevation white pines may face greater risk (Dudney et al., 2021).

Some of the predominant pests and diseases affecting California's forests are:

Fir engraver beetle (S*colytus ventralis*). Fir engraver beetle is a native insect significantly impacting California red fir and white fir and caused most of the detected mortality in California in 2022 and 2023 (USFS, 2025). Drought is a primary stressor that weakens the trees and makes them susceptible to infestations.

Western pine beetle (*Dendroctonus brevicomis*). The western pine beetle, a native bark beetle, has caused severe ponderosa pine mortality in California's Sierra Nevada, especially during drought. Significant tree mortality of low-elevation ponderosa pines was attributed to the western pine beetle during the 2012–2015 drought based on an analysis of 11.3-m fixed-radius plots installed within three elevation bands on the Eldorado, Stanislaus, Sierra and Sequoia National Forests (914–1219, 1220–1524 and 1525–1829 m), two elevation bands on the Eldorado, Stanislaus, and Sierra National Forests (1219–1524, 1525–1829) and one elevation band on Sequoia National Forest (1830–2134 m), where tree mortality was most severe (Fettig et al., 2019). A study encompassing the Eldorado, Stanislaus, Sierra, and Sequoia National Forests, Kings Canyon, Sequoia, and Yosemite National Parks, and adjoining areas of the Sierra Nevada found that during the 2012–2015 drought, warmer temperatures increased beetle-caused mortality by 30% (Robbins

et al., 2022) by accelerating beetle development and reducing winter die-off (Bentz et al., 2023; Robbins et al., 2022). The resulting beetle outbreaks, combined with drought stress, have boosted wildfire fuel loads and subsequent tree mortality (Wayman and Safford, 2021).

Sudden oak death (*Phytophthora ramorum*). In coastal northern California, sudden oak death (SOD) is the leading cause of tree mortality. First detected around 1990, this invasive pathogen infects over 130 plant species (Cobb et al., 2020). It kills tanoak (*Notholithocarpus densiflorus*), coast live oak (*Quercus agrifolia*), and California black oak (*Q. kelloggii*); while California bay laurel (*Umbellularia californica)* serves as a carrier. The SOD pathogen thrives in warm, wet conditions, and although a direct link is unconfirmed, winter temperatures in California's north coast have warmed by about 1.3°F (0.72°C) since 1951 (Flint et al. 2021; analysis by Thorne, personal communication).

Shothole Borers (*Euwallacea* spp.). Some urban and natural forests in southern California have been severely affected by beetle-related tree mortality. Invasive shothole borers are two closely related species of small, non-native, beetles that bore into trees and introduce fungi that cause a tree disease called Fusarium dieback (UCANR, 2026). These beetles have killed thousands of trees in Southern California, and can impact riparian, agricultural and urban tree species (Boland 2018; Eskalen et al., 2018). They have also moved into riparian systems in Southern California, including the Tijuana River and the Santa Clara River riparian forests (Bennett, 2020).

Goldspotted Oak Borer (*Agrilus auroguttatus*). Also in Southern California, the invasive goldspotted oak borer, introduced from Arizona, kills oaks such as coast live oak and black oak (Coleman et al., 2017). For example, the Iipay Nation of Santa Ysabel and the Barona Band of Mission Indians, the Pala Band of Mission Indians (and others) have reported widespread oak deaths on their reservations.

Technical considerations

Data characteristics

The aerial tree mortality surveys were based on annual small plane reconnaissance over California's forested lands. Forested areas were mapped on a one-acre basis, and the following were recorded: (a) damage type, (b) number of trees affected, and (c) affected tree species. Generally, areas with <1 tree per acre of mortality were considered to have "background" or "normal" levels of mortality and were not usually mapped during the flight. If low levels of mortality were indicative of a localized pest-related event, the areas were supposed to be mapped; however, it is usually not possible to systematically discern the cause of such low-level mortality using visual aerial surveys.

For the aerial surveys, lands dominated by hardwood and conifer tree species were considered forest lands. Affected trees were recorded to species level, when possible (sugar pine and white fir), or to genus level (pine, fir). In areas where two or more tree species were affected, the surveyor designated the proportion of damage affecting each species (e.g., 25% sugar pine, 75% white fir), or preferably, an estimate of trees per acre for each species affected was recorded. Lands characterized as urban, orchards, and windbreaks were not mapped. Tree injuries that were recorded were typically defoliation, discoloration, dieback or more commonly death.

Survey results provide a reasonable estimate of dead trees that aid in the understanding of the mortality event (USFS, 2019). There will be some level of error in the density estimates, however, over large areas, the results should show the correct trends.

Strengths and limitations of the data

Aerial surveys cannot detect mortality until the trees have been dead some months and the foliage has dried out and faded from green to a red or yellow color. Thus, currently infested, still-living trees that still look healthy from a distance may not be counted in the aerial survey. The aerial detection survey program was suspended in 2020 due to the COVID-19 pandemic and no estimates are available that year. Aside from 2020, aerial surveys covered most of California forests every year up to 2024 (J. Moore, personal

communication, March 2024). The 2021 Aerial Detection Survey (ADS) did not include all areas covered by past aerial survey operations; instead remote sensing was used to analyze some of the areas.

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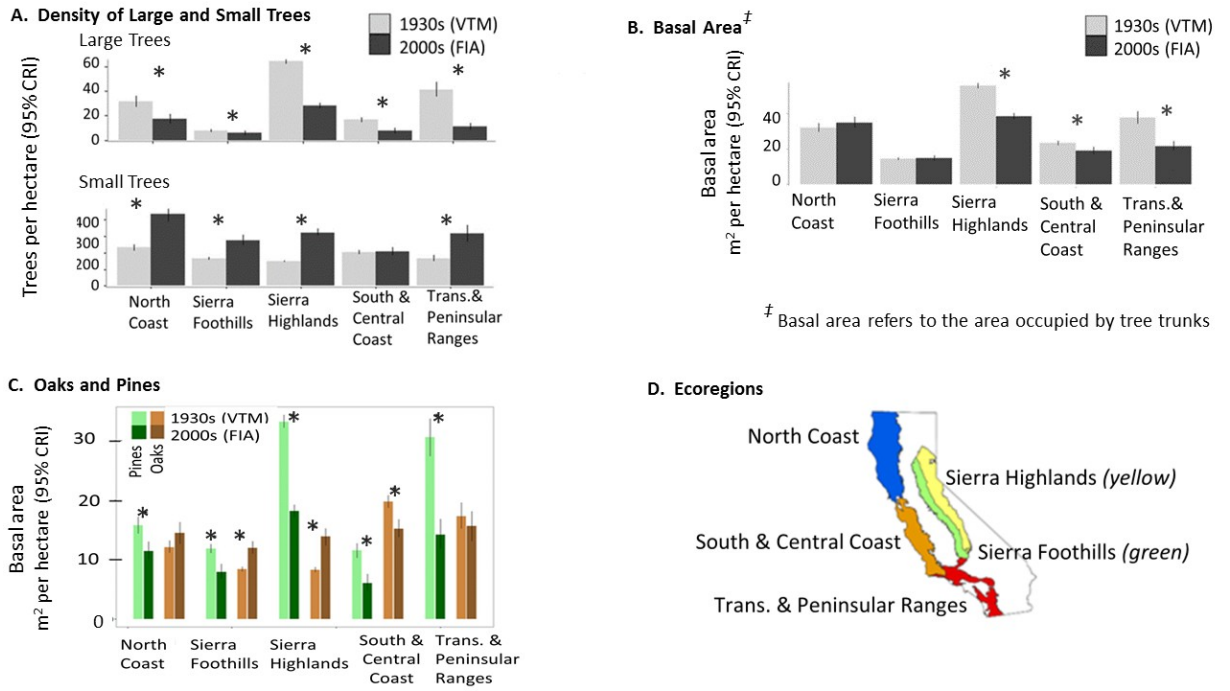
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4.3 Changes in Forests and Woodlands Composition

Compared to 80 years ago, California's forests today have more small trees and fewer large trees. The areas occupied by pines have decreased in all regions studied, while the areas occupied by oaks have increased in the Sierra Nevada but have decreased in the South and Central Coast. These changes are associated with decreased water availability driven by warmer temperatures.

About this indicator: This indicator was first presented in OEHHA's 2018 report, titled "Changes in Forests and Woodlands". While the underlying data have not been updated since 2018, we have incorporated more recent findings from scientific literature.

Figure 4.3.1. Changes in Forest Structure and Composition Historical (1929-1936) vs. Contemporary (2000-2010)[a]



[a] Historical from Wieslander Vegetation Map (VTM); Contemporary from Forest Inventory Analysis (FIA)

* Statistically significant differences

Source: McIntyre et al. (2015)

What does this indicator show?

The structure and composition of California's forests have changed, and this is associated with climate change related water availability. This indicator consists of three metrics tracking changes in the structure and composition of forests across five regions in California. These metrics are based on a comparison of data from a 1930s survey of the state's vegetation (documented in the Wieslander Vegetation Type Map, or VTM) with data from surveys conducted between 2000 to 2010 as part of the US Forest Service's Forest Inventory Analysis, or FIA (McIntyre et al., 2015). Forest structure refers to the distribution of small, medium, and large-sized trees, while species composition refers to the diversity of tree species present.

Figure 4.3.1A displays the first metric, which shows changes in the density of large and small trees. Large trees are defined as greater than (>) 61 centimeters (cm), or >24 inches (in), in diameter at a height of 4.5 feet ("diameter at breast height," or dbh), and small trees are defined as 10–30 cm, or 4–12 in, dbh. Decreases in large tree density were observed in all regions studied. The greatest decrease occurred in the Transverse and Peninsular ranges of Southern California, where large tree density in the contemporary period was less than 30% of the density in the historical dataset—40.8 compared to 10.6 trees per hectare (trees/ha). Declines of about 50% in large tree densities were observed in the Sierra Nevada highlands (64.3 compared to 28.03 trees/ha), the Coast Ranges of Southern and Central California (16.6 compared to 7.5 trees/ha), and Northern California (30.6 compared to 16.7 trees/ha). Declines in large trees were lowest in the Sierra Nevada foothills (7.6 compared to 5.7 trees/ha), the region where large tree densities are lowest.

From the historical to the contemporary period, densities of small trees increased over two-fold within the Sierra Nevada highlands (149 compared to 315 trees/ha), and over 50% in the Sierra Nevada foothills (165 compared to 268 trees/ha), the North Coast region (229 vs. 412 trees/ha) and the Transverse and Peninsular ranges (165 compared to 301 trees/ha) (**Figure 4.3.1C** and **4.3.1D**). The density of small trees was unchanged in the South and Central Coast Region (200 compared to 197 trees/ha). Patterns of

change for intermediate-sized trees (31–60 cm or 12–24 in dbh) were variable across the two time periods (not shown).

Figure 4.3.1B illustrates the second metric, which shows changes in basal area — the amount of area occupied by tree trunks within a given area (expressed in units of square meters per hectare, m^2/ha). Basal area, which reflects biomass, decreased in three of the five regions: up to 40% in the Transverse and Peninsular Ranges Region (37.8 compared to 21.6 m^2/ha, 30% in the Sierra Nevada Highlands Region (55.9 compared to 38.5 m^2/ha), and 18% in the South and Central Coast Region (23.3 compared to 19.0 m^2/ha). In the North Coast and Sierra Nevada Foothills Regions, the reductions in basal area due to large tree declines were balanced by increases in smaller size classes, hence no decline in overall basal area was observed.

The third metric is displayed in **Figure 4.3.1C**, which compares historical and contemporary basal area occupied by pines and oaks. Changes in the relative abundance of these tree species represent changes in forest composition. Pines have declined in all regions, whereas oaks increased in two Sierra Nevada regions but decreased in the South and Central Coastal ranges.

Changes in forest composition and their drivers are not uniform across the state, however. In some areas of California, shrublands are replacing conifer and hardwood forests (Bhoot et al., 2026). 30% of Sierra Nevada's conifer forest transitioned to non-forest vegetation during 2011–2020, primarily due to the combined effects of wildfires, drought, and drought-associated beetle epidemics (Steel et al., 2022). The increasing pace and intensity of wildfires in California have led to losses in spatial extent of forests between 0.25 and 0.47% per year, leading to deforestation of about 150,000 ha/year in 2021-2023 (Safford and Stewart, 2026). Along California's central coast, grassland cover declined by 26% over an 80-year period, while shrubland and oak woodland increased by 31% and 16%, respectively, in areas that had not burned (Genua et al., 2024). In the northern Bay Area, woodland and shrub patches were most susceptible to change, with many areas transitioning to denser forest stands, while herbaceous and forest patches showed greater persistence. Wildfires and topographic variables like elevation were identified as important influences on the likelihood of vegetation

persistence in this region, while slope and water availability were not. Unburned, higher-elevation, and Northwest-facing areas were more likely to persist as forest vegetation, whereas higher-elevation and Northwest-facing shrub and woodland sites were more likely to convert to forest (Fertel et al., 2023).

Forest composition in some parts of California has shifted toward increased dominance by oaks relative to pines, a subgroup of conifers (McIntyre et al., 2015). In the Six Rivers National Forest of the Klamath Mountains, however, comparisons between historical inventories (1872–1884) and modern surveys (2008–2017) document declines in oaks alongside increases in pines, Douglas-fir, and small trees across a 36-square-mile study area. These changes were primarily attributed to fire suppression in the 1900s, in which small, low-intensity traditional burns by Native Californian tribes were disrupted and reduced. Densification of contemporary forests in Six Rivers as a result of fire suppression, coupled with a warming climate, likely contributed to unusually large wildfires in recent years. Average hectares (ha) burned in the 2010s was greater than in any other decade between 1908 and 1999. Between 2000 and 2018, over 500,000 ha burned, compared to nearly 200,000 ha during the entire previous century (Knight et al., 2020).

In addition to changes in forest structure and composition, elevational range shifts are also occurring. For example, the lower edge of conifer-dominated forests in the Sierra Nevada has retreated upslope since the 1930s, overlapping with an upslope shift of the winter freezeline (Thorne et al., 2008 and 2015; see also the *Ponderosa Pine Forest Retreat* chapter in OEHHA, 2018 and 2022). In the northern Sierra Nevada, three of twelve tree species—red fir (*Abies magnifica*), western white pine (*Pinus monticola*), and mountain hemlock (*Tsuga mertensiana*)—shifted upward in elevation by an average of 112–119 meters over an 80-year period (Wright et al., 2016). Together with large wildfires that have affected lower-elevation forests, tree mortality events likely contribute to the ongoing upslope retreat of ponderosa pine (Hill et al., 2023).

Why is this indicator important?

California's diverse climate and topography support a wide range of forest ecosystems that cover more than 33 million acres across the state, including some of the largest,

tallest, and oldest trees in the world. California's forests support extensive biodiversity, economic activity, and substantial carbon storage (CAL FIRE, 2018; CARB, 2026). They provide critical ecosystem services, including clean water, clean air, wildlife habitat, and recreation. Forested watersheds in the Sierra Nevada alone supply about 30% of California's total water supply, provide about 60% of water consumed by the state's population, and generate nearly half of the state's hydroelectric power (Soderquist and Luce, 2021).

The pine and oak-dominated forests and woodlands of California provide ecosystem benefits such as erosion control, water provision and carbon sequestration, as well as wildlife habitat, timber, and opportunities for recreation. Changes in forest structure and tree species composition can impact these functions.

This indicator describes how forest conditions have changed relative to historical climate change by comparing the 90-year-old VTM survey with modern-day observations and is bolstered by more recent studies focused on changes in forest structure, composition and extents. It shows that the state's forests are transitioning from one set of species to another. Since these changes may be a natural ecosystem response to warming and drying conditions, monitoring them provides valuable insight into future forest responses to climate change. There is evidence that wildfires at elevations up to about 5,000 feet where pines and oaks grow together can initiate this shift in species dominance by removing the dominant conifers (including pines but also other needle-leafed trees), allowing resident oaks and chaparral to establish and become the dominant vegetation. Another VTM-based study estimates that 13.5 million acres in California are at risk of this conversion (Goforth and Minnich, 2008). Decreases in large coniferous trees, including pines and firs in California montane (mountainous) forests have also been documented in other studies (Dolanc et al., 2013; Lutz et al., 2009; van Mantgem and Stephenson, 2007); furthermore, dieback of trees has been reported on all continents (Allen et al., 2015) and across the western United States (van Mantgem et al., 2009).

Despite a nearly 40% overall increase in tree density, the decline in large trees has resulted in about a 20% decline in basal area and associated biomass (not shown).

What factors influence this indicator?

California Native American tribes have stewarded these lands for thousands of years, and forests remain integral to their cultures and subsistence. For millennia, forests were shaped by frequent fire from both natural ignitions and Indigenous land management practices (CAL FIRE, 2018; Knight et al., 2022). During the twentieth century, widespread fire suppression and a warming climate altered forest structure, resulting in increased tree density and increasingly large wildfires (Klimaszewski-Patterson et al., 2024; Knight et al., 2022). Changes in forest structure are particularly pronounced on private timberlands, where densities of small trees (<10.2 cm diameter) have increased by as much as 400% since 1930 (Easterday et al., 2018). The density of small trees in the subalpine zone (2,300 to 3,400 meters or approximately 7,500 to 11,000 feet elevation) of central Sierra Nevada has increased by 62% since the 1930s while large tree densities decreased by 21%. These shifts are ubiquitous throughout the subalpine zone (Dolanc et al., 2013; also see the *Subalpine Forest Density* chapter in OEHHA, 2018 and 2022). The combined pressures of land-use change, climate change, and their interactions with wildland fire are reshaping the forests of the western United States (Hurteau et al., 2025).

Statewide, the decline in large trees and increases in the relative abundance of oaks compared to pines are associated with climatic water deficit (CWD), while changes in small tree densities are not (McIntyre et al., 2015). CWD is the cumulative annual excess of potential versus actual evapotranspiration of water from plants. Drought, and therefore CWD, can be intensified by unusually warm temperatures. When combined with very low precipitation and snowpack, extreme heat can lead to decreased streamflow, dry soils, and large-scale tree deaths. These conditions create increased potential for extreme wildfires that spread rapidly, burn with more severity, and are costly to suppress (NOAA, 2026).

The ratio of oak to pine basal area was correlated with estimates of CWD in the time periods of both forest surveys (McIntyre et al., 2015). In addition, the contemporary survey shows an increased relative dominance by oaks that was associated with increases in CWD. The paleological record is consistent with this: in the past 150,000

years, oaks dominated in warmer, drier interglacial periods, and pines in colder, more mesic (characterized by moderate or well-balanced supply of moisture) glacial periods (Heusser, 1992).

The changes in forest species composition and basal area described here are occurring in California forest and woodland areas at elevations that are subject to seasonal drought; these areas represent water-limited ecosystems throughout the low to mid-elevations of the state, from the southern coastal and transverse mountains to near the northern end of the foothills of the Sierra Nevada Mountains. Although there are several potential causes for these dynamics at lower elevations, hotter drought conditions are the lead environmental cause.

Other factors potentially contributing to shifts in the oak: pine ratio include fire suppression, wildfires, and logging practices. Widespread fire suppression in the western United States has led to the buildup of forest litter and increased density of small trees, including the establishment of the highly flammable white fir (*Abies concolor*) — changes which have potentially contributed to the more frequent and larger wildfires today. Further, a warming climate is contributing to the increasing frequency and intensity of wildfires in the western United States (Westerling et al., 2006; also see the *Wildfires* chapter).

As noted above, wildfires can initiate the conversion of coniferous to broadleaf forests and woodlands or chaparral by removing dominant conifers. A large stand-replacing fire at Cuyamaca Rancho State Park near San Diego (the Cedar fire, October 24-28, 2003) happened after eight decades of fire suppression. A seedling census four years after the fire found that while various oak species had re-established, few to no conifer seedlings had done so, resulting in the conversion of a mixed conifer-oak forest to one dominated principally by oaks (Goforth and Minnich, 2008). The authors did not examine changes in climatic conditions. The authors predict this transition is to be expected for the ~13.6 million acres of this forest type in California, including large swaths of the Sierra Nevada foothills and most of the forests and woodlands near coastal urban areas. This prediction is also in line with change documented on the western slope of the Sierra Nevada Mountains where lower elevations of coniferous

forests are retracting upslope (Thorne et al., 2008; see also the *Ponderosa Pine Forest Retreat* chapter in OEHHA, 2018 and 2022). This was corroborated by a 2016 study that examined post-fire seedling regeneration after 14 large wildfires in Northern California. Welch et al. (2016) found that in 10 of the 14 fires, conifer regeneration was not high enough to meet US Forest Service stocking standards, indicative of a return of the site to a conifer forest.

Differences among species in postfire recovery may contribute to changes in forest composition. A long history of fire exclusion has created denser conifer stands, and encroachment by Douglas fir (*Pseudotsuga menziesii*) into oak woodlands and shrublands in certain coastal regions of California, has created forests that are now more vulnerable to high-severity wildfire (Polasek et al., 2026). Conifer forests in California generally recover slower than hardwood forests after wildfires, in part because many California hardwood species can resprout after fire, allowing more rapid recovery, while most conifers rely on seed-based regeneration, which can be limited after large, high-severity fires and under hot, dry postfire conditions. In a 32-year remote sensing study of forest recovery after large and severe wildfires in California, Bhoot et al. (2026) found that conifer forests recovered more slowly, on average, than hardwood forests. In addition, conifer forest recovery rates slowed in the second half, during which time overall hardwood forest extents also declined.

As the climate continues to warm and extreme events such as droughts and large wildfires become more frequent, further changes to California forests are expected. Approximately 19.5% of Sierra Nevada conifer forests occur in areas experiencing “vegetation climate mismatch,” where climate conditions have become unsuitable for the current vegetation, but species composition has not yet changed. Nearly 95% of these areas occur below 2,356 meters elevation, and the probability of vegetation type conversion increases by roughly 9.2% for every 10% decline in habitat suitability (Hill et al., 2023).

Technical considerations

Data characteristics

The indicator is based on a study comparing forested plots from the Wieslander Vegetation Type Map (VTM) survey (between 1929 and 1936) with US Forest Service Forest Inventory Analysis (FIA) plots (between 2000 and 2010). Across California, 9,388 VTM plots and 5,198 FIA plots were identified as forested (having at least one tree >10.2 cm dbh, the cutoff for a tree in the VTM data). Only plots occurring within 5 km of a plot from the other time period were selected, resulting in 6,572 VTM and 1,909 FIA focal plots. The plots were similar in slope, aspect, and elevation, as well as location across latitudinal and longitudinal gradients.

A modified version of the Jepson Manual eco-regions of California was used in identifying plots by region, as follows: South and Central Coast; Transverse and Peninsular Ranges; North Coast; Foothills of the Sierra Nevada and southern Cascades; Highlands of the Sierra Nevada and southern Cascades. (The Central Valley and desert regions are not included because they did not have a sufficient number of forested plots). Changes in tree density were compared with changes in CWD between 1910–1940 and 1981–2010 using 30-year averages from each time period. CWD is the seasonally integrated excess in potential evapotranspiration (PET) versus actual evapotranspiration. Details on the methodology are described in McIntyre et al. (2015).

Strengths and limitations of the data

Historical reconstructions, whether of climate or vegetation, are dependent on the quality of the data. In the case of the 1930s historical vegetation survey, the plot areas surveyed were not permanently marked, and this comparison used contemporary US Forest Service plots to compare densities of trees in similar locations as paired plots that had similar slope, aspect and elevation. The VTM survey only classed trees to size classes, so the modern survey, which has actual diameter at breast height values for every tree was re-classed to the same size classes. This reduced some of the precision with regards to tree size. However, the historical VTM was one of the most complete and thorough efforts to document the forests of California, and the use of these data was a unique opportunity to examine shifts statewide.

OEHHA acknowledges the expert contribution of the following to this report:

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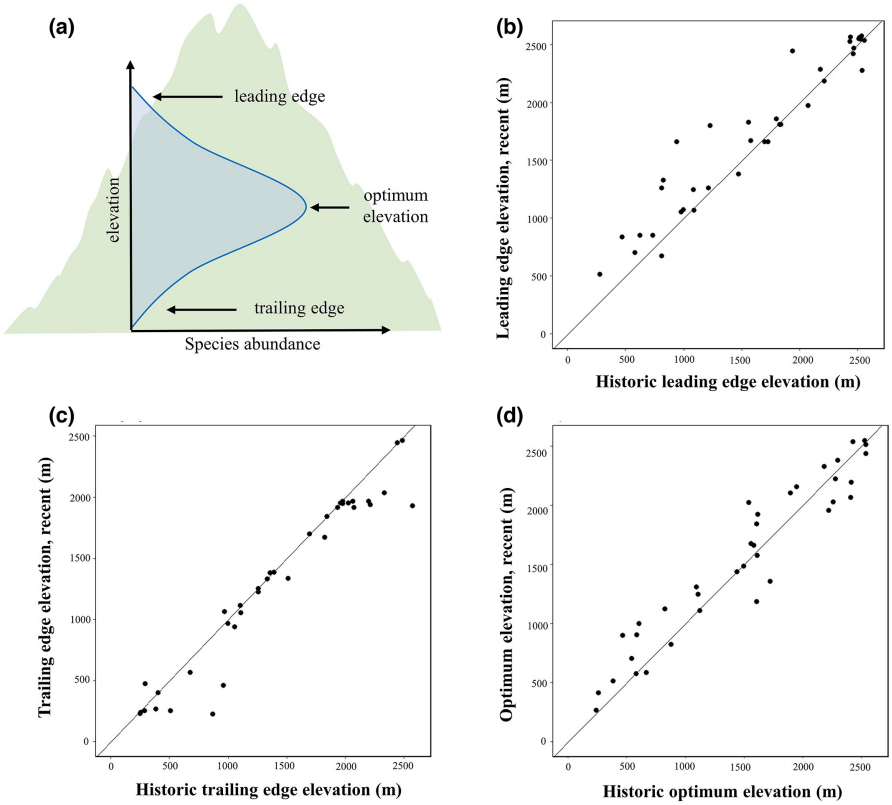
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4.4 Vegetation Distribution Shifts

Increasing climate stress in an extreme desert environment is pushing many plant species toward their physiological limits. Along an elevational transect in the Sonoran Desert, vegetation has shifted to higher elevations in response to climate change. Taller and slower-growing species moved upward and declined in abundance, whereas smaller, faster-growing species shifted to lower elevations and increased in abundance.

Figure 4.4.1. Changes in Species Elevational Ranges.



The graphs above compare recent (2019) vs historic (1977) elevational ranges of 36 plant species in the Deep Canyon Transect in the Santa Rosa Mountains of the Sonoran Desert. a) conceptual diagram illustrating species abundance across elevation; b) the leading edge (where the plant species expand into new areas); c) trailing edge (the contracting or retreating edge); and d) the optimal elevation of each species.

Source: Madsen-Hepp et al. (2023)

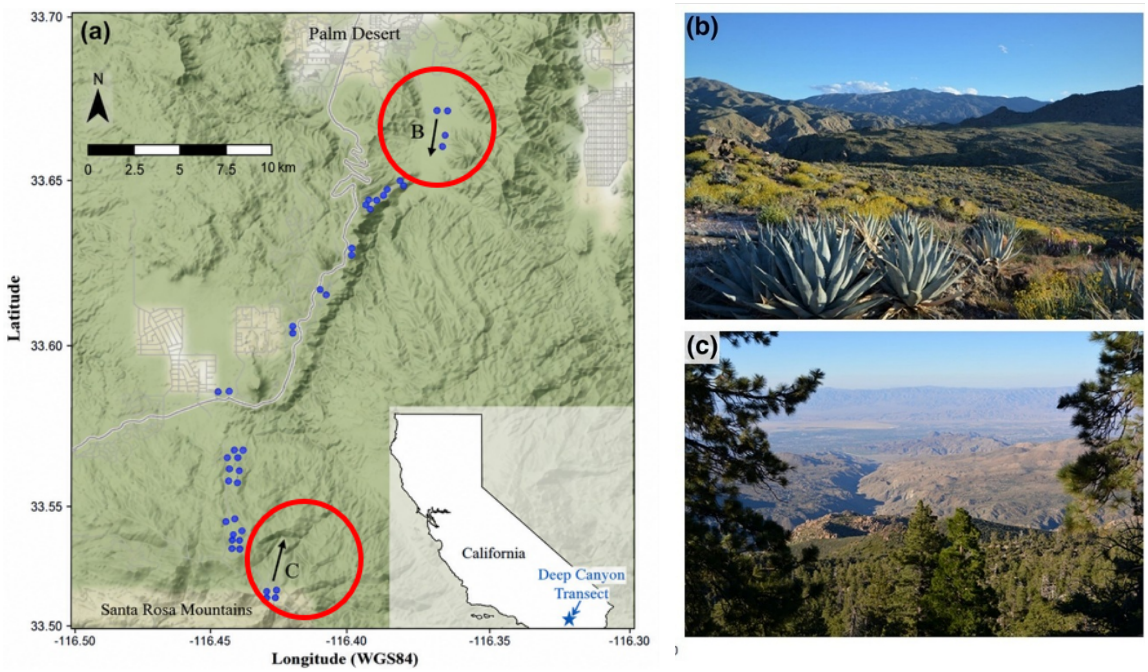
What does the indicator show?

Vegetation in a steep elevation gradient in the Sonoran Desert underwent substantial range shifts (**Figure 4.4.1**) as well as pronounced changes in patterns of species abundance from 1977 to 2019. Range shifts occurred at both the leading edge (advancing or colonizing front where the species is expanding into new, previously unoccupied areas) and the trailing edge (retreating or contracting edge). At about 29 meters per decade, the overall upward range shifts are on par with the higher end of global rates for plant movement in response to climate warming — on average, plants in temperate regions have shown range shift rates between 5 and 30 meters a decade (Madsen-Hepp et al., 2023)

The vegetation shifts were observed in the Deep Canyon Transect, part of the Boyd Deep Canyon Desert Research Center in the Sonoran Desert of southern California, a steep elevational gradient gaining 2438 meters (m) over 16 kilometers (km) (**Figure 4.4.2**). The gradient encompasses nine distinct plant communities, represented by over 600 species documented in the original 1977 survey (Zabriskie, 1979). In 2008, Kelly and Goulden documented extensive range shifts in the 10 most widely distributed species, attributed to climate change (Kelly and Goulden, 2008).

Some lower-elevation trees declined in abundance and shifted upwards, while other species moved down into hotter and drier parts of the desert. Taller species exhibiting more conservative traits (i.e., traits that favor slow growth and conserved use of resources) shifted upward in their leading-edge range limit as well as their average elevation, and trailing edge range limit. Substantial downward shifts occurred among shorter species with more acquisitive traits (i.e., traits that promote faster growth), including white bursage (*Ambrosia dumosa)*, brittlebush (*Encelia farinose*), big galleta (*Hilaria rigida*), and muttongrass (*Poa fendleriana*), which increased in abundance at their trailing edge and increased their total range size.

Figure 4.4.2. Study Location in Sonoran Desert.



The following figures show (a) elevational distribution of sub-transects where each paired dot represents east and west boundaries of a 400 m sub-transect. The inset map depicts the general location of the Deep Canyon Transect. (b) View from sub-transect 1 looking to sub-transect 20, in **Figure 4.4.2(a)** this is marked with a 'B' (circled in red) and an arrow depicting direction of view. (c) View from sub-transect 20 looking to sub-transect 1, in **Figure 4.4.2(a)** this is marked with a 'C' (circled in red) and an arrow depicting direction of view.

Source: Madsen-Hepp et al. (2023)

The Sonoran Desert became more barren, as taller trees and plants shift to higher elevations and declined in numbers, while smaller brush-like plants filled in the gaps. Specifically, stress-tolerant species like California Juniper and Pinyon pine declined or shifted upwards and did not appear to be thriving at their new ranges. Plant species with shallower root systems, such as brittlebush, burrow bush, and ocotillo, moved downward. These shorter plants rely less on deep soil water (increasingly scarce in the region). In addition, they grow faster and invest fewer resources in their leaves, and are drought-deciduous (i.e., their leaves drop during drought). Plants that retain their leaves all year tend to have thicker leaves with a higher carbon content. They are at a disadvantage compared to plants that are more easily able to shed leaves: when plants

drop leaves, the atmosphere can no longer pull water from them, which eases the demand on the roots to make up for the lost water.

Why is this indicator important?

Global climate change is rapidly altering terrestrial biodiversity (Díaz et al., 2019). While many studies have shown how hotter and drier temperatures are redistributing plant species in alpine regions and mountain ranges, observations from the Deep Canyon transect show that even hardy desert vegetation – long thought to be tolerant to stressors like drought and heat – are vulnerable to the impacts of climate change. The high incidence of range-shifting species in Deep Canyon may result in novel biotic interactions, including both the gain in antagonistic interactions (novel competitors, pathogens and herbivores) and the loss of mutualists (soil microbes and pollinators), which could either facilitate or hinder species' distributional changes (Alexander et al., 2015; Hagedorn et al., 2019; Keeler et al., 2021).

Moreover, dryland ecosystems have a disproportionate role in the global carbon budget (Ahlström et al., 2015). The replacement towards more acquisitive leaf traits in response to climate change will likely alter nutrient cycling and carbon sequestration (Buzzard et al., 2019). The increasing prevalence of acquisitive leaf traits in dryland ecosystems may, furthermore, be associated with the beginning of an ‘ecosystem breakdown’ threshold of aridification, where the mortality of resource conservative species occurs as they are no longer able to cope with increasingly scarce water and nutrient availability (Berdugo et al., 2020). Indeed, normalized difference vegetation index (NDVI) patterns across Southern California's Sonoran Desert region show declining vegetation cover (particularly in the more xeric areas) suggesting that the region may already be crossing this threshold (Hantson et al., 2021). Given the paucity of long-term vegetation data from dryland ecosystems, and that more than 20% of the Earth's terrestrial surface is expected to cross at least one threshold of aridification by 2100 (Berdugo et al., 2020), observations in Deep Canyon provide critical insight into the distributions of dryland plant species in California under rapidly changing conditions and how trait-mediated changes might impact future ecosystem functioning.

The climate and vegetation gradient of Deep Canyon's slopes is analogous to the south-to-north gradient of California. Deep Canyon's climate ranges from hot desert at the mountain base, stretching upward through warm chaparral, and finally into mild conifer forests at the mountain peak. This pattern is similar to the transition along the state of California, from the southern deserts northward through chaparral-covered foothills and mountains, and into the mild evergreen forests of northern California. Understanding the effects of local climate change on Deep Canyon's vegetation gradient can provide insight into how California's vegetation may respond to a warmer or drier climate.

What factors influence this indicator?

Dryland ecosystems such as Deep Canyon are experiencing anthropogenic-driven elevated temperatures and increased chronic and extreme drought (Williams et al., 2020) which has and will continue to decrease soil moisture (Bradford et al., 2020), disproportionately impacting species reliant on deeper soil water (Schlaepfer et al., 2017). Taller species with more conservative traits which typically rely on deeper water sources show upward shifts and decline at their lower and median elevations (Goulden and Bales, 2019).

Nearby weather station data showed pronounced changes since 1947, with general increases in nearly all temperature variables. Gridded climate data from the lowest, middle and highest elevation transects showed substantial warming trends, with annual minimum temperature increasing by 2.77 Celsius (°C) (4.99 degrees Fahrenheit (°F)) at the lowest, 3.84°C (6.91°F) at the middle and 2.3°C (4.14°F) at the highest elevation between the years preceding the first and most recent surveys.

Notably, climatic changes varied among elevations, where rate and magnitude of warming was generally highest at the middle elevation, while the lowest elevation exhibited increases in precipitation (54 millimeter (mm)) and decreases in vapor pressure deficit (VPD, a measure of air dryness, defined as the difference between the amount of moisture in the air and the maximum moisture the air could hold) and maximum temperature between the first and second surveys.

Long-term climate data dating to 1961 from the Boyd Deep Canyon center station showed increased interannual precipitation variability over time, and no overall significant changes in mean annual or seasonal (winter and summer) precipitation. However, there was a significant increase in average minimum temperature (0.98°C (1.76°F)) and average maximum temperature (3.61°C (6.5°F)) over the same time period. Substantial increases in winter minimum temperatures were more pronounced at lower and mid elevations.

These results support recent work highlighting elevational differences in warming rates (Pepin et al., 2015), and findings of elevational differences in climate help explain some of the heterogeneity of range redistributions. For instance, the downward shift in lower elevation range margins occurred following a period of cooler and wetter conditions at the lowest elevation, while the upward shifts in leading edge margins occurred over the same interval, where the middle and highest elevations showed pronounced increases in temperature and VPD.

Additionally, smaller and faster-growing species exhibited downward shift in leading-edge margins between the second and most recent survey, a period characterized by anomalously warm regional drought which caused extensive mortality (Dong et al., 2019; Goulden and Bales, 2019). These conditions likely affected newly establishing juveniles of species that had previously shown upward leading-edge shifts. In contrast to more temperate mountain ecosystems (Pepin et al., 2015), these elevation-dependent range shifts likely reflect more rapid warming at lower elevations in this dryland system, consistent with recent work highlighting the potential for differences in climate exposure to drive geographical variation in species' responses (Kling et al., 2020; Oldfather et al., 2019).

Despite this heterogeneity in climate change exposure, species showed responses consistent with increasing aridification, where more variable precipitation and hotter drought periods across southern California appear to be promoting the replacement of stress-tolerant species, such as California juniper and pinyon pine, alongside increases in more resource-acquisitive species that possess drought avoidant traits, including brittlebush, burrow bush, and ocotillo (Berdugo et al., 2020).

The observed change in plant distribution in Deep Canyon may be attributed in part to a severe drought from 1999 to 2002. This drought caused marked vegetation mortality throughout Southern California, directly through drought stress and indirectly through insect attack, and many recently dead plants were observed during the survey. However, recent mortality alone could not explain the elevation shifts. Many plants that had died before the 1999–2002 drought were also noted, as well as an increase in cover in the upper half of the species' ranges. These trends indicate that warming and/or drying of climate has been stressing the lower elevation plants and providing more favorable conditions for plants at higher elevations over the 30-year period. These changes are consistent with predictions of the effects of climate warming and drought on mountain ecosystems.

Several considerations in the 2008 survey (Kelly and Goulden, 2008) provide evidence that the observed vegetation redistribution is attributable to climate change:

- Vegetation shifts were uniform across elevation, implying that the ultimate causal factor was uniformly distributed. Recent climatic trends in Southern California do not appear to vary strongly with elevation.
- The vegetation shifts are consistent with the expected bioclimatic effects of most of the observed climatic shifts. Increased temperature, longer frost-free period, increased elevation of the snow line, and occurrence of severe drought should increase plant stress in some years. This increased stress would be expected to decrease a species' ability to survive in the drier, warmer, lower parts of its range and increase its ability to survive in the wetter, cooler, upper parts of its range.
- The change from a symmetrical vegetation distribution to an upwardly skewed distribution, when averaged across species and elevation, can be interpreted as evidence of the impact of climate change on vegetation distributions.
- The vegetation shifts resulted in part from mortality during the 1987–1990 and 1999–2002 droughts. The connection between mortality and drought is consistent with a fingerprint of climate change.

Two alternative explanations for the vegetation redistribution, changes in fire frequency or air pollution, merit consideration. The wildfire regime in Southern California has

changed over the last century, resulting in plant demographic shifts, especially in montane forest. However, the fire regime in Deep Canyon is similar to its historical norm, and fire effects would not produce uniform changes across the elevation gradient. Schwilk and Keeley (2012) claim that the upslope redistribution of one species in Deep Canyon, *Ceanothus greggii*, was due to elevational differences in historic fires and not by climate warming. However, observations of postfire recovery of *C. greggii* outlined in Zammit and Zedler (1993) support the conclusion that an influence stronger than fire history is redistributing Deep Canyon's dominant species upwards. Air pollution as an explanation is similarly problematic: ozone-related mortality is concentrated at higher elevations and would not produce the uniform changes observed across the elevation gradient.

The observed local changes could reflect regional urban heat island effects or long-term climate fluctuations, such as the Pacific Decadal Oscillation. Nonetheless, the documented climate changes are similar to those predicted or attributed to anthropogenic climate change. Findings from the resurveys in the Deep Canyon transect suggest that surprisingly rapid shifts in the distribution of plants can be expected with climate change, at least in areas where seed dispersal is not a major constraint, and that global climate change may already be influencing the distribution of vegetation.

Additionally, the exact mechanisms of the plant mortality remain unknown. How trees die in response to drought is an active area of scientific investigation (Breshears et al., 2009; van Mantgem et al., 2009; Waring, 1987). However, drought and warming have caused forest mortality worldwide, and no alternative explanation currently better accounts for the vegetation shifts were observed.

Technical considerations

Data characteristics

The original survey in the Deep Canyon Transect (Zabriskie, 1979) consisted of 22 linear transects along the elevation gradient, equally spaced at 122-meter intervals beginning at 24 meters elevation and following 400-m isocontours. Due to urban development in the Coachella Valley, the lowermost transect was lost beneath an

irrigated golf course subdivision, and therefore surveys in 2019 only resurveyed 21 of the original transects. All transects at peak biomass were surveyed across the elevational gradient, from March 2019 at the lowest elevation, to August 2019 at the highest elevation. At each 400-m transect, all perennial plant species were identified, and their abundance was estimated as the amount of foliage intercepted by the tape to the nearest centimeter. Permits were obtained for sampling on the Boyd Deep Canyon reserve, and no permits were needed at other locations.

Climate data was analyzed from local weather stations within 75 km of the study site, representing the elevation range within the transect, and containing nearly continuous records since 1947. Also analyzed were site-specific weather station data from the Boyd Deep Canyon Desert Research Center, which is the only climate dataset available from the study site which includes years preceding the first survey in 1977.

To analyze climatic trends across the elevation gradient, changes in 800-m resolution gridded climate data (PRISM, 2022) were analyzed using the location of transects at the lowest, highest and middle elevations. PRISM data are interpolated from nearby climate station data that are physiographically similar by calculating a local climate-elevation regression that also uses six other topographic predictors; they accurately characterize topoclimate in mountainous areas of the western US (Daly et al., 2008). For this data, we evaluated trends in annual minimum, maximum and mean temperature, along with annual precipitation and VPD. Climatic changes across survey intervals were compared between each survey period using t-tests.

Strengths and limitations of the data

A common challenge in revisiting historic studies is finding the exact location of the original sites. Discussion with Zabriskie, original maps, careful and consistent site location criteria, and a relatively small geographic area, provide confidence in the investigators' accuracy in relocating the original survey sites. Location inaccuracy is the largest source of uncertainty in the data. The vegetation coverage methodology was identical to Zabriskie's and could result in biases of less than a few percent per transect. Year-to-year fluctuations could be a problem in extrapolating one survey to a 42-year

trend. A major strength of this survey is that the species evaluated in this survey are generally long-lived, thus the vegetation changes observed are the result of long-term trends and not short-term variability. Species in the survey such as yucca, white fir, creosote, and California lilac have lifespans of decades to centuries, and thus high mortality rates within 42 years are considered significant changes. Finally, weather station data does not come from within the survey site; the climate data comes from nearby stations around the Southern California desert mountains.

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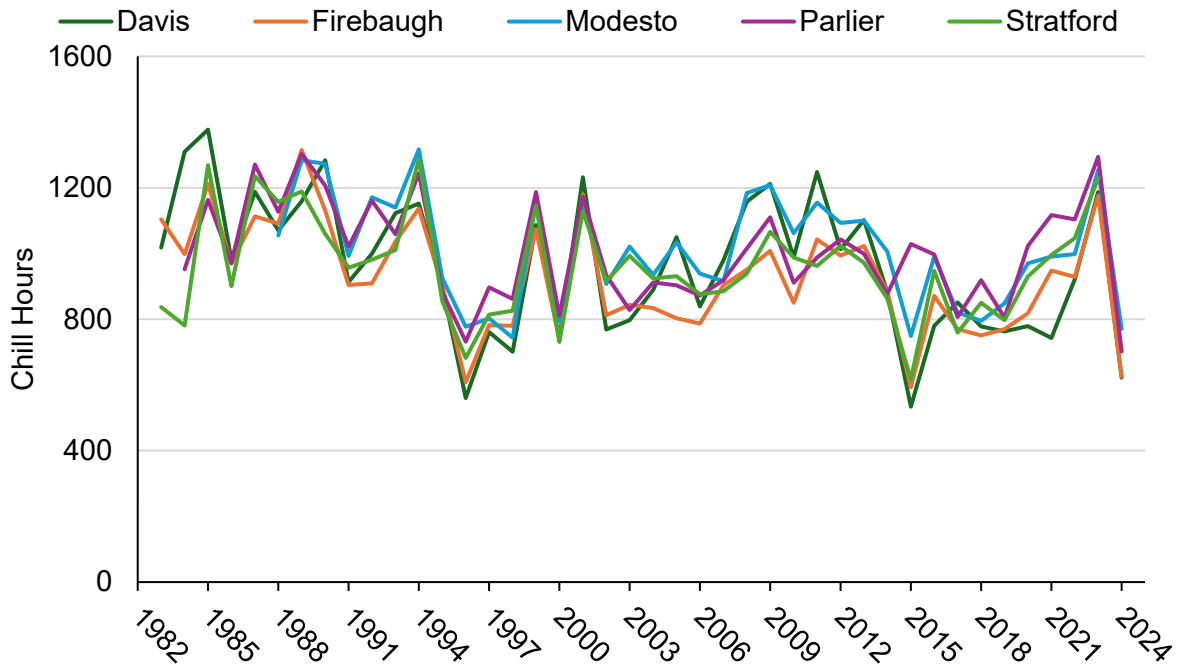
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4.5 Winter Chill

Warming winter temperatures are reflected in declining trends in “winter chill,” the period of cold temperatures above freezing required for fruit and nut trees to produce flowers and fruits. Winter chill is tracked in two ways. “Chill hours,” a metric used since the 1940s, represents the number of hours accumulated during winter when temperatures remain within a defined cold range. “Chill portions,” a biologically based metric, quantifies winter chill by accounting for both cold temperatures and the negating effects of warmer temperatures. As a result, it more closely reflects how California’s agricultural trees experience winter conditions. Both metrics show decreasing trends in California’s Central Valley from 1983 to 2024.

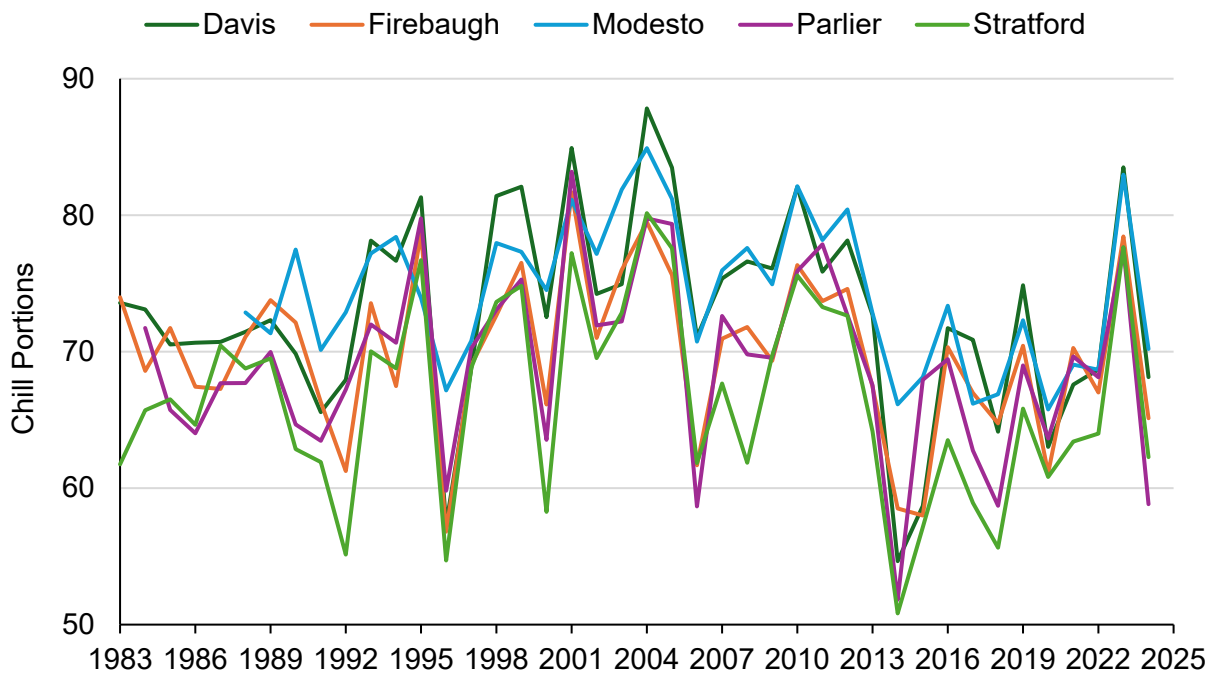
Figure 4.5.1. Chill Hours in the Central Valley.



The graph shows the annual sum of chill hours at selected stations in the Central Valley from 1983 to 2024. Chill hours represent the number of accumulated hours equal to or less than 45°F and above 32°F (less than 7.22°C and above 0°C) over the winter season (beginning of November to end of February).

Source: University of California, Davis (2025)

Figure 4.5.2. Chill Portions in the Central Valley.



The graph shows the annual sum of chill portions at selected stations in the Central Valley from 1983 to 2024. Chill portions accumulate most of the time between 43° and 47°F (between 6.11°C and 8.33°C), and progressively less at either side of this range, dropping to zero at 32°F and 54°F (0°C and 12.22°C); periods of warm temperature can cancel this accumulation.

Source: University of California, Davis (2025)

Table 4.5.1. Long-term Decadal Trends in Winter Chill.

Station	Years included	Chill hours decadal trend	Chill portions decadal trend
Davis	1983-2024	-84	-0.4
Firebaugh/Telles	1983-2024	-53	-0.66
Modesto	1988-2024	-52	-1.4
Parlier	1984-2024	-33	-0.5
Stratford	1983-2024	-31	-0.66

The table shows the decadal trends for chill hours and chill portions at selected stations in the Central Valley from various start years in the 1980s to 2024.

Source: University of California, Davis (2025)

What does the indicator show?

Winter chill is a period of cold temperatures above freezing required for deciduous fruit and nut trees to produce flowers and fruits. Two commonly used winter chill metrics are presented. The first metric, chill hours (**Figure 4.5.1**), represents the number of accumulated hours above 32°F (0°C) and less than or equal to 45°F (7.22°C) over the winter season. Chill hours have been used since the 1940s. However, recent research favors the use of a more biologically based metric, chill portions (**Figure 4.5.2**). Chill portions accumulate in a two-step process: (1) exposure to cold temperatures accumulates as a "chill intermediate," which can be negated by exposure to temperatures above 54°F (12.22°C); (2) when a certain quantity of these intermediates amass, a "chill portion" is accumulated and cannot be reversed by high temperatures (Luedeling et al., 2009). Overall, both metrics suggest declines in winter chill across California, though magnitude and statistical significance of trends vary among locations.

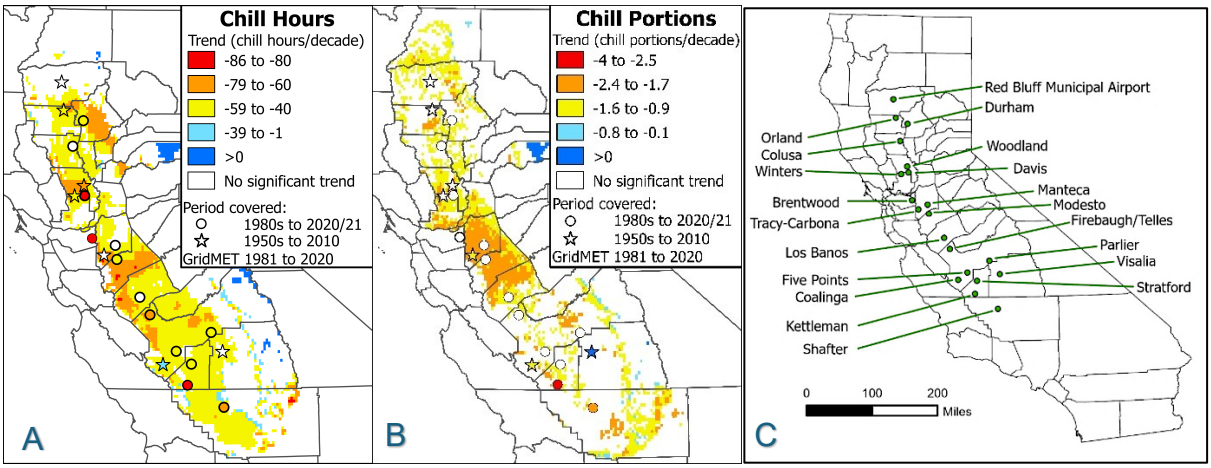
The influence of temperature on the biological processes underlying the breaking of dormancy – and the processes themselves – are poorly understood. It is known, however, that not all "chill" is effective. The chill portion metric considers this by incorporating a more biologically based theoretical framework: temperatures above 54°F (12.22°C) – common during the winter months in California – cancel the effect of previous chill accumulation (Luedeling et al., 2009). Chill hours, which count the number of winter hours when temperatures are between the freezing point and 45°F (7.22°C), do not account for this canceling effect. For California's Mediterranean climate and mild winters in California's fruit and nut-growing regions, chill portions are better suited for tracking winter chill than chill hours. (See *Technical considerations* for how these metrics are calculated). The amount of chill that is required is dependent on the type of tree; for example, almonds require 250 to 350 chill hours or 22 to 32 chill portions; apples, 1200 to 1500 chill hours or 50 chill portions; and Bing cherries, 1000 to 1300 chill hours or 65 chill portions (Erez, 2000; Ryugo, 1988).

Trends shown in **Figure 4.5.1** and **Figure 4.5.2** are consistent with those found in a previous analysis of chill hours and chill portions in the Central Valley spanning the 1950s–2020. Weather stations included in this analysis were selected based on the

availability of online chill hour and chill portion data, continued station operation, and records extending back to the 1980s. **Figure 4.5.3** presents findings from this analysis, which are based on two sources: temperature observations from weather stations (stars and circles) and modeled high-spatial resolution surface temperatures (gridMET) (colored or white areas on the map).

Weather station data show that chill hours have declined at more than half of the weather stations studied (12 out of 20, $p<0.05$; at two other stations, $p=0.05$). Chill portions show statistically significant declining trends at just four weather stations – Kettleman, Coalinga, Shafter, and Tracy-Carbona (at one other station, $p=0.05$) – and a significant increasing trend at the Visalia station. Winter chill trends were calculated using gridMET for 19 counties within the Central Valley: Butte, Colusa, Glenn, Fresno, Kern, Kings, Madera, Merced, Placer, San Joaquin, Sacramento, Shasta, Solano, Stanislaus, Sutter, Tehama, Tulare, Yolo, and Yuba. These estimates show declining chill hours in much of the Central Valley; chill portions are also declining, although to a smaller spatial extent. The latter suggests that although temperatures have warmed in certain areas, they may not have warmed enough across the region to affect the accumulation of biologically based chill portions, which account for hours at a higher temperature threshold (54°F or 12.22°C) than chill hours (32°F- 45°F or 0°C- 7.22°C).

Figure 4.5.3. Chill Hours and Chill Portions in the Central Valley.



Station	Years included	Chill hours trend *(p-value)**	Chill portions trend (*p-value*)
Brentwood	1985-2019	-81.2 *(0.01)**	-2.4 *(0.17)*
Coalinga	1952-2010	-33.9 *(<0.01)**	-1.6 *(<0.01)**
Colusa	1983-2016	-70.7 (0.06)	0 (0.99)
Davis	1983-2021	-85.9 *(<0.01)**	-1.5 *(0.14)*
Durham	1983-2021	-46.8 *(0.03)**	-0.9 *(0.38)*
Firebaugh/Telles	1983-2020	-76.0 *(<0.01)**	-0.9 *(0.29)*
Five Points/WSFS USDA	1983-2020	-45.9 *(0.03)**	-0.8 *(0.38)*
Kettleman	1982-2016	-106.6 *(<0.01)**	-3.3 (0.02)*
Los Banos	1989-2020	-38.4 *(0.21)*	-1.5 *(0.23)*
Manteca	1988-2021	-30.1 *(0.29)*	-2.1 *(0.07)*
Modesto	1988-2021	-50.1 *(0.05)*	-2.0 *(0.05)*
Orland	1952-2010	-45.8 *(<0.01)**	-0.8 *(0.14)*
Parlier	1984-2021	-51.0 *(0.01)**	-1.1 *(0.32)*
Red Bluff Municipal Airport	1952-2010	-7.9 *(0.60)*	-0.1 *(0.84)*
Shafter/USDA	1983-2020	-69.6 *(<0.01)**	-1.9 *(0.03)**
Stratford	1983-2020	-43.6 *(0.04)**	-1.3 *(0.19)*
Tracy-Carbona	1952-2007	-19.7 *(0.23)*	-1.2 *(0.03)**
Visalia	1952-2010	-27.3 *(0.05)*	+1.2 *(0.02)**
Winters	1951-2010	-43.0 *(<0.01)**	-1.0 *(0.07)*
Woodland	1952-2010	-60.4 *(<0.01)**	-0.5 *(0.38)*

The maps show decadal trends of chill hours and chill portions. Stars and circles represent long-term decadal trends in A) chill hours and B) chill portions at weather stations. Coloring throughout the map represents trends derived from gridMET, a spatial data set, where white areas indicate non-significant trends ($p<0.05$). Trends for weather station sites use winter dates from November 1st to February 28th; gridMET-based trends use winter dates from November 1st to January 31st. The map on the right (C) shows the location of weather stations analyzed.

* Statistically significant trends (where $p<0.05$) are indicated with an asterisk

Source: GridMET analysis based on Zhang et al. (2021); weather station analysis based on University of California, Davis (2021)

Why is this indicator important?

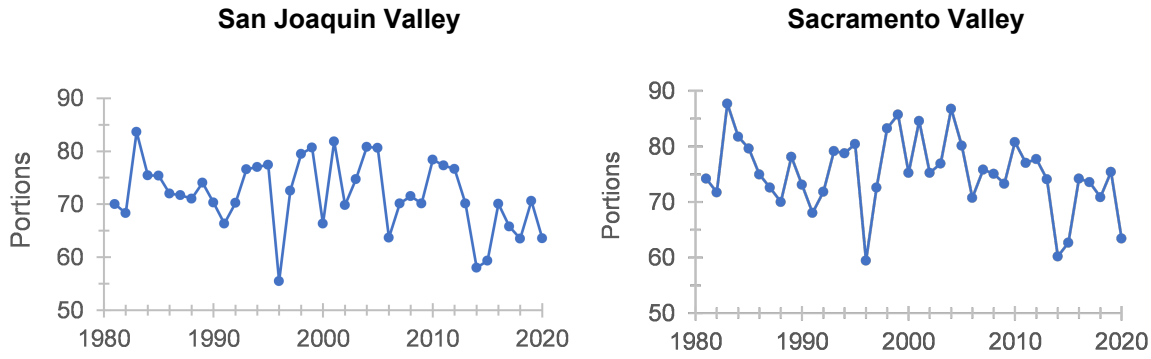
Many fruit and nut trees rely on a sufficient period of winter chill to regulate dormancy, flowering, and fruit development. As noted above, this chill requirement can vary widely from one fruit or nut to another and even across varieties of the same fruit or nut. Fruit and nut trees need 200 to 1,500 hours of temperature between 32°F and 45°F (between 0°C and 7.22°C) during the winter (Baldocchi and Wong, 2006), or between 13 and 75 chill portions to produce flowers and fruits (Pope et al., 2014b).

The warm winters of 1997–1998 and 2013–2014 demonstrated the importance of winter chill (**Figure 4.5.4**). Above-normal temperatures in January and February of 1998 meant many fruit and nut trees did not receive sufficient chilling time necessary for dormancy; revenues from almonds and cherries dropped by about 40 and 50 percent, respectively, compared to the two prior years (USDA, 2022). During 2013–2014, the Central Valley's average chill portions dropped by 25 percent. As a result, orchards for many crops showed delayed and extended bloom, poor pollinizer overlap (when the pollen-producing flowers and the fruit-producing flowers do not open simultaneously), and weak leaf-out (when fewer leaves emerge). Reduced chill was likely responsible for much of the unusual tree behavior and low yields. Delayed bloom can extend later into spring, when conditions may be too warm for successful pollination. Extended bloom can result in changes in fruit or nut maturation timing, which could mean a more prolonged, costly harvest and an increased risk of pests eating crops (Pope, 2014a).

Tribal Connection 4.5.1

Decreasing fruit and nut yield impact food sovereignty for many California tribes. For example, both homegrown and farmed avocado and citrus are significant crops for the Pala Band of Mission Indians in northern San Diego County. "*Pala has observed impacts to production of some crops cultivated on the Reservation, including avocado and citrus fruit. These trees need a certain number of chilling hours in the winter […]; as temperatures increase and chilling hours are reduced, crop yield decreases*" (Pala Band of Mission Indians, 2026).

Figure 4.5.4. Chill Portions in San Joaquin and Sacramento Valleys.



The graphs above show annual chill portions within two regions of the Central Valley (San Joaquin Valley and Sacramento Valley) from 1980 to 2020.

Source: Parker et al. (2022)

Prolonged periods of fog during the winter in the California Central Valley provide favorable conditions to meet dormancy requirements. In an analysis of weather data and satellite imagery for the Central Valley during the years 1981–2014, scientists found the number of winter fog events decreased by 46 percent, on average, with much year-to-year variability (Baldocchi and Waller, 2014). If prolonged periods of winter fog disappear in the future, the sun hitting buds in the Central Valley will increase the internal temperature in the buds, thus reducing the number of hours below the critical temperature. Agronomists are finding methods to adapt to this. Reflective films applied to plant surfaces can act as sunscreen to reflect sunlight or modify incoming light (Beede, 2016; Thakur et al., 2025). Future trend projections show that continued warming will reduce the accumulated winter chill in the Central Valley (Luedeling et al., 2009). By the middle to the end of the 21st century, projections suggest that climatic conditions will no longer support current varieties of some of the main tree crops currently grown in California. Chill hours are projected to show greater declines than chill portions, and current varieties of major tree crops may tolerate a 20 percent decline in the winter chill. This decline would jeopardize the region's ability to sustain its production of high-value nuts and fruits like almonds, cherries, and apricots, resulting in

serious economic, dietary, and social consequences. The tree crop industry will likely need to develop agricultural adaptation measures (e.g., using chill-compensating products or growing low-chill varieties) to cope with these projected changes.

What factors influence this indicator?

The indicator is derived from temperature data and therefore influenced by the same factors that affect air temperature; the increase in winter (primarily minimum or nighttime) temperatures in the Central Valley is reflected in the decrease in chill hours at most of the weather stations and throughout the region. In addition to regional influences such as topography and proximity to the ocean, local factors such as degree of urbanization and land use can affect temperature. Furthermore, “microclimates” exist within the same orchard, so temperature differences could occur at smaller spatial scales.

The choice of metric affects how winter chill is characterized. Chill hours and chill portions both quantify chill accumulation but respond differently to temperature variation. For example, one study using weather data and several greenhouse gas emissions scenarios throughout California’s Central Valley projected chill portions to decrease by 14 to 21 percent and chill hours to decrease by 29 to 39 percent between 1950 and 2050 (Luedeling et al., 2009). Projected impacts appear far more dramatic when seen through the lens of chill hours, although the chill hours model appear to be more sensitive to changes in temperature than the trees themselves.

While both metrics quantify chill accumulation, uncertainty is also introduced by how well weather station data represent actual orchard conditions. Factors such as station location, proximity to orchards, and the presence of microclimates can affect whether measured temperatures accurately reflect what trees are experiencing.

Technical considerations

Data characteristics

The indicator presents two metrics for winter chill: chill hours and chill portions. The primary differences in the calculations for these two metrics are:

- Chill hours equally count every hour when temperatures are between 32°F and 45°F (between 0°C and 7.22°C). Chill portions accumulate when temperatures are between 32°F and 54°F (between 0°C and 12.22°C), with the most accumulation occurring between 43°F and 47°F (between 6.11°C and 8.33°C).
- Chill hours count to 45°F (7.22°C), while chill portions count to 54°F (12.22°C). Because of this, chill portions better approximate effective chilling for trees grown in mild climates.
- Chill hours sum all qualifying hours equally, with no adjustment for warm periods. Chill portions use a two-step accumulation process (described above) in which warm temperatures above 54°F (12.22°C) can cancel accumulated intermediates (Luedeling et al., 2009).

Data for **Figure 4.5.1** and **Figure 4.5.2** were downloaded from the University of California Statewide Integrated Pest Management Program (UCIPM) database, which used hourly data from weather stations that are part of the California Irrigation Management Information System (CIMIS). Weather station-based chill hours and chill portions in **Figure 4.5.3** were calculated using “chillR," a statistical model for phenology analysis (Luedeling, 2017). The model is an extension to a commonly used statistics software, R. Weather station data for Central Valley locations listed in Baldocchi and Wong (2008) were retrieved through the chillR downloading interface. Stations for which data were not retrievable from the UCIPM archive were omitted from the analysis.

The “chilling requirement” is the best existing approximation for winter cold that a species or variety needs to break dormancy, bloom, and fruit. The chilling requirement has been quantified by manipulating or modeling the conditions that lead dormant buds to break. However, the physiological processes that affect budbreak are different from those that control crop yield. Physiological processes beyond chilling requirements should be considered when estimating the amount of winter chill needed before crops yield starts to decline and when assessing potential impacts of climate change (Pope et al., 2014b).

Strengths and limitations of the data

Summary statistics that are commonly used to track temperature (such as average, minimum and maximum) generally do not provide the resolution necessary to examine climate trends relevant to agriculture. Deriving chill accumulation from temperature data for the winter months yields a more meaningful measure for tracking a change in climate that would be more predictive of fruit production. Winter chill accumulation provides an indication of whether specific fruit and nut trees are experiencing sufficient periods of dormancy.

The hourly data from CIMIS provides direct input into the calculation of winter chill degree hours. CIMIS weather stations are designed to monitor agricultural climate conditions. Thus, they are almost exclusively in agricultural areas, with the monitoring equipment located in a well-irrigated pasture. However, spatial variability in weather limits the ability to generalize these trends to specific locations not represented by the station data (Martínez-Lüscher et al., 2022).

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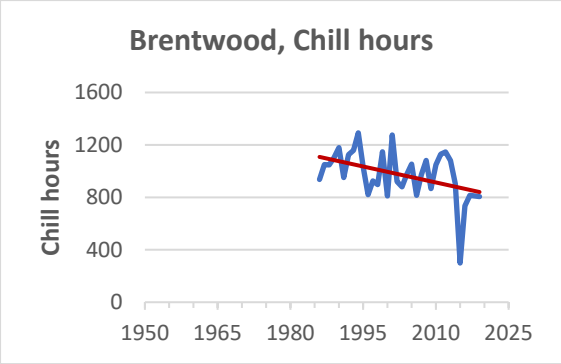
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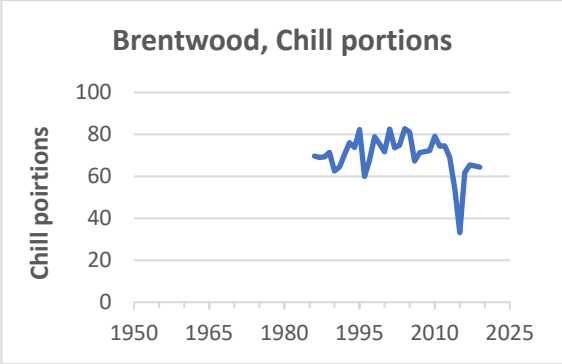
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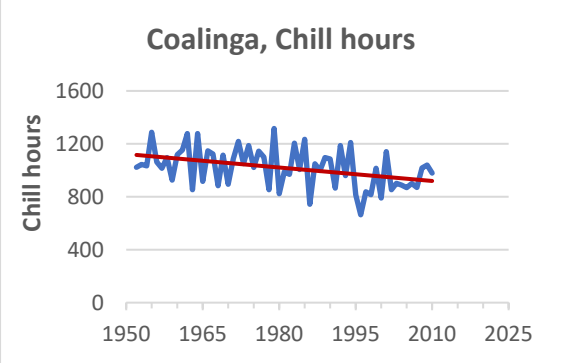
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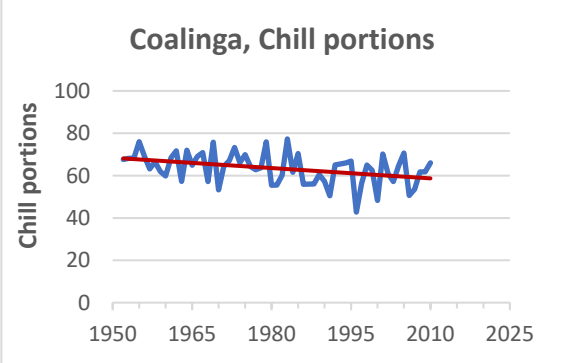
Figure 4.5.A-1. Long-term Trends in Chill Hours and Chill Portions, by Location.

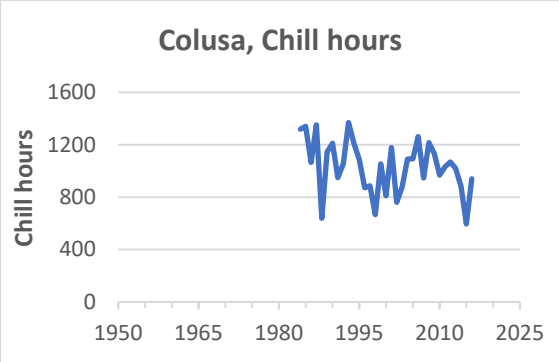
Statistically significant trends ($p<0.05$) are shown as red lines; no trend line is shown for non-significant trends.

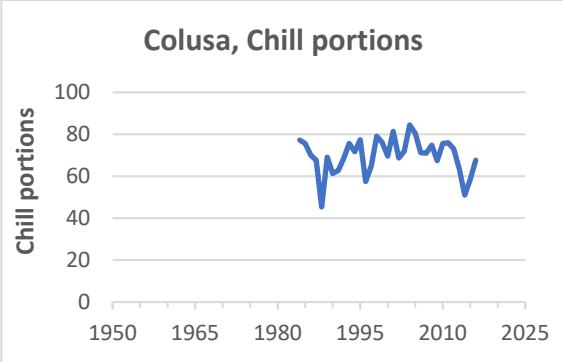


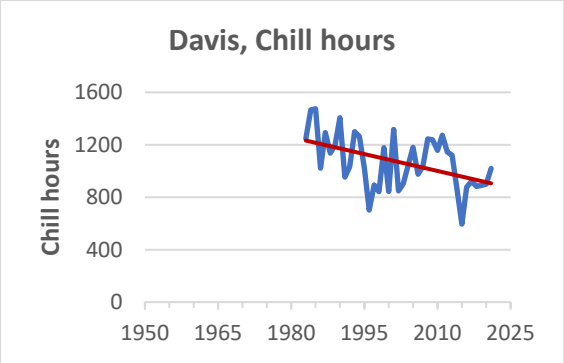


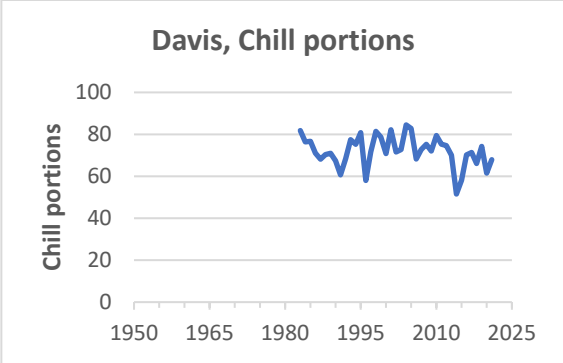


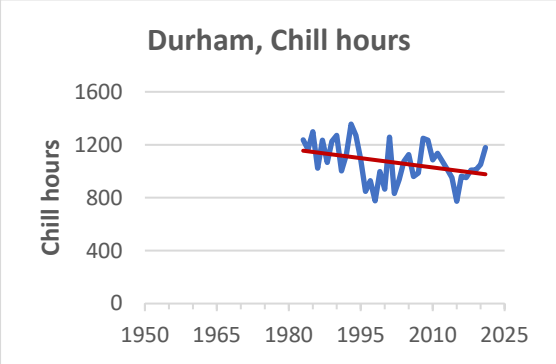


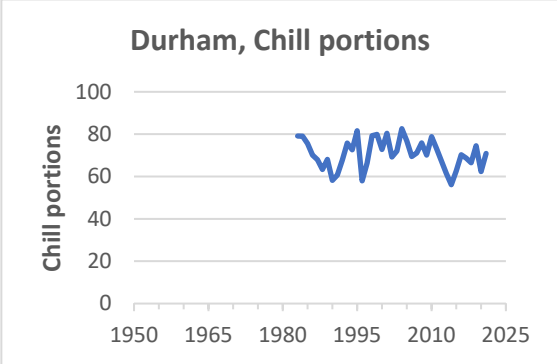


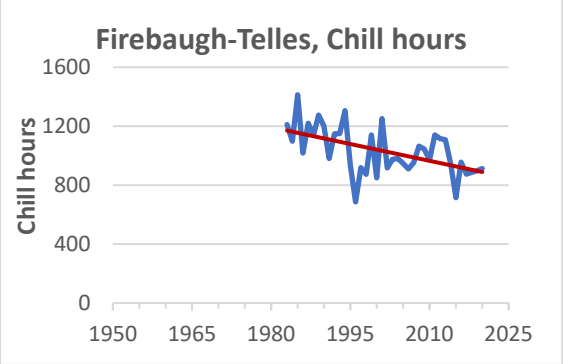


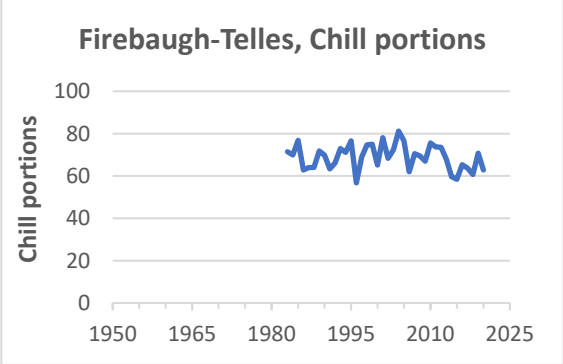

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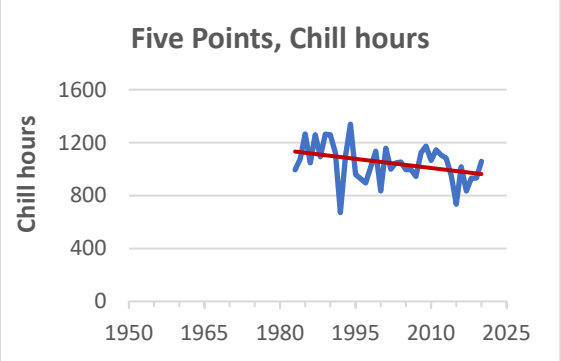

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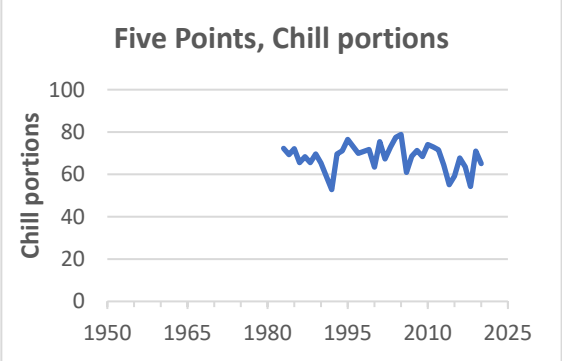

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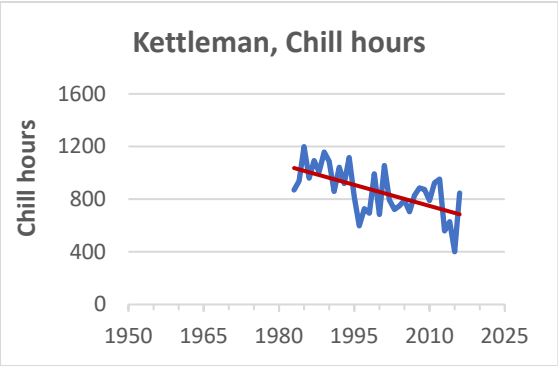

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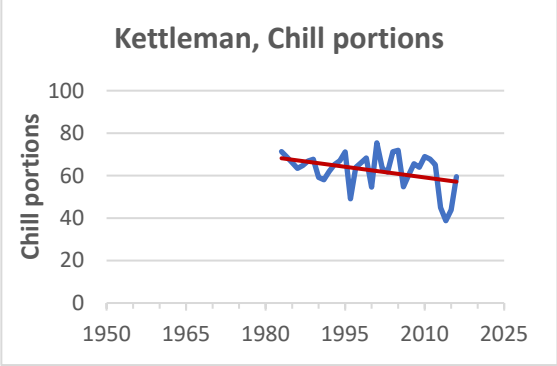

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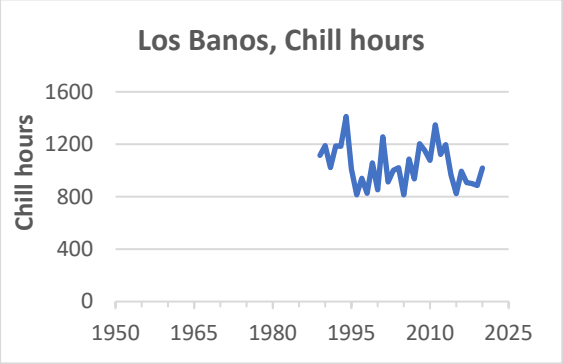

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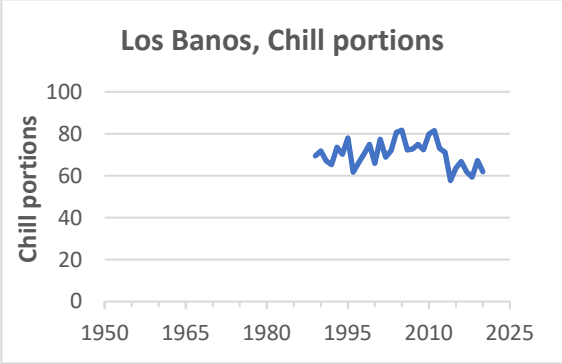

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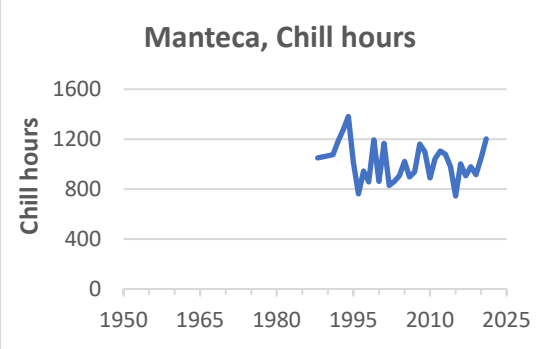

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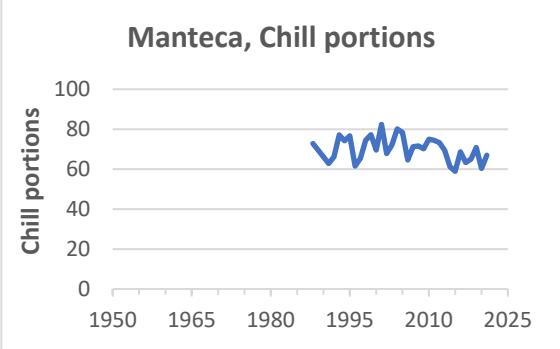

Kettleman, Chill hours
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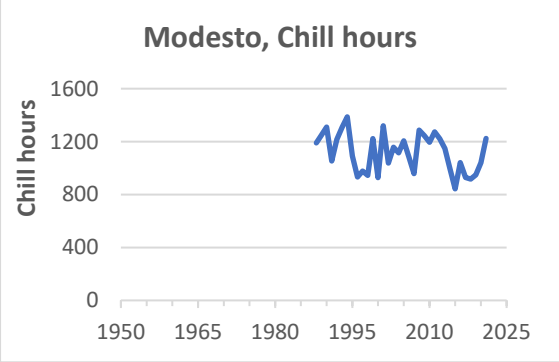

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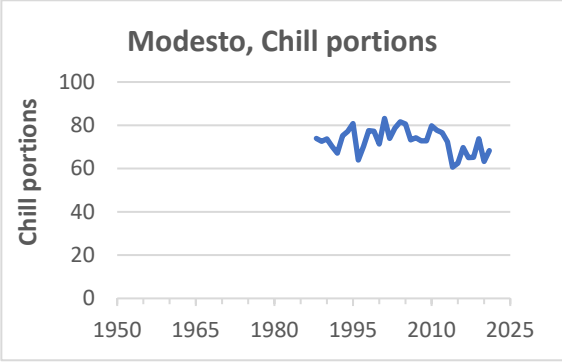

Los Banos, Chill hours
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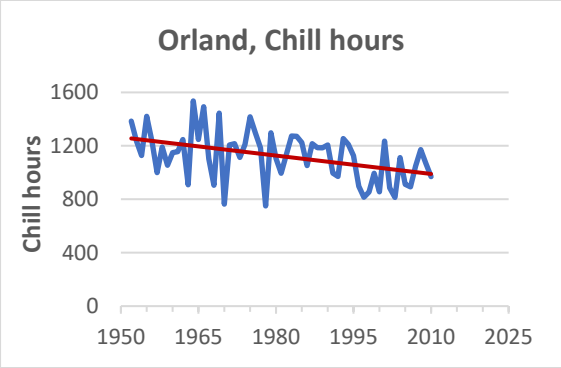

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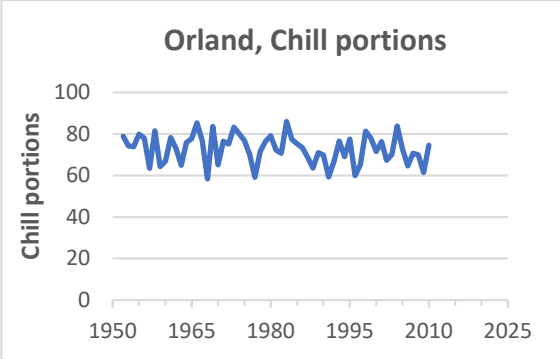

Manteca, Chill hours
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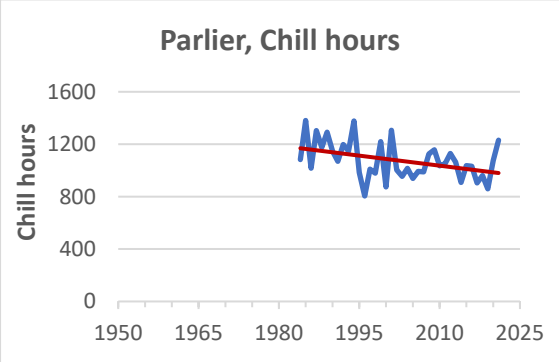

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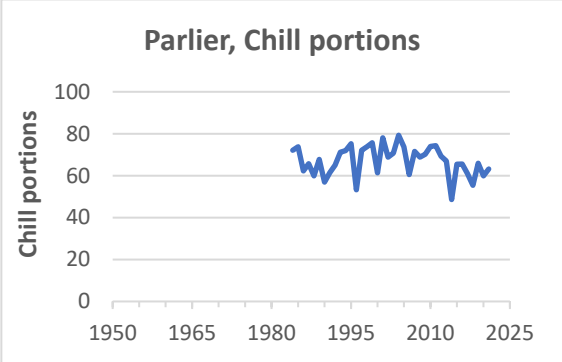

Modesto, Chill hours
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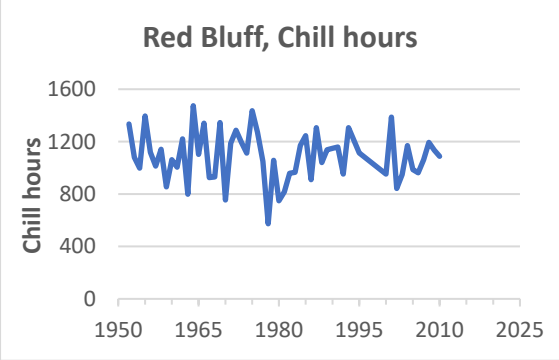

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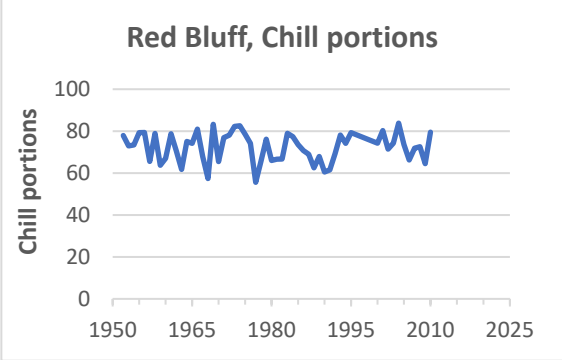

Orland, Chill hours
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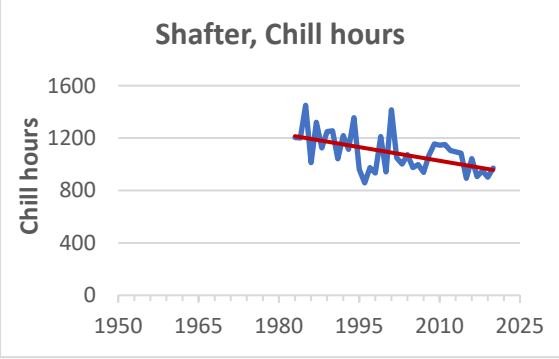

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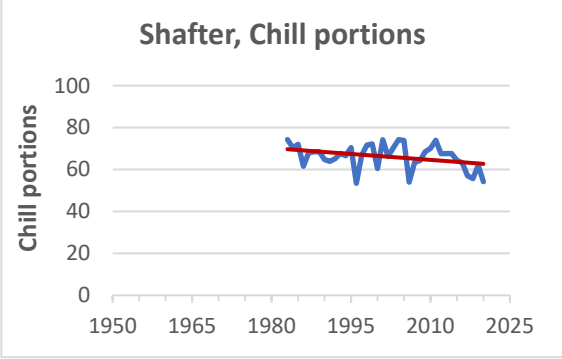

Parlier, Chill hours
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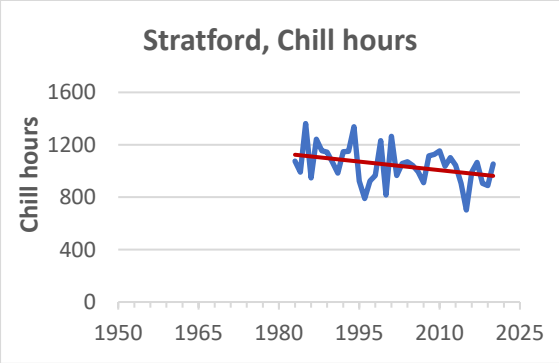

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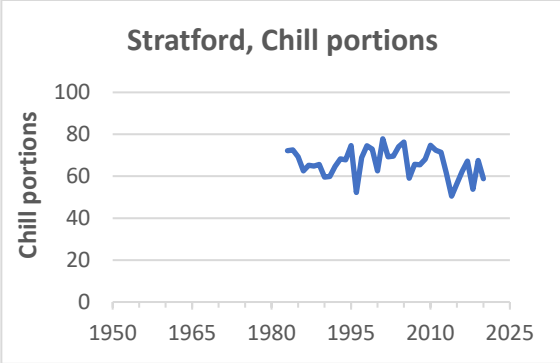

Red Bluff, Chill hours
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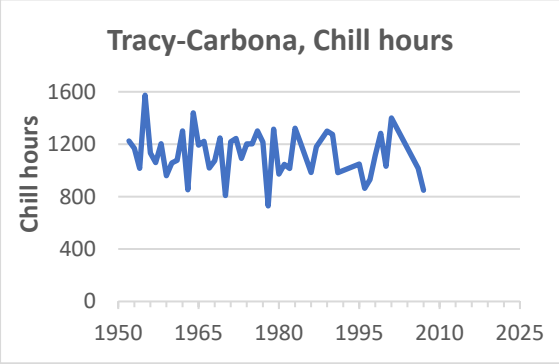

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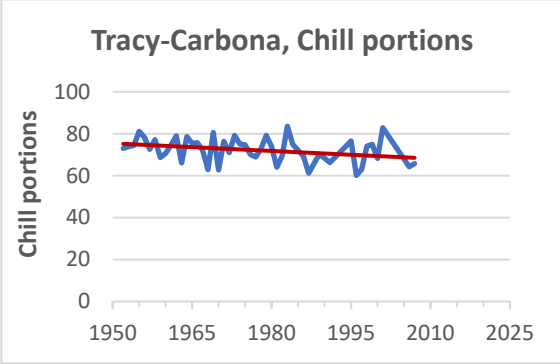

Shafter, Chill hours
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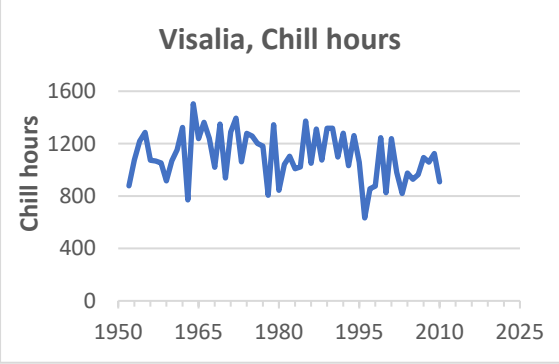

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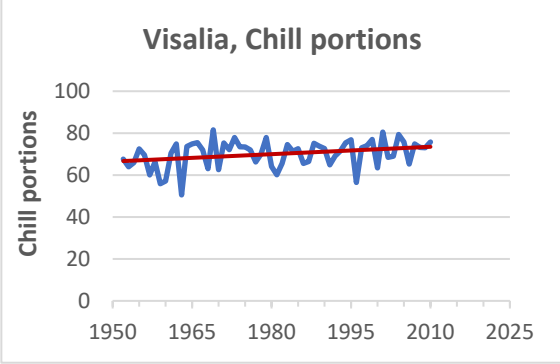

Stratford, Chill hours
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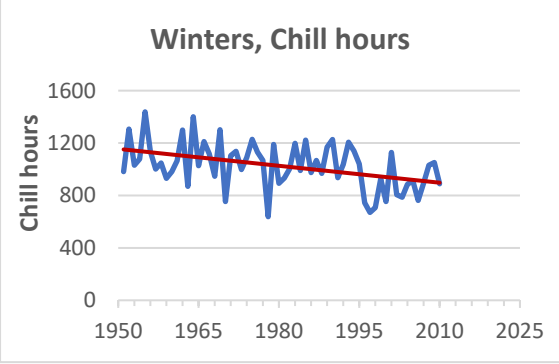

Stratford, Chill portions
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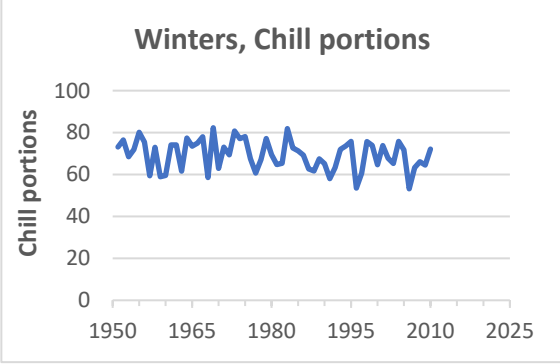

Tracy-Carbona, Chill hours
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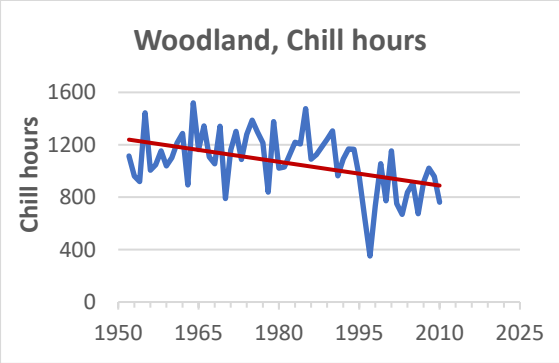

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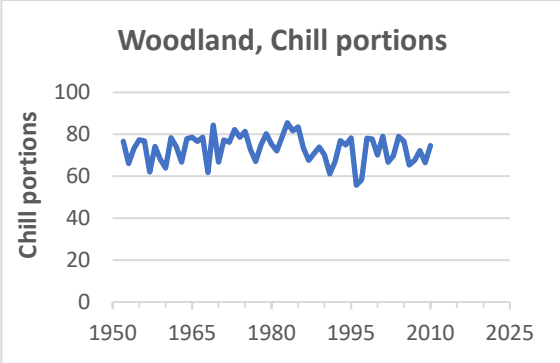

Visalia, Chill hours
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Visalia, Chill portions
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Winters, Chill hours
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Winters, Chill portions
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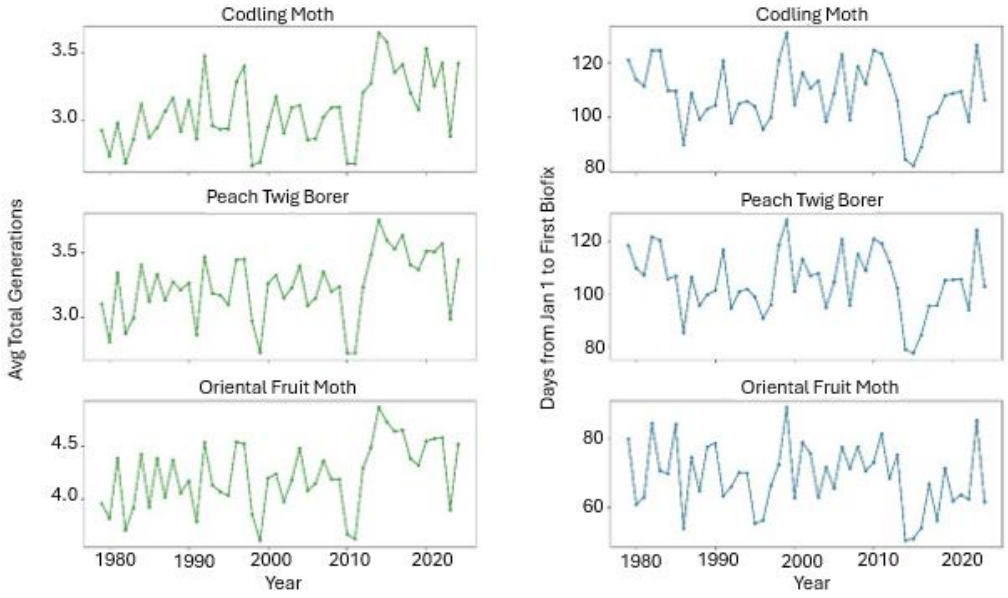

Woodland, Chill hours
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Woodland, Chill portions
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4.6 Fruit and Nut Pest Abundances

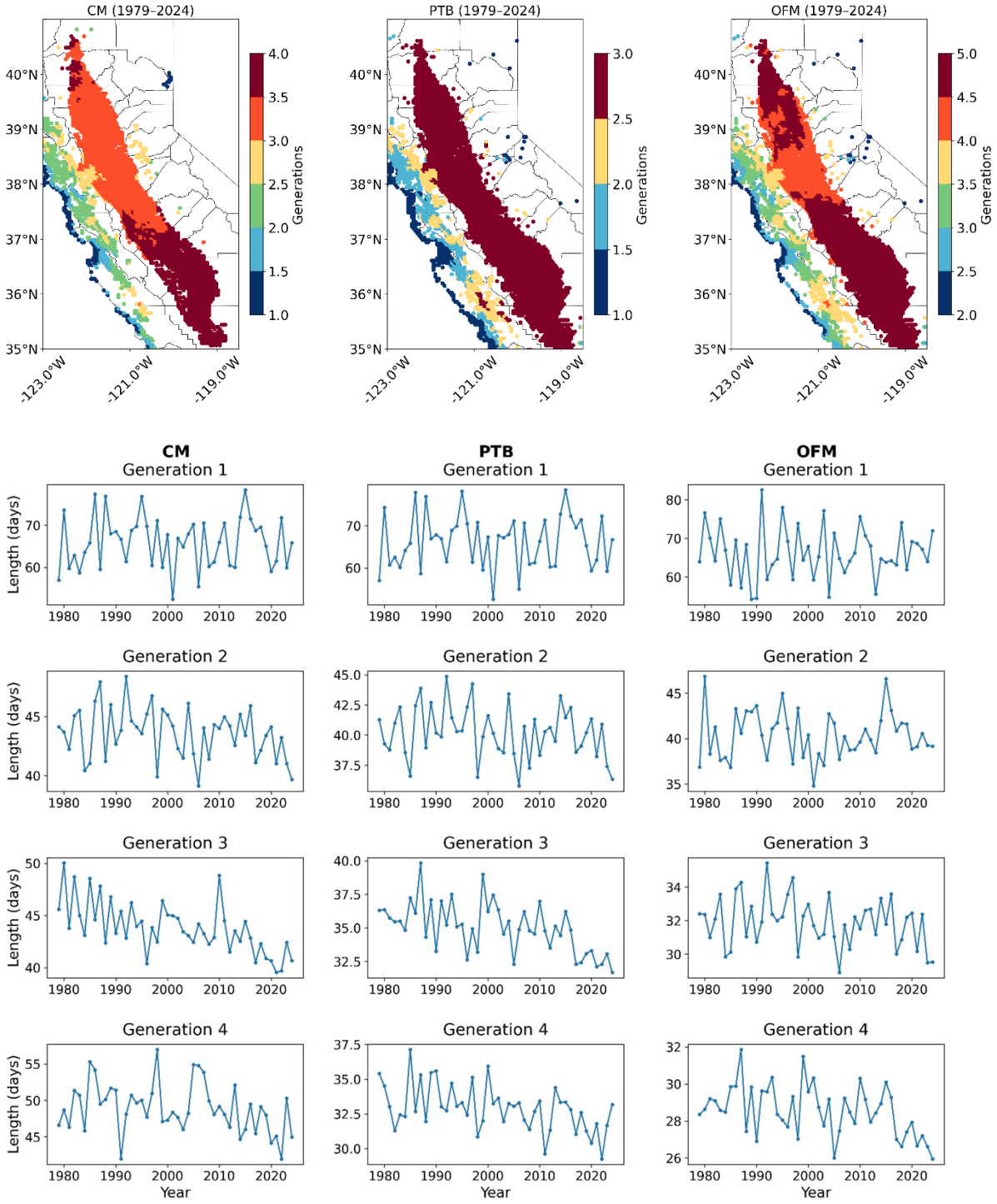
Temperature-based estimates suggest that major pests of high-value fruit and nut crops in California (the codling moth, peach twig borer, oriental fruit moth, and navel orangeworm) are developing faster. As temperatures have increased, so too have the average number of generations each year, while the time required for these pests to complete their lifecycles (from eggs to adults) has declined.

Figure 4.6.1. Estimated Number of Generations and Biofix Length.



The graphs on the left show the annual average number of days from January 1 to the first "biofix" (first adult moth emergence) for the codling moth, peach twig borer, and oriental fruit moth in major agricultural regions of California. The graphs on the right show the annual average total number of generations for each species (each generation represents one lifecycle, from egg to adult). Source: T Pathak/UC Merced, analysis based on metrics published in Jha et al. (2024)

Figure 4.6.2. Trends in the Number and Length of Generations.



The figures show rates of change from 1979 to 2024 in the number and length of generations for the codling moth, peach twig borer, and the oriental fruit moth (labeled CM, PTB, and OFM in the maps and graphs). Source: T Pathak/UC Merced, analysis based on metrics published in Jha et al. (2024)

What does the indicator show?

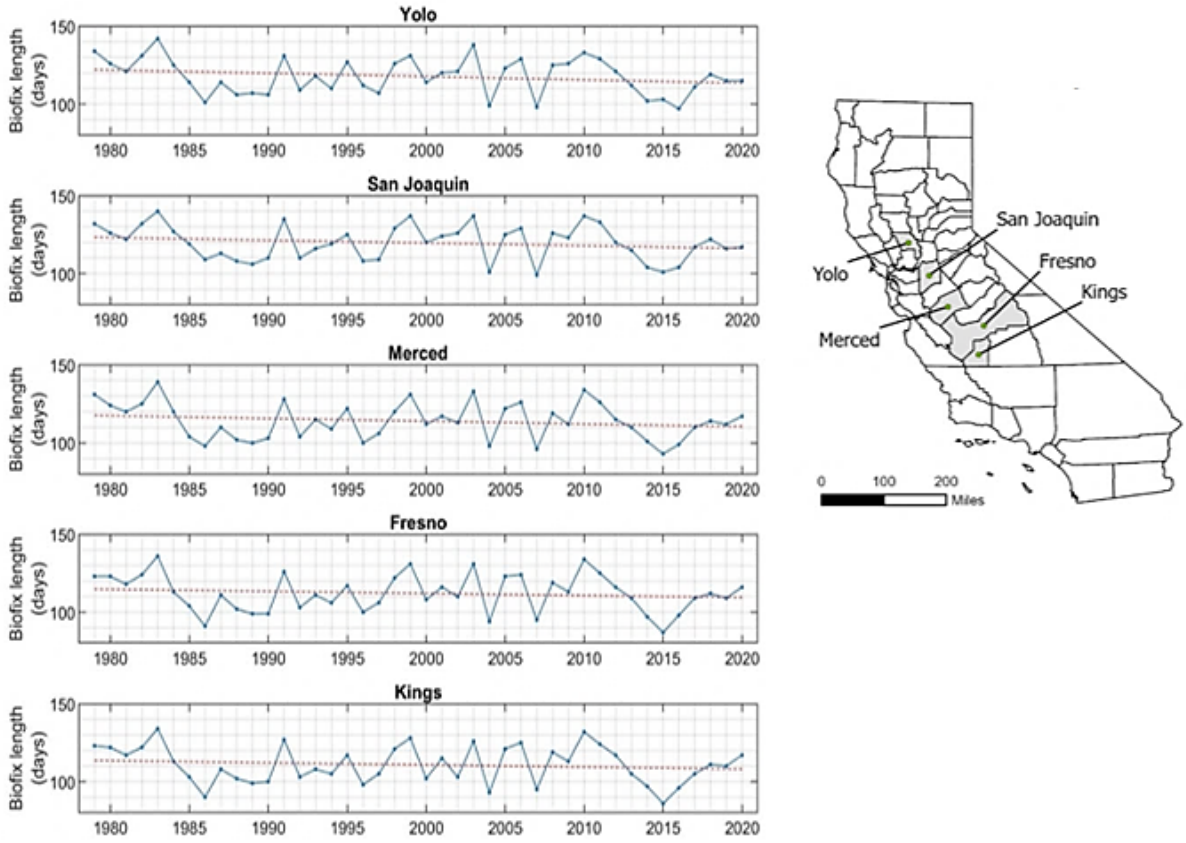
Lepidopteran (moth) pests, mainly codling moth (*Cydia pomonella*), peach twig borer (*Anarsia lineatella*), oriental fruit moth (*Grapholita molesta*), and navel orangeworm (*Amyelois transitella*), damage walnuts (*Juglans regia*), almonds (*Prunus dulcis*), and peaches (*Prunus persica*) - high-value specialty crops in California with a combined value exceeding $6 billion (CDFA, 2025; Jha et al., 2024; Pathak et al., 2021).

Pest development is tracked using temperature-based “growing degree day” models, which measure heat accumulation over time. Field-based observational data of pest lifecycles in the locations studied were incorporated into the model. Like crops, insects require a certain amount of accumulated heat to reach developmental stages and complete their life cycles. As temperatures rise, these heat thresholds are reached more quickly, accelerating development.

Consistent with warming trends, these pests are developing faster, resulting in shorter life cycles and more generations per year. **Figure 4.6.1** shows the number of days from January 1 to first adult emergence (“biofix”, used to calculate growing degree days and to track pest activity during the season). While this timing varies by year, the long-term trend since 1980 shows an annual increase in the number of generations, alongside a decrease in the time required to complete each generation (**Figure 4.6.2**). However, these trends do vary by region as changes to pest lifecycles occur more rapidly in the Central Valley than along the coast.

The navel orangeworm, another major pest of walnuts, almonds, and pistachios, shows similar patterns in the Central Valley. Over the past 41 years, the time required to complete each generation has declined (**Figure 4.6.3**), with the largest reductions occurring in the third and fourth generations, which develop during the warmest part of the season.

Figure 4.6.3. Estimated Biofix Length of Navel Orangeworm in Almond for Selected Counties in the Central Valley, 1979-2020



The dotted line represents the long-term linear trend. Source: T Pathak/UC Merced, analysis based on metrics published in Pathak et al. (2021)

Why is this indicator important?

Increased number of generations of pests also increases the number of sprays needed to control them, increasing the production cost for growers. A recent economic analysis estimated that the total cost of pest management for nine major crops in California was up to $36.86 per acre in 2022 with pyrethroid applications (which increased in use from about 3 million acres treated statewide in 2002 to almost 6 million acres in 2022) and even higher with other methods (Goodhue et al., 2026). In 2023, about 176 million pounds of active pesticide ingredients were used in California (DPR, 2025). Plus, more use of insecticides has consequences for beneficial insects, the environment, and

human health. Tracking estimated changes in insect generations informs the agricultural industry about expected crop outcomes and supports investments in making varieties more resilient to these damaging pests. This information can be used to understand patterns in pest life cycles during the growing season for effective pest management. Publicly available decision support tools that integrate this and other important agricultural information to inform agricultural practices include the CalAgroClimate tool.

Almost all walnuts grown in California are susceptible to damage from codling moth (UC IPM, 2023). This pest overwinters as a full-grown larva, whose first flight begins around late March to early April and can complete two or three generations in most places, with fourth generations found in some warmer areas (UC IPM, 2023). Each overwintered female lays about 30 eggs and this number doubles to 60 in later generations. The feeding of the first-generation larvae causes nutlets to drop from the tree, and the later generations feed on the kernels rendering them unsellable.

Damaged nuts, such as from codling moth infestations, serve as a breeding ground for navel orangeworm, which is the most damaging pest across three nut crops – almonds, walnuts and pistachios (Grant et al., 2020; Haviland et al., 2021). Navel orangeworm female moths lay eggs on a naturally split suture of the nuts. The freshly hatched larvae directly feed on the kernel, rendering it unmarketable (**Figure 4.6.4**). The damaged kernels become a preferred target for the saprophytic fungi *Aspergillus* spp., which produce carcinogenic toxins (aflatoxins) (Bentley et al., 2017; Grant et al., 2020; Haviland et al., 2019). Additionally, as damage to crops from navel orangeworms becomes more prevalent, greater use of pest control and pest management techniques will become necessary.

Figure 4.6.4. Damaged Nuts Due to Feeding of Navel Orangeworm Larva.



Source: Wilson et al. (2020)

The peach twig borer (*Anarsia lineatella)* is a major pest of almonds and peaches in California. Female peach twig borers lay eggs on twigs, fruits and leaves. The peach twig borer completes three to four generations each year (UC IPM, 2023). In almonds, larvae feed on both shoots and nuts causing damage to twigs and reducing the quality of kernels. The peach twig borer can attack shoots and fruits of peach as well. It starts attacking peach fruits from the color break stage until harvest and therefore multiple insecticide sprays are needed to minimize economic loss (Hasey et al., 2016).

The oriental fruit moth (*Grapholita molesta)* larvae bore deeper into the shoots of peaches and almonds than the peach twig borer. These pests can typically complete five generations per year, and up to six in years with warm early springs and late falls (UC IPM, 2023). The early generations (first and second) larvae attack peach shoots but as the fruits begin to develop and mature, they prefer to feed on fruit, which makes the fruit unmarketable. The early larval instar enters the fruit, feeds on and grows inside until the advanced larval stage, and then exits the fruit to pupate.

In addition, lifecycle trends may reflect a broader pattern across California of increased generations and faster development of agricultural pests, including invasive species introduced into California and are regulated by the California Department of Food and Agriculture and the U.S. Department of Agriculture to prevent permanent infestations.

These species may expand into previously unsuitable habitats as temperatures continue to rise. Warmer temperatures can also increase overwintering survival and allow some pests to complete more generations per year, increasing the potential for establishment and crop damage (OEHHA, 2022).

What factors influence this indicator?

Temperature directly affects the development of orchard pests, with estimated developmental thresholds ranging from 10°C to 31°C (50°F to 88°F) for codling moth and peach twig borer, 7°C to 32°C (45°F to 90°F) for oriental fruit moth, and 13°C to 35°C (55°F to 95°F) for navel orangeworm (Jha et al., 2024; Pathak et al., 2021). Globally, insect growth rates in tropical regions are expected to decline because current temperatures are already near their optimal range, whereas growth rates for insects in temperate regions (such as those in California) are projected to increase as temperatures continue to rise (Sunil et al., 2023). Humidity, precipitation, and wind affect the body temperature and thus the development of these pests as well (Pathak et al., 2021). Humidity can enhance body temperature, while wind and precipitation can lower it. Orchard sanitization, pesticides, and early harvest are examples of agricultural practices that may reduce their populations (Bentley et al., 2017; Grant et al., 2020; Haviland et al., 2019).

Technical considerations

Data characteristics

The metrics presented for the codling moth, peach twig borer, oriental fruit moth, and navel orangeworm are based on Jha et al. (2024) and Pathak et al. (2021). Gridded temperature data from gridMET were generated by blending spatially rich data from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) with temporally rich data from the North American Land Data Assimilation System Phase 2 (NLDAS-2) using climatically aided interpolation (Abatzoglou, 2011). Daily minimum and maximum temperature data at 4-km spatial resolution from 1979 to 2024 for the codling moth, peach twig borer, and oriental fruit moth, and 1979 to 2020 for the navel orangeworm, were collected and used in this analysis.

A growing degree-days model was used to predict the timing of various life stages of the selected pest species. In this model, growing degree days, which represent daily heat accumulations, were calculated from the minimum and maximum temperatures based on pest species' biological thresholds. Calculations of the number of days required to reach biofix and to complete the life cycle enabled estimates of the total number of generations. Details of the calculations and variables used (e.g., temperature thresholds, growing degree day end dates, generation lengths, etc.) can be found in Jha et al. (2024) and Pathak et al. (2021).

Strengths and limitations of the data

Temperature-based degree-days models to estimate the lifecycle of agricultural pests have been used globally. Zalom et al. (1997) validated the navel orangeworm degree-days model in field conditions. Despite this, uncertainties associated with model parameters and inherent model uncertainties can influence the outputs. Models also do not capture every possible environmental condition, such as mortality due to extreme heat.

OEHHA acknowledges the expert contributions of the following to this report:

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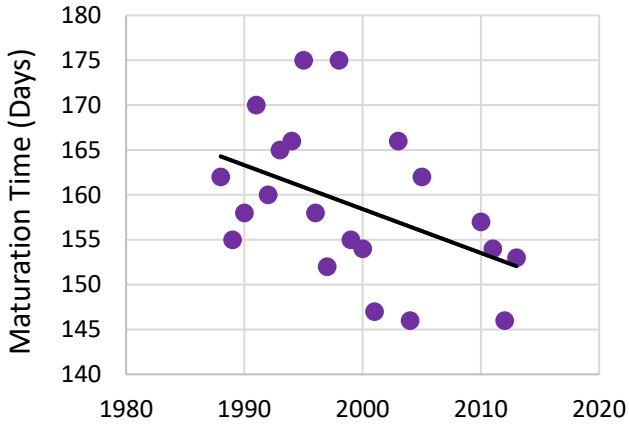
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4.7 Fruit and Nut Maturation Time (No Update)

With warming air temperatures, one walnut variety and several prune varieties in the Central Valley are maturing more rapidly, leading to earlier harvests. Temperature-based estimates indicate that processing tomatoes are also maturing faster.

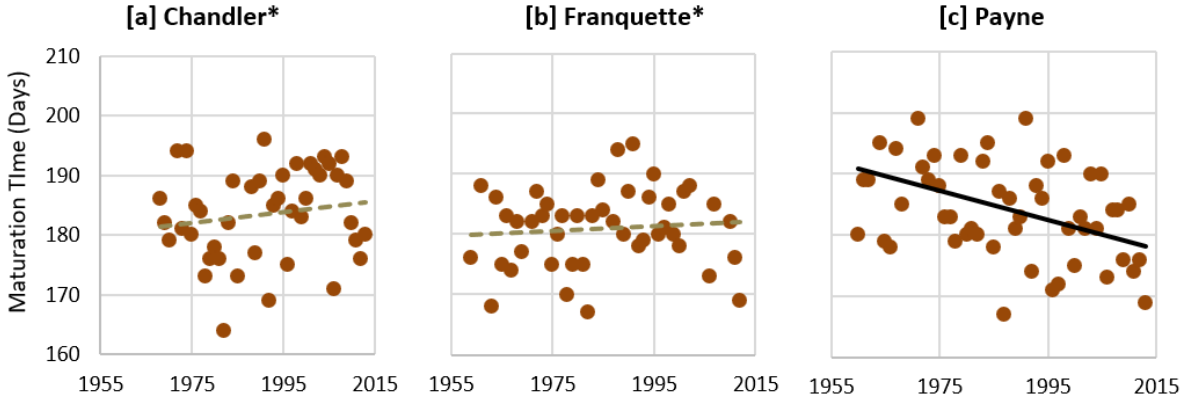
About this indicator: This chapter was originally published in the 2018 Indicators of Climate Change in California report with an updated section added in the 2022 report. It has not been updated for this 5th edition.

Figure 4.7.1. Prune Maturation Time in Parlier.



Source: Jarvis-Shean et al. (2016)

Figure 4.7.2. Walnut Maturation Time in Davis (3 Cultivars).



*Trend not significant (dashed line)

Source: Jarvis-Shean et al. (2016)

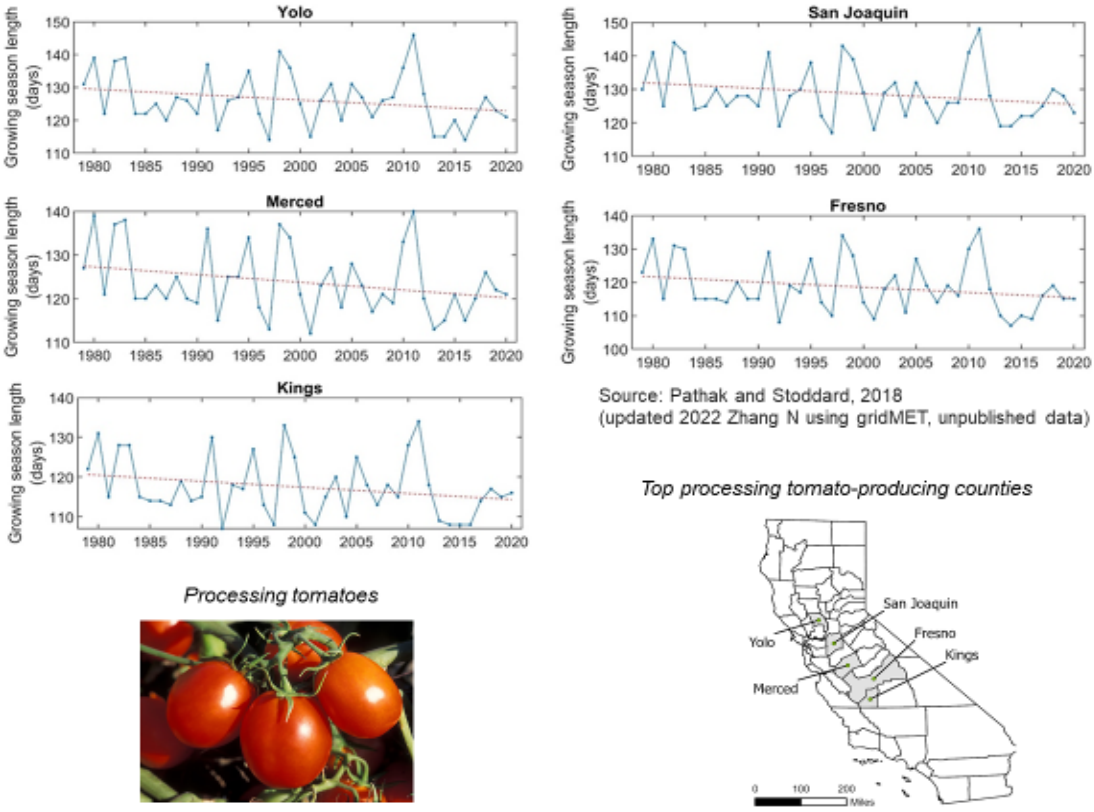
What does the indicator show?

Figure 4.7.1 shows maturation times for California prunes and **Figure 4.7.2** shows three cultivated walnut varieties ("cultivars"), grown respectively in two Central Valley locations: Parlier (Fresno County) and Davis (Yolo County). "Maturation time" refers to the period between bloom and harvest — specifically, flowering and fruit maturity for the prune, and leaf-out and first harvest for the walnut.

From 1988 to 2013, prune maturation (**Figure 4.7.1**) time decreased on average by about 12 days. The maturation time for one of the walnut cultivars, the Payne walnut (**Figure 4.7.2c**), similarly decreased by approximately 11 days since 1960. Maturation times for two other walnut cultivars, the Chandler and the Franquette (**Figure 4.7.2a** and **b**), have remained relatively constant since 1968 and 1959, respectively.

Processing tomatoes are a type of tomato that eventually get canned, dehydrated, or turned into paste, puree, ketchup, tomato sauce, or tomato juice. California accounts for 95% of the nation's and 30% of the world's processed tomatoes. Fresno, Kings, Merced, San Joaquin, and Yolo counties in the Central Valley are the top five tomato-producing counties in the state. Processing tomatoes have been maturing faster over the past four decades in these counties (Pathak et al., 2018). The estimated length of the tomato growing season – the period between planting (March 15) and maturity (harvest) – in these five counties has been declining (see **Figure 4.7.3**). These estimates were derived from temperature data using a "growing degree day" model to calculate the accumulation of "heat units". When sufficient heat units are accumulated, tomatoes reach maturity. As temperatures increase, heat units accumulate faster and maturation occurs earlier. Consequently, estimates from 1979 to 2020 show that processing tomatoes in these counties are reaching maturity about 6 to 8 days earlier.

Figure 4.7.3. Tomato Growing Season Length at Top Processing Tomato-Producing Counties, 1979-2020.



Why is this indicator important?

California accounts for an estimated 96% of the prunes grown in the US, with about half consumed domestically and half exported. The state currently supplies about 40% of the world's prunes (Lazicki et al., 2016). The prune industry in California is dependent on a single cultivar, the "Improved French Prune."

California growers produce 99% of the commercial US supply of walnuts with about a third of the crop exported (Geisseler and Horwath, 2016). The industry generates $1.4 billion in farm gate revenue annually (net value after subtracting marketing costs) and supports some 60,000 jobs directly and indirectly (California Walnut Board, 2017).

Climatic conditions following flowering and leaf-out for fruits and nuts are critical to the development of a robust crop. In general, shorter maturation times lead to smaller fruits and nuts. Because larger fruits command a premium price, this change can lead to a significant loss of revenue for growers and suppliers. For prunes, this can be somewhat offset by fruit thinning earlier in the year, which can promote larger fruits. This is not practical for walnuts, due to the size of the trees.

Shorter maturation times mean that crops are ripening more quickly. This results in a shorter timeframe for harvest and processing. During harvest season, farmers draw on a limited supply of workers and equipment. If the harvest timeframe shortens, hiring workers and renting equipment can present challenges. Thus, a compressed harvest schedule puts farmers at risk for significant loss of crop quality.

The trend toward earlier maturation for some cultivars of walnuts has some positive impact. Walnuts are often harvested in October — the beginning of the rainy season in the Central Valley. Rain immediately before or during the harvest can be catastrophic, making it difficult to properly dry the nuts, leaving them vulnerable to mold growth. The earlier in the season that walnuts mature, the less likely they are to encounter rain at harvest time.

Warming is expected on an annual, seasonal, and even daily basis in California, with impacts differing by region. The significant, overall outcome of warming is the likely reduction in yield of some of California's most valuable specialty crops, particularly perennial crops.

What factors influence this indicator?

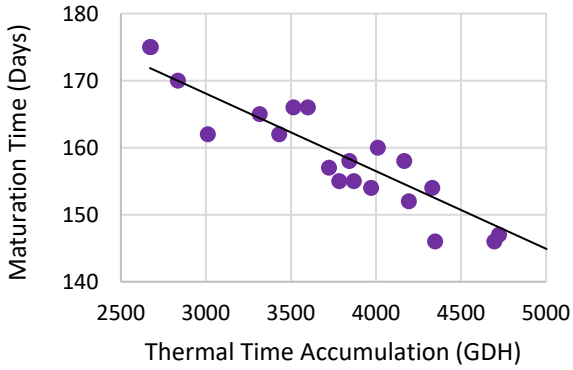
Temperature influences how fast the fruits on a plant develop and mature. Following a period of dormancy in the winter (see *Winter Chill* chapter), fruit and nut trees begin to bloom by opening flowers or leaf buds. Prune trees have flower buds that produce flowers and vegetative buds that produce leaves. Flowering occurs before vegetative bud breaks. Walnuts have male buds that produce pollen and mixed buds that produce leaves and female flowers. Leaf emergence precedes the opening of the female flowers (Ramos, 1997).

During the first 30 to 90 days after bloom, the amount and duration of warm weather experienced by the plant — referred to as heat accumulation — is the most significant factor that determines harvest timing. This period occurs during the months of April, May, June and July, depending on the variety of walnuts. With warmer temperatures, the fruit or nut develops and matures more quickly, leading to an earlier harvest. However, temperatures that are too high (such as during hot days in the Central Valley) can slow development as trees divert energy from fruit development towards self-cooling and preventing or repairing heat damage (Jarvis-Shean et al., 2016)

Different crops have different heat requirements for fruit development; these requirements are typically expressed as thermal time accumulation. In its simplest form, thermal time measures the difference between a given temperature and a certain threshold or base temperature, and the length of time this difference occurs in a day or other unit of time. Thermal time accumulation is calculated by summing hourly thermal time. A fruit or nut reaches maturity when it has accumulated sufficient thermal time. “Growing degree hours” (GDH) is a commonly used unit of thermal time accumulation.

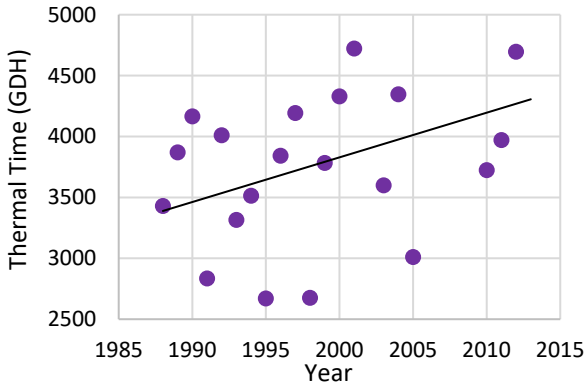
Fruit or nut maturity represents the first possible harvest date. The timing of maturity is partially determined by the timing of flowering. Generally, a tree that blooms earlier will also be ready to harvest earlier. Consequently, changes in harvest readiness date can be due to changes in flowering dates as well as changes in temperature after flowering. Time to Maturity tracks the time between flowering and maturity, and thus the influence of temperature on changes occurring after flowering. As shown in **Figure 4.7.4**, prune maturation time responded very strongly to thermal time accumulation: the greater the thermal time accumulation in a given season, the shorter the maturation time. In fact, thermal time accumulation for French prunes in Parlier has been increasing since 1988 (**Figure 4.7.5**) — a trend consistent with the decreasing season length. There is, however, too much variation in the data to make any strong conclusions currently. If thermal time accumulation in Parlier continues to increase as the trend suggests, prune maturation times will most likely continue to shorten with increasing temperatures projected with climate change. Since 1931, minimum temperatures have been increasing for most months of the year in Parlier, while maximum temperatures have been decreasing.

Figure 4.7.4. Prune Maturation Time in Response to Thermal Time Accumulation in Parlier.



Source: Jarvis-Shean et al. (2016)

Figure 4.7.5. Thermal Time Accumulation for Prunes in Parlier.

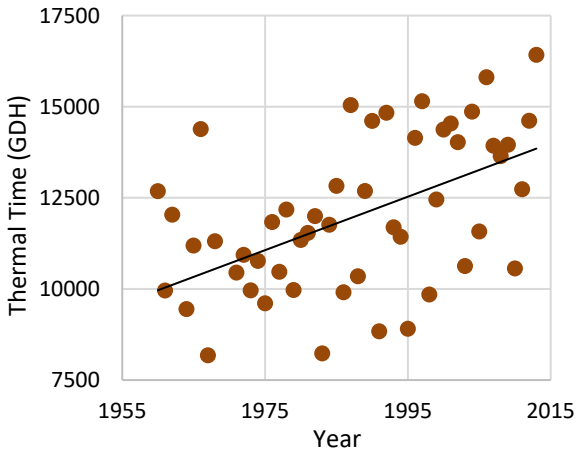


Source: Jarvis-Shean et al. (2016)

Of the three walnut varieties, only Payne showed a significant decreasing trend in maturation time length over the past 60 years. As with the prune, Payne maturation time responded strongly to thermal time accumulation, showing decreasing maturation times with increasing thermal time accumulation (**Figure 4.7.7**). Payne thermal time accumulation has been increasing since 1960 (**Figure 4.7.6**), indicating that maturation time for these walnuts will shorten with warming conditions associated with climate change. Although maturation times for both the Chandler and Franquette walnuts did

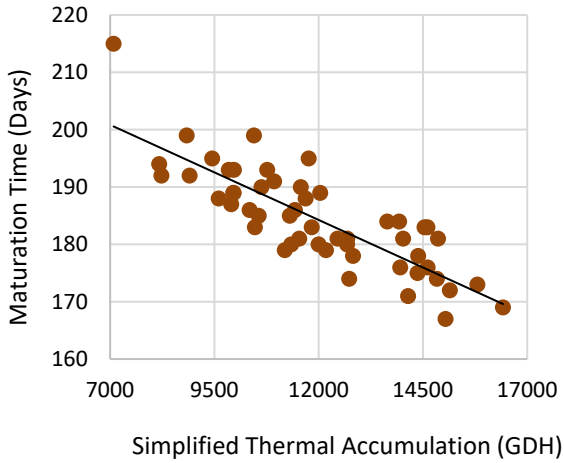
not change appreciably over the past 46 and 54 years, respectively, thermal time accumulation for both cultivars increased over time, and showed a strong relationship with maturation time (not shown). Researchers anticipate that maturation times for these cultivars will likely shorten in the future with increasing thermal time accumulation.

Figure 4.7.6. Thermal Time Accumulation for Payne Walnut in Davis.



Source: Jarvis-Shean et al. (2016)

Figure 4.7.7. Payne Walnut Maturation Time in Response to Thermal Time Accumulation in Davis.



Source: Jarvis-Shean et al. (2016)

No definitive conclusions can be drawn regarding trends in the maturation times of three almond cultivars, given the short period for which observations are available (nine years).

Technical considerations

Data characteristics

Climate data:

Temperature data were obtained from the National Climatic Data Center of the National Oceanic and Atmospheric Administration (Menne et al., 2015) and from the California Irrigation Management Information System (CIMIS). CIMIS, developed by the California Department of Water Resources and the University of California at Davis, is a repository of climatological data collected at more than 100 computerized weather stations throughout California.

Temperature data were retrieved from stations closest to the fruit and nut orchard locations. When data was missing from a primary station, temperature data from a nearby station were used to supplement the dataset. In Davis, for days when climatological data was absent from the primary station, temperatures from other surrounding locations were used in a model to estimate Davis temperatures.

Temperature time series going back to 1988 (prune) and 1960 (walnut) were analyzed to match up with the duration of maturation time. Spring thermal time accumulation was calculated using the Growing Degree Hours (GDH) model of Anderson et al. (1986). This model counts the highest GDH accumulation at an optimal temperature of 25 degrees centigrade (˚C); at temperatures above a minimum (4˚C) and below a maximum (36˚C), heat accumulates at fractions of the highest possible amount.

Prune bloom/leaf-out data and walnut maturity/harvest data:

Flowering onset and maturity data for prunes were provided by the University of California Dried Plum/Prune Cultivar Development Program. Full bloom is defined as when 50% of the flower buds on the tree have opened. The maturity date is defined as

when the fruit can withstand 3 to 4 pounds of pressure (a penetrometer measures the pressure necessary to force a plunger of specified size into the pulp of a fruit).

The leaf-out and harvest data for walnuts were obtained from the University of California at Davis Walnut Breeding Program. Leaf-out is defined as the time at which 50% of the vegetative buds have started to open. The harvest date is the time at which the hull, the outer fleshy part, separates from the shell of the nut.

Strengths and limitations of the data

The prune and walnut orchards from which data were collected were at the same or nearby locations over the entire study periods. The walnut dataset is long by phenology data standards, with an average of 44 years of observation, a minimum of 35 years, and a maximum of 59 years, depending on cultivar. The prune dataset, although 25 years in length, provides sufficient information for evaluating phenology trends. In both cases, it would be advantageous to have records of walnut and prune phenology at multiple locations. Not only do crops responses change at different latitudes, but the climate effects may vary throughout California. Evaluating data at multiple sites would allow for a better understanding of how climate change may be affecting different agricultural regions within the state.

To measure prune maturity, the amount of pressure a fruit can withstand when punctured, is a very precise and consistent method. For walnuts, the measure of harvest readiness (hullsplit) is affected by humidity. Higher humidity accelerates nut maturity and can introduce uncertainty in timing of harvest readiness date.

For both the prune and the walnut data sets, a small number of researchers were collecting prune bloom/leaf-out data and walnut maturity/harvest data measurements. Researchers trained their successors to ensure consistency in data collection over time.

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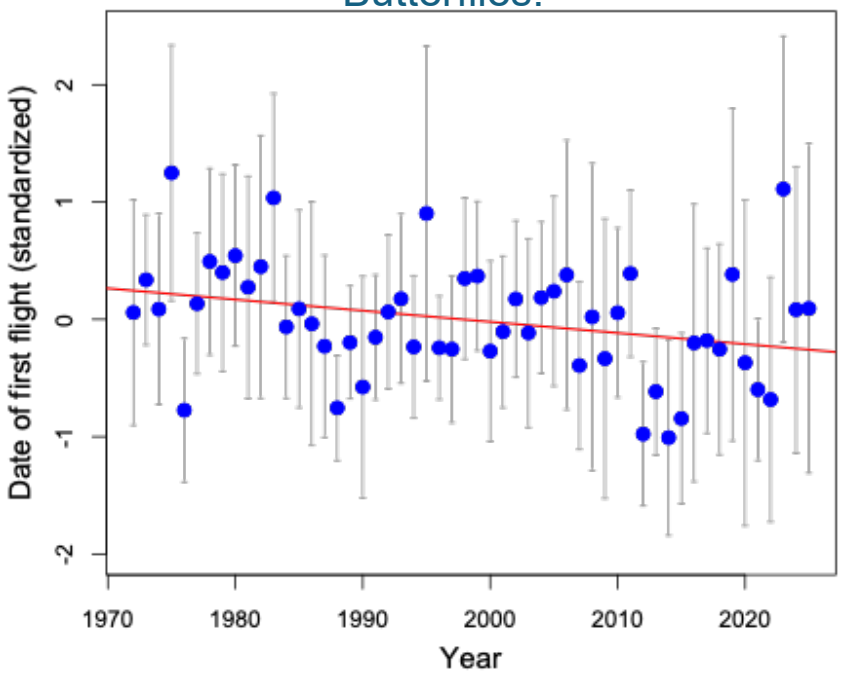
4.8 Spring Flight of California Central Valley Butterflies

Over the past 50 years, common butterfly species have been appearing in the Central Valley earlier in the spring.



Painted lady (*Vanessa cardui*)
Photo: Jim Ellis

Figure 4.8.1. Date of First Spring Flight (DFF) of Central Valley Butterflies.



The graph shows the date of the first spring flight (referred to as DFF, days since the start of the calendar year when the first adult is observed in the field) for each butterfly species studied in the Central Valley portions of three field sites in Yolo, Solano, and Sacramento counties of Northern California. The red line in the graph indicates the overall trend towards earlier emergence. The original study focused on 23 species, but two species were extirpated from the study area. Source: Forister and Shapiro (2003), updated 2025

What does the indicator show?

Over the past 50 years, the average date of first flight (DFF) of a suite of butterfly species in the Central Valley of California has been shifting towards an earlier date in the spring. The DFF refers to the date that the first adult of a species is observed in the field in a given calendar year. Change in DFF tracks shifts in the phenology (the timing of seasonal life cycle events) in the emergence of butterflies in the Central Valley. In addition, as exemplified by the loss of two butterfly species in the study region, *E. ausonides* and *P. campestris* (discussed below), butterfly populations are declining across the United States.

Earlier date of first spring flight

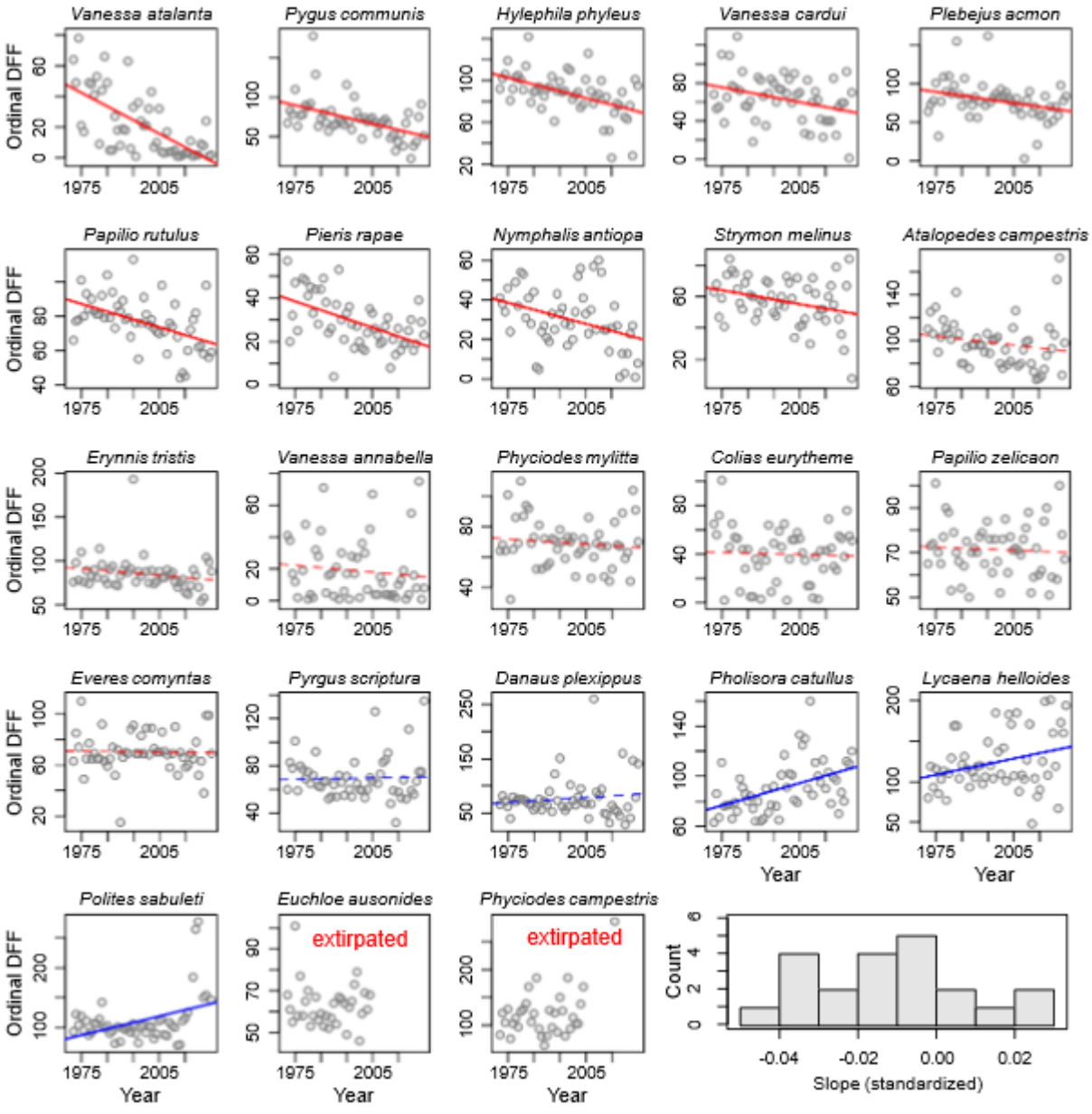
In **Figure 4.8.1**, the value shown for each year is the aggregate of DFFs across species, calculated as described in the *Technical Considerations* section below. The higher the value on the graph, the later the DFF. A negative value indicates DFF that is earlier than the average; a positive value, later than the average. The red line in the graph indicates the overall trend towards earlier emergence (Forister and Shapiro, 2003, updated data available from UCD, 2025).

Figure 4.8.2 presents DFF by year for each butterfly species, starting with species emerging earlier in the year, and ending with species emerging later. Across the 9 species with individually significant responses for earlier emergence, the average slope is -0.54 days per year, indicating that the spring phenology of these species is advancing by approximately 5 days per decade. Graphs of the two species that are now extirpated are also shown.

The histogram in the lower right of **Figure 4.8.2** shows that the distribution of slope values across all species has shifted towards the negative, consistent with generally earlier emergence (one-sample t test = -2.37, df = 20, $P = 0.028$) and the pattern shown

in **Figure 4.8.1** (note that the t test is for 21 species, not including the two that have been extirpated, while all 23 species are included in **Figure 4.8.1** so that the now-extirpated species contribute information during the years they were present; similarly to the t-test, the histogram in **Figure 4.8.2** is for 21 species, excluding the two extirpated).

Figure 4.8.2. Date of First Spring Flight for 23 Butterfly Species.



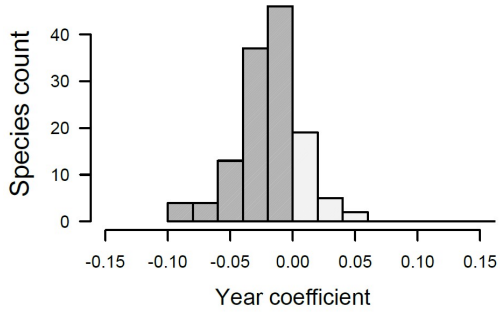
The graphs show ordinal DFF (days from the start of the calendar year) for each butterfly species studied. Solid lines are drawn on plots if individual trends are significant in simple linear

models with DFF predicted by year, at $P < 0.05$: red for species emerging earlier (the first nine), and blue for species emerging later (the last three), and dashed lines are drawn for lines at $P > 0.05$. Source: Forister and Shapiro 2003 (updated 2025).

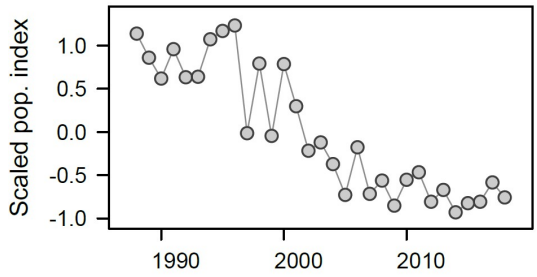
Widespread butterfly declines have been detected across the western United States. Specifically, Forister et al. (2021) estimated 1.6% fewer butterflies are being observed per year across all western states. That result is based on 72 sites (with 10 or more years of data) monitored by community scientists organized by the North American Butterfly Association (NABA). Changes in the total numbers of butterflies at those sites were modeled as a function of a range of climate and landscape factors, and the most powerful predictors were indices of climate change. Locations where fall months had warmed the most (in maximum daily temperatures) were the locations where annual reductions in total butterfly densities were most pronounced (Forister et al. 2021). More recently, a decline of a comparable magnitude across the entire continental United States has been confirmed using a similar approach (with monitoring data, including from NABA) by Edwards et al. (2025).

Consistent with the broader trend throughout the western United States, a majority of species in the Northern California dataset that includes the butterfly species tracked by this indicator have been seen less frequently over time (**Figure 4.8.3A**). This data set consists of observations from ten study sites that include large urban and agricultural areas from the Bay Area to the Sierra Nevada Mountains, and the population changes reflect both the effects of habitat loss or degradation and climate change. Annual changes in the probability of being observed (which is used as an index of population density) for two species are shown in **Figure 4.8.3B** and **C**.

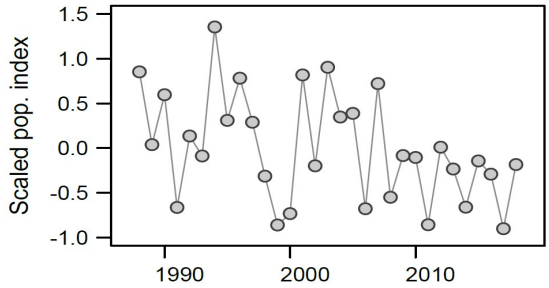
Figure 4.8.3. Declining Northern California Butterfly Populations.



A) Magnitude of population changes for butterfly species from ten northern California sites monitored biweekly during the butterfly season for 33 to 49 years. Year coefficients indicate population trends and were estimated using binomial regressions; negative values (dark gray) represent most species with declining population trends. One species with a large positive value is excluded for visualization of the larger pattern.



B) Probability of *Euchloe ausonides* being observed for each year, 1988-2018. This species is extirpated from the study region in the Central Valley but is still present (albeit declining) across the western United States.



C) Probability of *Atalopedes campestris* (not to be confused with *P. campestris*) being observed for each year, 1988-2018.

Source: Forister et al. (2021)

This indicator complements similar studies from Austria, Switzerland, the United Kingdom and other European countries and demonstrates the ubiquitous phenological

response of spring butterflies to warming and drying conditions (e.g., Altermatt, 2012; Hill et al., 2021; Peñuelas et al., 2002; Roy and Sparks, 2000).

The Central Valley has undergone intense land conversion, both to urban development and to agriculture (Forister et al., 2016). Thus, the data indicates that the phenological impacts of climate change are not restricted to northern latitudes or to pristine ecological conditions. Continued monitoring of phenological changes adds to the growing body of data that elucidate butterfly responses to changing temperature and precipitation linked to climate change, that are occurring alongside changing land use, increasing pesticide use, and other stressors (Chmura et al., 2019).

Why is this indicator important?

Tracking changes in the spring flight of Central Valley butterflies provides visible evidence of biological shifts consistent with the impacts of a changing climate. Plants and animals reproduce, grow and survive within specific ranges of climatic and environmental conditions. Species may respond when these conditions change beyond tolerances by moving to more favorable habitats (often poleward or to higher elevations), sometimes changing in morphology such as body size or wing color, or altering phenologically with respect to the timing of events such as migration, egg-laying or emergence (Hill et al., 2021; Root et al., 2003).

Many studies have investigated the relationship between phenology and changes in climate conditions. These studies, however, have often been from higher, temperate latitudes, where minor climatic changes can have large impacts on species that are often at the limits of their ranges (Chambers et al., 2013; Parmesan, 2006; Root et al., 2003; Walther et al., 2002). In contrast, species from lower latitudes like the Central Valley, where the climate is highly variable with large fluctuations in temperature and precipitation, might be expected to be adapted to such variability. The shifting phenology of these species is correlated with the hotter and drier conditions in the region in recent decades (Forister and Shapiro, 2003; Forister et al., 2018; Halsch et al., 2021) (see *Air Temperature*, *Precipitation,* and *Drought* chapters). The data supporting this indicator suggest that Central Valley butterflies are not only responding to changing

climate conditions, but also that their responses have been like butterflies from higher-latitude climates.

Changes in the seasonal timing among species that interact, for example, between butterflies and their plant their food sources, or between prey and predators, could disrupt population dynamics and species abundance across trophic levels (Weiskopf et al., 2020). Declining populations of butterflies and other insects have been reported globally (Wagner, 2020), underscoring the urgency to better understand how changes in climate, habitat degradation, pollution, and other stressors interact to affect insect populations (Halsch et al., 2021).

Butterfly population declines

Additionally, population densities are declining across the United States. Population densities in the northern Central Valley of California are declining in response to shifting land use, increased use of pesticides, and climate change (Casner et al., 2014; Forister et al., 2016). As previously mentioned, *Euchloe ausonides* and *Phyciodes campestris* have been in severe decline in the Central Valley study region, and similarly severe declines have also been observed in areas not immediately adjacent to intense agricultural development and urbanization. During and after the mega-drought years of 2011 to 2015, butterfly populations in the Sierra Nevada Mountains reached historic lows that rival the declines previously seen in the Central Valley (Halsch et al., 2021).

What factors influence this indicator?

Climatic conditions have a significant impact on the phenology of butterflies. Butterflies in the temperate latitudes enter a dormant state during the winter months; in the spring, temperature cues cause them to hatch, to resume activity, or to emerge from pupae as adults (Dennis, 1993; Shapiro, 2007). As climatic conditions during key times of the year have changed, the timing of butterfly life-history events has undergone a corresponding change. The butterfly species monitored overwinter in different life history stages: eggs (1 species), larvae (8 species), pupae (9 species) and adults (3 species); two of the species emigrate in the spring from distant over-wintering sites. Statistical analyses to determine the association between DFF and twelve different weather variables show winter conditions—specifically winter precipitation, average winter daily maximum

temperature, and average winter daily minimum temperature—have the strongest associations with DFF (Forister and Shapiro, 2003). Between 2011 and 2015 (during the drought years), DFFs advanced at the same low-elevation locations in the Central Valley, as well as at higher-elevation sites in the Sierra Nevada (Forister et al., 2018). However, dates of last flights remained close to the long-term average at low elevation sites, while advancing at higher elevations, thereby compressing the length of the flight window.

Other factors may impact the phenological observations described here, such as nectar and host plant availability. Plant resources may in turn be affected by habitat conversion, though it is not obvious how these factors could lead to the earlier emergence of a fauna. Finally, the impacts that a shifting insect phenology may have on other species at higher and lower trophic levels, including larval hosts and predators, are also unknown.

Technical Considerations

Data characteristics

The data described here consists of the date of first spring adult flight (DFF) for 23 butterfly species (including the two recent extirpations). These were first reported by Forister and Shapiro (2003). The primary result remains unchanged by the updated data: an overall shift towards earlier emergence, with more dramatic shifts in a subset of species. Information about ongoing monitoring of study sites can be found at https://butterfly.ucdavis.edu/ and https://sites.google.com/view/westernbutterflies/; data are available upon request.

The study area is in the Central Valley portions (below 65-meter elevation) of three Northern California counties: Yolo, Sacramento, and Solano. Three permanent field sites in these counties are visited by an investigator at two-week intervals during “good butterfly weather.” Most of the observations (> 90%) of DFF come from those permanent sites; however, if a butterfly was observed each year to be flying first at a location within the three counties but outside of the permanent sites, that observation was included as well.

The values for **Figure 4.8.1** were derived as follows:

- Calendar dates were first converted into days since the start of the year, also known as "ordinal" dates.
- The ordinal dates of first flight (DFF values) were transformed into z-scores separately for each species. To do this, the mean and standard deviation of DFF values across years were calculated. The difference between each DFF value and the mean was then found, and that result divided by the standard deviation to produce a z-score corresponding to the number of standard deviations a value is from the long-term average DFF for that species. For example, a z-score of -1 indicates a DFF that is one standard deviation earlier than the average for that species, and a value of 1 indicates a DFF that is one standard deviation later than average.
- The z-score mean across the 23 species for each year is shown in **Figure 4.8.1**, along with the standard deviation of the z-score values.
- The red line in **Figure 4.8.1** is fit to the mean z-score values across years. It shows that the mean values have decreased over time, and corresponds to an overall trend towards earlier emergence that is significant.

Strengths and limitations of the data

Since the data are collected and compiled entirely by one observer (Arthur Shapiro), any biases in data collection should be consistent across years. This would not be true in studies which involve multiple workers—with variable levels of training—across years.

The primary limitation of the data stems from the fact that DFF is only one aspect of a potentially multi-faceted suite of population-level dynamics. For example, if the spring phenology of a species shifts, does this affect the total flight window? Does it affect peak or total abundance throughout the season? These detection challenges are compounded by documented declines in low-elevation butterfly populations in the region that have been reported by Forister et al. (2010). If populations are in overall decline, with lower densities of individuals throughout the year, this could lower detection probabilities. This is true particularly early in the season for multivoltine species (i.e., species that produce more than one generation in a season where the first generation tends to be smaller). Lower detection probabilities could appear as later

phenological emergence (i.e., a “backwards” shift in time), and this is likely the case for *P. catullus* and *P. sabuleti* in the bottom right of the second figure. These issues are addressed in more detail in Forister et al. (2011); and for further discussion of relevant biological complexities, see Shapiro et al. (2003) and Thorne et al. (2006).

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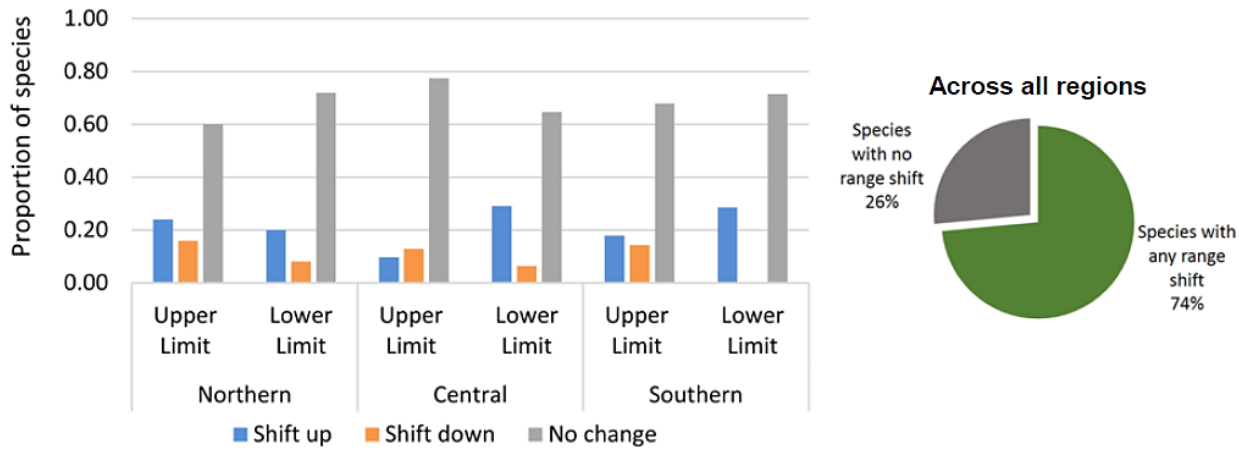
4.9 Changes in Small Mammal and Avian Distributions

Over the past century, many bird and small mammal species in California have shifted their geographic and elevational ranges in response to climate change. Recent resurveys also show that climate change is altering wildlife communities in different ways across the state, including changes in species occupancy, community composition, and species richness. In the Mojave Desert, where conditions have become warmer and drier over the past century, bird communities have collapsed, while small mammal communities have remained relatively stable. Other regions of California show more variable responses, including stable or increasing avian species richness.

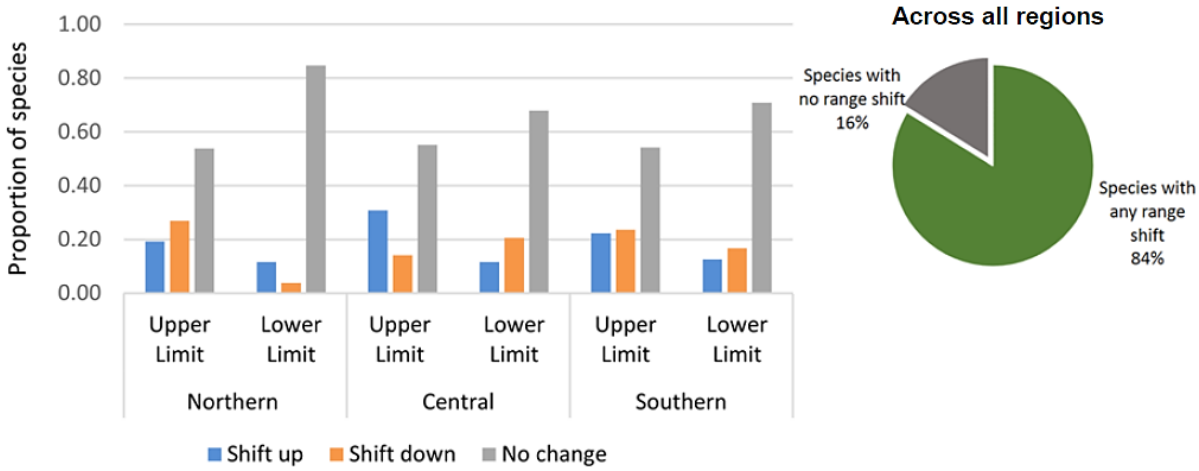
*About this indicator: **Figure 4.9.1** and the underlying Sierra Nevada range-shift data have not been updated since OEHHA's 2018 report. This edition incorporates recent studies that broaden the discussion to include changes in bird and small mammal communities across California.*

Figure 4.9.1. Shifts in Elevational Range Limits in Sierra Nevada.

A. Small mammal range shifts



B. Bird range shifts



Bars show the proportion of species that have shifted their upper or lower elevational limits to higher ("shift up") or lower ("shift down") elevations, or that have shown no elevational change ("no change") over the past century, in the northern (Lassen), central (Yosemite), and southern (Sequoia/Kings Canyon) regions of the Sierra Nevada. Pie charts show the percentages of species that shifted in any direction in any region (green) and that did not shift at all (gray).

Based on data from: Rowe et al. (2015) (mammals); Tingley et al. (2012) (birds)

What does the indicator show?

Over the past century, birds and small mammals across California have altered their distributions in response to changing climate conditions. In the Sierra Nevada, many species have shifted their elevational ranges, while California's deserts, Central Valley, and urbanized regions show changes in species occupancy, community composition, and species richness. **Figure 4.9.1** highlights elevational range shifts observed in three Sierra Nevada study regions (See **Figure 4.9.2** for map showing the study regions, and appendix for graphs showing species-specific elevational changes).

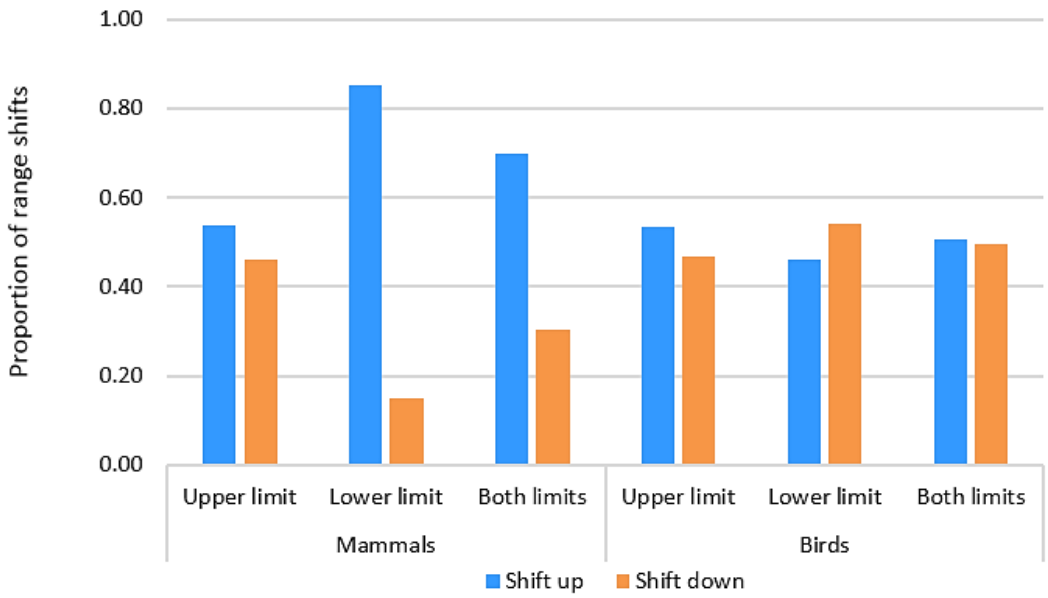
Significant changes have occurred in the elevational range of small mammals (**Figure 4.9.1A**) and birds (**Figure 4.9.1B**) in three study regions in the Sierra Nevada: the northern (Lassen), central (Yosemite) and southern (Sequoia and King's Canyon) regions (see map, **Figure 4.9.2**). The shifts reflect changes that have occurred since a survey conducted by Joseph Grinnell and a team of scientists in the early 20th century. Current ranges are based on resurveys of the same field sites conducted between 2003 and 2010. (See *Technical Considerations* for more information.)

Of the 34 mammalian species surveyed, 25 were found to have shifted their elevational ranges in at least one region (**Figure 4.9.1A**). A shift involves a contraction or expansion of the upper and/or lower limits of a species' elevational range. About two-thirds of the species ranges across the three regions remained unchanged at either or both the upper and lower elevational limits. Of the 22 species found in the three regions, none shifted both their upper and lower limits consistently in the same direction in all the regions (see Appendix, **Figure 4.9.A-1**).

Across the three regions, elevational limits were more than twice as likely to have moved upslope as downslope (**Figure 4.9.2**). High-elevation species were more likely to contract their ranges (typically because of an upslope shift of their lower limits) than to expand them, whereas low-elevation species were just as likely to have contracted their limits as expanded them (Rowe et al., 2015).

Figure 4.9.2. Proportion of Range Shifts Across Regions.

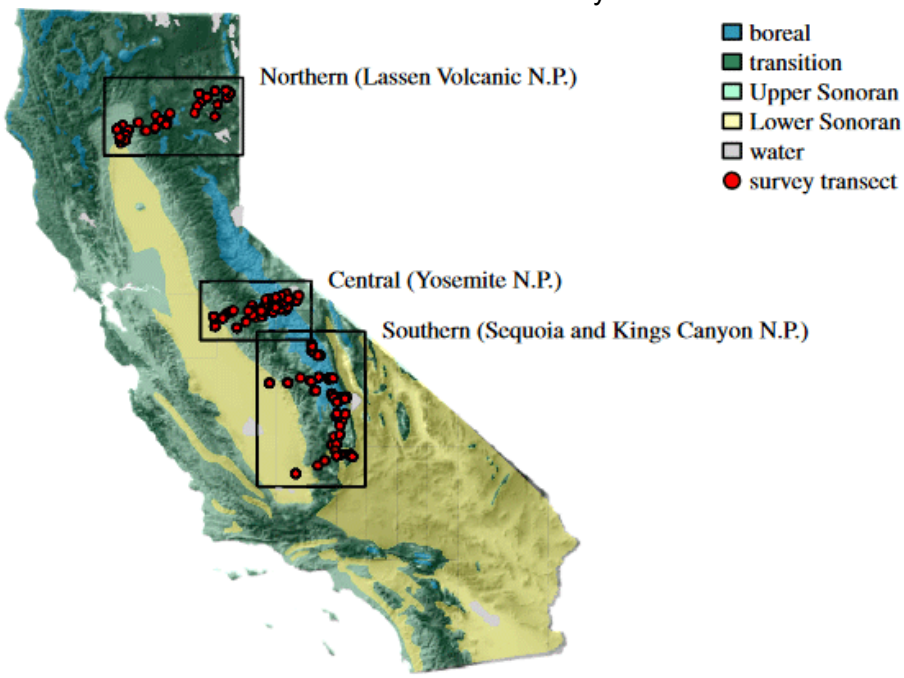
A. Small mammal and bird range shifts



B. Survey locations

Figure 4.9.2, continued.

Location of Sierra Nevada survey transects.



Based on data from: Rowe et al. (2015) (mammals [**A**], and map [**B**]); Tingley et al. (2012) (birds [**A**]).

Shifts in elevation among birds were more frequent than among mammals; 84% of bird species shifted their elevational distribution (**Figure 4.9.1B**). Upslope shifts occurred in 46% of lower elevation limits (resulting in range contraction), and 53% of upper limits (resulting in range expansion) (**Figure 4.9.2***).* Downward shifts were as common as upward shifts (Tingley et al., 2012).

Tribal Connection 4.9.1

California tribes are observing changes in bird populations across the state, including areas that are not part of the surveys mentioned above. For example, the Big Valley Band of Pomo Indians, living around Clear Lake in Lake County, write: "*The Tribe has observed fewer flicker and red-wing blackbird species. These are important birds because the Tribe uses the feathers in regalia and other important cultural activities. With the loss of these birds, the passing on of skills, vocabulary, and ceremony to younger generations is impacted. This*

> *constitutes a larger loss than just having to change which feathers the Tribe uses for regalia; it constitutes a loss of culture and an important part of tribal identity and long-standing traditions*" (Big Valley Band of Pomo Indians, 2026).

Additional resurveys conducted across California have expanded understanding of how birds and mammals are responding to climate change in different ecosystems. These studies complement the Sierra Nevada findings shown in **Figure 4.9.1** and provide insight into how species and communities are changing across deserts, valleys, and other regions of the state.

Recent resurveys of sites originally visited in the early 20th century by Joseph Grinnell and colleagues examined changes in bird and mammal communities across California, including California's deserts (Mojave, Sonoran, and Great Basin Deserts). Desert conditions, already defined by extremes in temperature and precipitation, test the physiological limits of many species. Climate-driven warming and drying threaten desert species through the direct impacts of heat and water stress, as well as through indirect effects on their habitat and food sources (Clare et al., 2025; Iknayan and Beissinger, 2018; Riddell et al., 2019).

At resurvey sites that have become warmer and drier over the past century in the Mojave Desert, birds and mammals have shown divergent responses (Riddell et al., 2021; Iknayan and Beissinger, 2018). Small mammal communities have remained stable while bird communities have collapsed. For mammals, occupancy decreased by 9% of species, 79% did not change, and 12% increased. In contrast, occupancy of the bird community greatly declined: 29% decreased, and only 1 species, the Common Raven, increased. Today's visitors to a site that Grinnell surveyed in the early 1900s would find about half the bird species but roughly the same number of mammal species as what Grinnell encountered.

The ability of small mammals to seek cooler microhabitats (such as underground burrows) reduced their exposures to high temperatures, allowing them to persist. Reduced precipitation drove community collapse in birds (such as prairie falcons, turkey vultures, northern mockingbirds, chipping sparrow and mourning dove), particularly at

sites that both warmed and dried (Iknayan and Beissinger, 2018). The increased water required for cooling body temperature in hotter, drier conditions was an important underlying mechanism in the decline in bird populations (Riddell et al., 2019). Larger species and those with animal-based diets that obtain water primarily from their food were especially vulnerable.

The Great Basin Desert, which lies north of the Mojave Desert, was resurveyed at 45 historic sites originally visited by Grinnell and colleagues. Although both deserts warmed substantially over the past century, the Mojave became drier while the Great Basin became wetter. As with the Mojave Desert, reduced occupancy was observed in the resurveyed Great Basin sites. Bird species adapted to warmer, drier conditions became more dominant in both deserts. Significant shifts in species ranges occurred in 60% of the bird species studied across both deserts. Community composition remained distinct between the deserts, and the transition zone between them appeared to limit northward movement of Mojave species into the Great Basin (Iknayan and Beissinger, 2020).

Beyond desert ecosystems, Grinnell Resurvey data have also been used to compare contemporary and early 20th century bird distributions in California's most transformed landscapes (MacLean et al., 2018; Beissinger et al., 2023). California's Central Valley and surrounding foothills experienced relatively modest changes in bird species richness over the past century, while the Los Angeles region experienced substantial declines in species richness and occupancy. The avian decline in the Los Angeles region is similar in magnitude to the bird community collapse in the Mojave Desert. Researchers attributed the stronger declines in southern California to the combined effects of climate change and extensive habitat loss from urbanization. In contrast, changes in the Central Valley reflected a mix of species declines and increases, with habitat generalists tending to fare better than species with specialized habitat requirements.

The birds in Los Angeles experienced a combined effect of intense climate change (strong warming by +1.8°C (+3.24°F) and drying by -77.2 mm) alongside large-scale habitat loss due to urbanization (Beissinger et al., 2023). Moderate warming

(+0.9°C(+1.62°F)) and wetting (+11.2 mm) occurred at Central Valley sites as well as less severe habitat loss from agriculture. In the Central Valley, declines were more common among species with specialized habitat preferences, while increases occurred among habitat generalists and those that utilized human-modified habitats (MacLean et al., 2018).

These trends were upheld when the resurvey data were pooled and analyzed for 185 diurnal bird species at 320 sites across the entire state (Clare et al., 2025). Results found the largest gains in species richness in California's Central and northerly coastal regions and greatest loss of species in hot and highly seasonal regions within the southern Great Basin and Mojave deserts.

These studies show that responses to climate change vary among species, regions, and ecosystems across California. While some species have shifted their ranges or maintained stable populations, others have experienced substantial declines in occupancy, local abundance, or species richness. This demonstrates that climate change is reshaping wildlife communities throughout the state, although the direction and magnitude of change may differ among locations and taxa.

Why is this indicator important?

Animals reproduce, grow and survive within specific ranges of climatic and environmental conditions. Species may respond to changes in these conditions by, among other things, a shift in range boundaries. Globally, broad patterns of species shifts in response to warming temperatures have occurred over historical time scales ranging from years to millennia. Models project with high confidence that species movement will be a common phenomenon with continued warming (IPCC, 2014).

Species respond uniquely to climatic and other environmental changes. This indicator shows both upslope and downslope shifts in elevation for small mammals and birds, demonstrating the idiosyncratic nature of species' responses to climate change. Range shifts can change community composition as the abundance of some species decreases or increases (IPCC, 2014). Changes in species occurrence can lead to competitive displacement, intensification of predation or new predator-prey interactions and ultimately a decline in biodiversity (Blios et al., 2013). In general, climate change

should favor species that are better able to tolerate warmer and more variable climatic conditions.

Certain species may not be able to shift their ranges fast enough to migrate to suitable environments, particularly where there has been loss or fragmentation of habitat or barriers to species movement (see *What factors influence this indicator?* below). Declines in population abundance can result. In extreme cases, extirpation (eradication) or extinction of species may occur (IPCC, 2014). For example, the American pika, a small mammal adapted to high altitudes and cold temperatures, has disappeared from a 64-square-mile span of habitat from Mount Shasta to the southern Sierra Nevada (Stewart et al., 2015). Resurveys of historical pika locations over six years found they no longer occurred at 10 of 67 (15%) historical sites. The authors suggested that pikas have experienced climate-mediated range contraction over the past century tied to increasing summer temperatures.

The indicator presented here tracks changes in the elevation at which species are found today, compared to earlier in the century. This information will help in understanding and anticipating the long-term dynamics of the distribution of small mammals and birds in California and examining the factors that influence them. This knowledge is crucial in efforts to identify which species are resilient or sensitive to climate change and, thus, to guide efforts to maintain species diversity in the face of regional warming. Models project with high confidence that species movement will be a common phenomenon with continued warming. The data from this indicator are useful in research to test the performance of model-based predictions of species' responses to changes in climate and land cover. Such research will improve predictions of future species' responses.

Changes in the composition of ecological communities, such as the loss of species, can change the ways in which ecosystems function (Hooper et al., 2005). Altered biodiversity has led to widespread concern for both economic (e.g., food sources) and non-economic (e.g., ethical, aesthetic) reasons. Wildlife and habitat conservation programs, government agencies and international scientific programs are taking steps to understand and minimize biodiversity loss and species invasions in an effort towards



preserving ecosystems. This is important for our national parks, where scientists predict future warming will cause substantial turnover of species (Moritz et al., 2008).

What factors influence this indicator?

Range shifts are in part a response to the stresses of climate change (temperature and precipitation). Both the magnitude and the rate of climate change can impact a species' ability to adapt and survive. Recent research suggests that the picture is complex: temperature, precipitation and habitat may force range shifts in multiple directions and affect upper and lower range limits differently, with the relative contribution of different factors varying by elevation (Santos et al., 2017). The mixed or heterogeneous responses described here may reflect a species' intrinsic sensitivity to temperature, precipitation or other physical factors, as well as altered interactions with biological elements of the community (such as food sources, vegetation, and competitors), all of which are changing in different ways in the three regions.

Changes in climate over the past century differed among the three study regions (Tingley et al., 2012; Rowe et al., 2015). The Central region reported the greatest and the Northern region the least increase in mean annual temperature. Across all three regions, the maximum temperature of the warmest month was relatively constant, while the minimum temperature of the coldest month increased. The Yosemite Valley record indicates a substantial increase in monthly minimum temperatures greater than 3 degrees Celsius (°C) or 5.4 degrees Fahrenheit (°F) from 1907 to 2002. This temperature increase is also evident from tree ring data and analyses of vegetation change (Millar et al., 2004), snowmelt data, and retraction of the Mt. Lyell glacier. Precipitation increased most in the Northern region, which also cooled, and in the Central region, but not in the Southern region. These kinds of spatially variable changes in climate over the past century in California can be seen in other ecosystem indicators, such as actual evapotranspiration and climatic water deficit (Rapacciuolo et al., 2014).

Small mammals may respond differently to changes in minimum and maximum temperatures based on differences in species traits, such as lifespan, dietary breadth, and reproduction habitat (Moritz et al., 2008). Increased temperatures have been identified as a likely cause of the contractions of the high-elevation small mammal

species and at least some of the upwards expansions of lower elevation species, although temperature effects on lower elevation species are less predictable. The effect of temperature is especially pronounced at higher elevations where changes in minimum temperature can affect thermoregulatory capacity, hibernation, behavior, and food-web structure (Santos et al., 2017). The average increase in elevation of about 500 meters for affected species in the Yosemite re-survey is consistent with what would be expected with the estimated temperature increase of 3˚C (5.4°F), assuming that the species ranges are limited primarily by physiology (Moritz et al., 2008). The mechanisms explaining downslope shifts and the variable responses among related species are not well understood. Other factors also could be at play, including community structure and competitive interactions. The effects of changing precipitation on small mammals are not as clear but include challenges in finding water or cover (e.g., below the snowpack). Changes in moisture can also have metabolic impacts, such as difficulties in thermoregulation through transpiration when relative humidity is high (Santos et al., 2017). Moreover, some species may be able to persist in refugia (that is, areas in which individuals can survive through a period of unfavorable conditions) created by anthropogenic changes to the habitat, such as campgrounds where food and water are available (Morelli et al., 2012 and 2017).

Birds showed more heterogeneous elevational range shifts within species and among the three study regions over the past century (Tingley et al., 2012). In general, birds shifted upslope with increasing temperatures and shifted downslope with increased precipitation. Species-specific factors were also associated with the elevational changes: species were more likely to shift elevational ranges if they had small clutch sizes, defended all-purpose territories (i.e., where courtship, mating nesting, foraging all occurred), and were non-migratory. The greatest changes to composition of montane bird communities occurred in the highest and lowest elevations (Tingley and Beissinger, 2013).

Birds have also been shown to respond to warming by breeding earlier to reduce the temperatures to which nests are exposed during breeding and to track shifting peaks in the availability of resources (Socolar et al., 2017). Using data from the Grinnell



Resurvey Project, researchers found that breeding dates in the Sierra Nevada and the Coast Range (from the Oregon border to north of San Luis Obispo) shifted 5 to 12 days earlier over the last century. These findings suggest that earlier breeding might reduce both the need and the opportunity to shift geographically.

A group of researchers have studied biogeographic responses in birds, mammals, butterflies, and plants in California along with regional patterns of climate data during the 20th century to better understand species responses to a warming climate (Rapacciuolo et al., 2014). Although the expected response with warming is upward elevational shifts, they describe how downslope shifts are as common as upslope shifts. One common finding (noted above) was contractions of lower limits of high-elevation mammal species occurring primarily in response to warmer temperatures. They suggested that the substantial heterogeneity in response to warming with low elevation species may be due to influences such as interspecific competition and the spread of invasive species. In addition to temperature alone, species responses were also reportedly affected by the shifting seasonal balance of temperature and precipitation (water availability). They found that species-specific sensitivities to local-scale trophic interactions and habitat changes can also influence range shift dynamics, highlighting a need to adopt a more multifaceted and finer-scale understanding of climate change impacts.

The topography of a habitat can play a role in how an animal is impacted by climate change. Topographically complex areas provide potential climate change “refugia” whereas low-relief topography can exacerbate climate change impacts as organisms must travel further to remain in the same climate space (Maher et al., 2017). Mountains provide an extremely important climate refuge for many species because the rate of displacement required to track climate is low (i.e., they can disperse relatively short distances upslope to track favorable environmental conditions). However, species that already occur near mountaintops are among the most threatened by climate change because they cannot move upwards. The consequences of losing favorable climate space are not yet well understood (IPCC, 2014).

In addition to topographic influences, research suggests that climate change effects on montane animals during the 20th century in California may have been largely affected by changes in vegetation rather than, or in addition to, direct physiological effects (Rapacciuolo et al., 2014), although warming winter temperatures are sometimes clearly important (Morelli et al., 2012). Substantial vegetation changes within the Central region (Yosemite National Park) have occurred since the early 1900's due to a number of factors, including fires, fire suppression efforts, and temperature changes. Of the 23 small mammal species in Yosemite National Park, 11 shifted their elevational ranges in the same direction as shifts in vegetation, six species shifted in a different direction, and the rest showed no relationship (Santos et al., 2015). Species that shifted in the same direction as vegetation were mostly inhabitants of low to intermediate elevations, while species that shifted in different direction inhabited high elevations. Vegetation change appears to directly affect some of the changes in the range of small mammals. For example, the expansion of the upper limit of the ranges of the California pocket mouse and the Piñon mouse (on the west slope) can be attributed to stand-replacing fires in the lower areas of the park. The large downwards shift in the elevation of the Montane shrew is probably related to its preference for wet meadows and the recovery of wet meadow systems in Yosemite Valley, following cessation of grazing and intense restoration efforts (Moritz et al., 2008).

Tribal Connection 4.9.2

The Bishop and Big Pine Paiute Tribes of Payahuunadü (Payahuunadü is also known as the Owens Valley) both note a decline in rabbit populations, especially black-tailed jackrabbits and in cottontails, as well as birds such as yellow-headed black bird, red-winged black bird, and swallows. (Big Pine Paiute Tribe, 2026; Bishop Paiute Tribe, 2026). Rabbits are an important form of sustenance for Tribal members, and bird feathers have served a central role in cultural regalia. The Tribes attribute the loss of these species primarily to drought and loss of vegetation, as both a food and water source for the animals. Continuing up the food chain, both Tribes have noticed a decline in predators of these species, such as eagles, and an increase in non-native species such as barred owls taking their place.

Technical considerations

Data characteristics

Resurveys of small mammals and birds were conducted between 2003 through 2010 along three elevational transects in the Sierra Nevada Mountains that spanned four National Parks (see map above) and numerous other state, federal and private land holdings. The surveys revisited sites that were originally studied between 1911-1920 by Joseph Grinnell and staff of the Museum of Vertebrate Zoology (MVZ), University of California at Berkeley (Grinnell, 1930). The resurveys provide updated information on habitat and community changes at each site over the past century, while documenting the presence as well as ranges (geographic and habitat) of species of special concern to the lay and scientific communities. Detailed information on the Grinnell Resurvey Project can be found at: http://mvz.berkeley.edu/Grinnell/index.html.

Small mammal surveys were conducted at 166 locations: 38 in the Northern, 81 in the Central and 47 in the Southern region. Species were categorized as low elevation, high elevation or widespread for purposes of observing how species at different elevations respond. Statistical analyses of range shifts were restricted to 34 species that were detected at more than 10% of sites for at least one region in both eras. Details can be found in Rowe et al. (2015).

The resurvey of bird species for the three regions was conducted during breeding season. Observers collected data with temporal sampling as follows: Lassen, 2006-07; Yosemite, 2003-04; Southern Sierra, 2008-09. A total of 251 modern surveys were conducted at 84 sites, with each site surveyed a maximum of 5 times. Over 87% of the survey sites were located on permanently protected lands. All sites contained “west slope Sierran” vegetation communities. Habitat descriptions were matched to historic field notes wherever possible. The data from this resurvey can be found at: http://arctos.database.museum. Details can be found in Tingley et al. (2012).

Strengths and limitations of the data

Detailed maps and field notes from the Grinnell investigators facilitated the relocation of actual sites, transects and trap lines. The position of all generalized sites, based on documentation of the actual campsite, has been reasonably well established.

Substantial differences in small mammal survey methodologies between the two survey periods may result in biases in trapability. The Grinnell team used shotguns and snap traps for all mammal surveys, while the recent survey used live traps. To assess the comparability of survey success for each species across the time periods, statistical ("Occupancy") analyses were conducted. For the 34 species of small mammals considered above, detectability probabilities were sufficiently high across the survey periods to yield robust results. The analysis of changes in elevational range of mammals incorporates differences in detectability between study periods.

Natural year-to-year fluctuations in species' abundances may affect the detection of particularly rare species, and hence the comparisons between the study periods.

For purposes of examining possible climate change impacts on species shifts, field surveys were conducted in protected areas where other human influences (e.g., land use changes) were limited.

OEHHA acknowledges the expert contribution of the following to this report:

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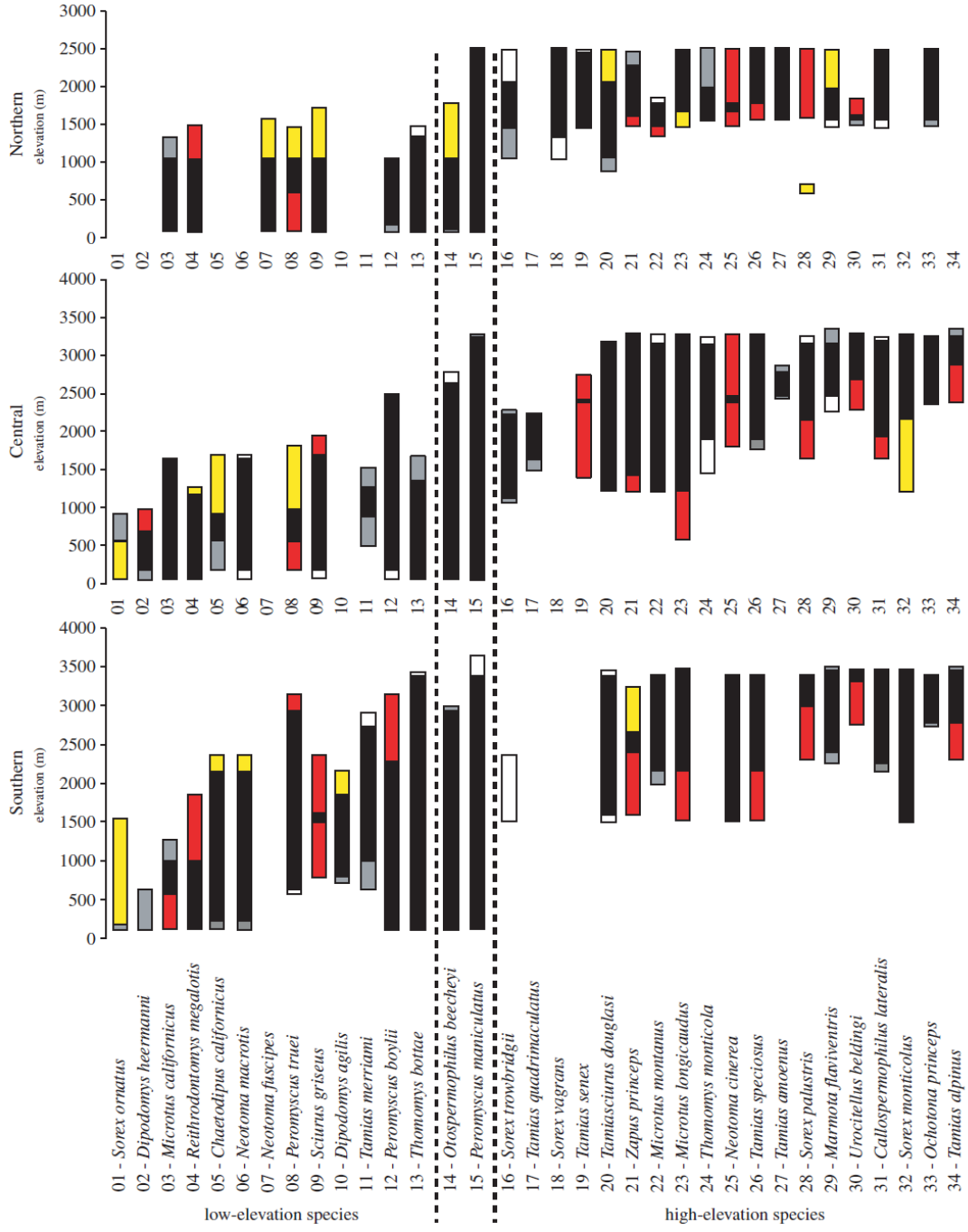
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APPENDIX

Figure 4.9.A-1 Small mammal range limit shifts, by species*



Red bars — range contractions; yellow bars — range expansions: gray bars — non-significant contractions; white bars — non-significant expansions (white); black bars — historic range. (Lack of a bar indicates that species is not found in that region.)

**List of common names follows.*

Source: Modified from Rowe et al., 2015

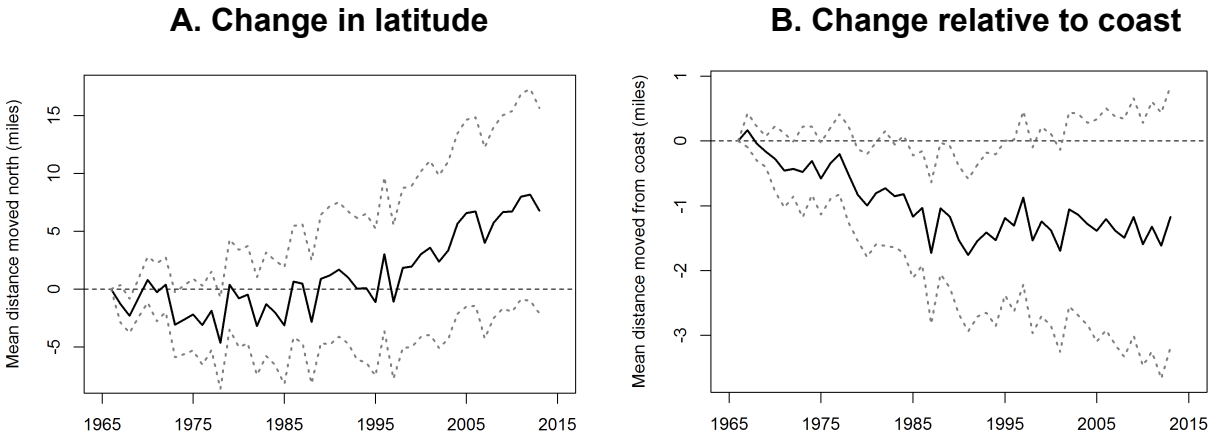
Common names for the species listed in Figure 4.9.A-1 are as follows:

01 *Sorex ornatus* (Ornate shrew)
02 *Dipodomys heermanni* (Heermann's kangaroo rat)
03 *Microtus californicus* (Amargosa vole)
04 *Reithrodontomys megalotis* (Western harvest mouse)
05 *Chaetodipus californicus* (California pocket mouse)
06 *Neotoma macrotis* (Big-eared woodrat)
07 *Neotoma fuscipes* (Dusky-footed woodrat)
08 *Peromyscus truei* (Pinyon mouse)
09 *Sciurus griseus* (Western gray squirrel)
10 *Dipodomys agilis* (Agile kangaroo rat)
11 *Tamias merriami* (Merriam's chipmunk)
12 *Peromyscus boylii* (Brush mouse)
13 *Thomomys bottae* (Botta's pocket gopher)
14 *Otospermophilus beecheyi* (California ground squirrel)
15 *Peromyscus maniculatus* (Deer mouse)
16 *Sorex trowbridgii* (Trowbridge's shrew)
17 *Tamias quadrimaculatus* (Long-eared chipmunk)
18 *Sorex vagrans* (Vagrant shrew)
19 *Tamias senex* (Allen's chipmunk)
20 *Tamiasciurus douglasii* (Douglas' squirrel)
21 *Zapus princeps* (Western jumping mouse)
22 *Microtus montanus* (Montane vole)
23 *Microtus longicaudus* (Long-tailed vole)
24 *Thomomys monticola* (Mountain pocket gopher)
25 *Neotoma cinerea* (Bushy-tailed woodrat)
26 *Tamias speciosus* (Lodgepole chipmunk)
27 *Tamias amoenus* (Yellow-pine chipmunk)
28 *Sorex palustris* (American water shrew)
29 *Marmota flaviventris* (Yellow-bellied marmot)
30 *Urocitellus beldingi* (Belding's ground squirrel)
31 *Callospermophilus lateralis* (Golden-mantled ground squirrel)
32 *Sorex monticolus* (Dusky shrew)
33 *Ochotona princeps* (American pika)
34 *Tamias alpinus* (Alpine chipmunk)

4.10 Bird Wintering Ranges (No Update)

Over the past 48 years, wintering bird species have collectively shifted their range northward and closer to the coast in California.

Figure 4.10.1. Changes in Wintering Bird Abundance in California (1966–2013).



Note: The dashed lines show the likely range of each year's values based on the number of observations and the precision of the methods used.

Source: Michel et al. (2017)

What does the indicator show?

This indicator examines changes in the ranges of 234 migratory and resident wintering California bird species between 1966 and 2013 and shows, in aggregate, a shift northward. Data for this indicator is the California subset of observations from the Christmas Bird Count (CBC), managed by the National Audubon Society. The CBC consists of observations recorded from December 14 to January 5 each year by over 50,000 volunteers across the Western Hemisphere, following a specified methodology. It is the longest-running census of birds that relies on public participation and collaboration (often referred to as "citizen science").

The graphs show the position of the center of abundance (the center of population distribution) for each year relative to the winter of 1965–1966, averaged across the

species for latitude (**Figure 4.10.1A**) and for distance from the coast (**Figure 4.10.1B**). An overall northward movement of about seven miles was observed between 1966 and 2013, as birds moved farther north than south (**Figure 4.10.1A**). Over the same period, a shift of approximately 1 mile toward the coast occurred (**Figure 4.10.1B**).

The center of abundance is a common way to characterize the general location of a population. In terms of latitude, half of the individuals in the population live north of the center of abundance and the other half live to the south. Similarly, in terms of distance to coast, half of the individuals live closer to the coast than the center of abundance, and the other half live further from the coast.

Why is this indicator important?

Monitoring changes in the geographic distribution of birds provides scientists with a way to track which birds may be responding to a changing climate — one of many factors that are threatening bird populations. A better understanding of these responses will help inform conservation strategies. As the climate continues to change, its pace may exceed many bird species' capacities to migrate to more favorable habitats (La Sorte and Jetz, 2012). The predicted increase in extreme weather events, such as severe storms, might also impact the ability of birds to make these range shifts. Birds that cannot adapt to changing conditions could experience a population decline as a result.

Birds are a particularly good indicator of environmental change for several reasons:

- Each species of bird has adapted or evolved to favor certain habitat types, food sources, and temperature ranges. In addition, the timing of certain events in their life cycles — such as migration and reproduction — is driven by cues from the environment. For example, many North American breeding birds follow a regular seasonal migration pattern; moving north to feed and breed in the summer, then moving south to spend the winter in warmer areas. Changing conditions can influence the distribution of both migratory and non-migratory birds as well as the timing of important life cycle events (La Sorte and Thompson, 2007).
  Birds are relatively easy to identify and count, and thus there is a wealth of scientific knowledge about their distribution and abundance. People have kept detailed records of bird observations for more than a century.

- There are many different species of birds living in a variety of habitats, including water birds, coastal birds, and land birds. If a change in behavior or range occurs across a range of bird types, it suggests that a common external factor might be the cause.

When bird wintering ranges shift, human and ecological communities lose not just the birds themselves, but also the valuable functions and services they provide. For example, western bluebirds eat insects that damage crops, nectar-eating birds like hummingbirds pollinate flowers, and birds like woodpeckers build roosting cavities in trees that other bird and mammal species use (Jedlicka et al., 2011; Kearns et al., 1998; Sekercioglu, 2006). The movement of a species to places where it was not previously present, or where it was present in lower numbers, may also disrupt complex ecosystem interactions. For example, a newcomer species may compete for food or other resources with species that already inhabit the area (Kearns and Inouye, 1997).

What factors influence this indicator?

In the Northern Hemisphere, a changing climate has been associated with shifts in the habitat ranges of certain animals toward more northern latitudes and higher elevations (Field et al., 2014; Moritz et al., 2008; Ralston et al., 2016). Warming temperatures may cause species to expand their wintering ranges further north into regions that were, until recently, too cold to support populations, and away from regions that are now too hot.

A continental-scale analysis of 305 bird species found that their wintering ranges moved approximately 40 miles north between 1966 and 2013, and that this change was related to warming winter temperatures (National Audubon Society, 2009; USEPA, 2016).

The movement of species toward the coast in California is the opposite of both what was expected and what was observed in the continental-scale study. The latter analysis found that bird wintering ranges moved about 13 miles away from the coast — a shift associated with a warming climate and a decrease of extreme cold inland. In California, in contrast, birds moved closer to the coast as temperatures increased. The California trend may be the result of the combined influence of climate and topography. Inland areas of the state, already drier compared to the coast, are further drying due to

warming temperatures, causing birds to move towards the coast to seek wetter conditions.

Both the continental and the California analysis found no significant longitudinal movement. This is not surprising given that there are no clear longitudinal gradients in temperature or precipitation, which instead vary in response to topographical features (e.g., elevation or location relative to mountain ranges).

Latitudinal range movement varied among the California species: 87 species (37%) moved northward, 74 species (32%) moved southward, and 73 (31%) showed no significant change. Some bird species moved farther than others. Snow goose showed the greatest northward shift of 326 miles, while Ross' goose showed the greatest southward shift of 242 miles. Similarly, distance shifted relative to the coast ranged from 84 miles towards the coast by Canada goose to 60 miles inland by Barrow's goldeneye. Eighty-six species (37%) moved towards the coast, while 86 other species moved inland and 62 (26%) showed no significant change. While equal numbers of species moved inland and towards the coast, the range shifts towards the coast involved greater distances than inland, resulting in an overall shift toward the coast. These differences in range shifts are not surprising. Species have been found to respond to environmental change in a highly variable and idiosyncratic fashion, reflecting the complex interplay between land cover, climate, species interactions, and other factors.

Many factors can influence bird ranges, including food availability, habitat alteration, and interactions with other species, and these factors may also be influenced by climate change. Some of the birds covered in this indicator might have moved northward or inland for reasons other than changing temperatures. Responses to climate change may also vary among different types of birds. However, within California, there were no differences in average movements north or towards the coast between birds differing in habitat use, diet, body size, life expectancy, clutch size, age at sexual maturity, or urban affiliation. Though moderate- and short-distance migrants moved slightly further north than year-round residents, migratory status did not influence movement towards the coast.

Technical considerations

Data characteristics

This indicator is based on data collected by the annual Christmas Bird Count (CBC), managed by the National Audubon Society. Data are collected in a citizen science activity by volunteer birdwatchers who systematically survey certain areas and identify and count all bird species they encounter within a specified area. Bird surveys take place each year in approximately 2,000 different locations throughout the contiguous 48 states and the southern portions of Alaska and Canada. This indicator used only data from CBC circles within the state of California. All local counts take place between December 14 and January 5 of each winter. Each local count takes place over a 24-hour period in a defined "count circle" that is 15 miles in diameter. A variable number of volunteer observers separate into field parties which survey different areas of the count circle and tally the total number of individuals of each species observed (National Audubon Society, 2009).

CBC data starting in 1966 are used, as data prior to 1966 lack sufficient quality and quantity for a North American-scaled analysis. At the end of the 24-hour observation period, each count circle tallies the total number of individuals of each species seen in the count circle. Audubon scientists then run the data through several levels of analysis and quality control to determine final count numbers from each circle and each region. Data processing steps include corrections for different levels of sampling effort — for example, if some count circles had more observers and more person-hours of effort than others. Population trends over the 48-year period of this indicator and annual indices of abundance were estimated for the entire survey area with hierarchical models in a Bayesian analysis using Markov chain Monte Carlo techniques (Soykan et al., 2016).

This indicator covers 234 bird species, listed in **Table 4.10.A-1**. These species were included because they are widespread, occur within California, and meet specific criteria for data availability. Information on study methods is available on the National Audubon Society website and in Soykan et al. (2016). Methods are largely based on those used for an earlier analysis, which is documented in the National Audubon Society (2009) report: *Northward Shifts in the Abundance of North American Birds in*

Early Winter: A Response to Warmer Winter Temperatures? For additional information on CBC survey design and methods, see Soykan et al. (2016) and the reports classified as "Methods" in the list at the National Audubon Society (website).

Strengths and limitations of the data

Although the indicator relies on human observation rather than precise measuring instruments, the people who collect the data are skilled observers who follow strict protocols that are consistent across time and space. These data have supported many peer-reviewed studies, a list of which can be found on the National Audubon Society's (website).

Uneven effort between count circles, such as inconsistent level of effort by volunteer observers, could lead to data variations. However, these differences are carefully corrected in Audubon's statistical analysis (Soykan et al., 2016). Rare or difficult-to-observe bird species could lead to increased variability. Gregarious species (i.e., species that tend to gather in large groups) can also be difficult to count, and they could be either overcounted or undercounted, depending on group size and the visibility of their roosts. These species tend to congregate in known and expected locations along CBC routes, however, so observers virtually always know to check these spots. Locations with large roosts are often assigned to observers with specific experience in estimating large numbers of birds. For this analysis, the National Audubon Society included only 234 widespread bird species that met criteria for abundance and the availability of data to enable the detection of meaningful trends.

The tendency for saltwater-dependent species to stay near coastlines could impact the change in distance to coast calculation for species living near the Pacific Ocean. By integrating these species into the distance to coast calculation, **Figure 4.10.1B** may understate the total extent of coastward or inland movement of species.

This indicator is based solely on shifts in the center of abundance of birds observed within the state of California. As a result, it represents only a small portion of the wintering range of many species and may either overestimate or underestimate distances move across the species' entire wintering ranges.

Figures 4.10.1A and **4.10.1B** show average distances moving north and towards the coast, based on an unweighted average of all species. Thus, no adjustments are made for population differences across species. No attempt was made to estimate trends prior to 1966 (i.e., prior to the availability of complete spatial coverage and standardized methods), and no attempt was made to project trends into the future. The entire study description, including analyses performed, can be found in National Audubon Society (2009), Soykan et al. (2016), and references therein. Information on this study is also available on the National Audubon Society website.

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Appendix

Table 4.10.A-1. Bird Species Included in the California wintering bird range shift climate change indicator analysis.

Common name	Scientific name
Acorn Woodpecker	*Melanerpes formicivorus*
American Avocet	*Recurvirostra americana*
American Bittern	*Botaurus lentiginosus*
American Coot	*Fulica americana*
American Crow	*Corvus brachyrhynchos*
American Dipper	*Cinclus mexicanus*
American Goldfinch	*Spinus tristis*
American Kestrel	*Falco sparverius*
American Pipit	*Anthus rubescens*
American Robin	*Turdus migratorius*
American Wigeon	*Anas americana*
Anna's Hummingbird	*Calypte anna*
Arctic and Pacific Loon¶	*Gavia arctica and G. pacifica*
American Tree Sparrow	*Spizelloides arborea*
American White Pelican	*Pelecanus erythrorhynchos*
Bald Eagle	*Haliaeetus leucocephalus*
Baltimore Oriole	*Icterus galbula*
Band-tailed Pigeon	*Patagioenas fasciata*
Barrow's Goldeneye	*Bucephala islandica*
Barn Owl	*Tyto alba*
Bell's and Sagebrush Sparrow††	*Amphispiza belli and A. nevadensis*
Belted Kingfisher	*Megaceryle alcyon*
Bewick's Wren	*Thryomanes bewickii*
Black-and-white Warbler	*Mniotilta varia*
Black-bellied Plover	*Pluvialis squatarola*
Black-billed Magpie	*Pica hudsonia*
Black-capped Chickadee	*Poecile atricapillus*
Black-crowned Night-Heron	*Nycticorax*
Blue-gray Gnatcatcher	*Polioptila caerulea*
Blue-headed, Cassin's, and Plumbeous Vireo‡‡‡	*Vireo solitarius, V. cassini, and V. plumbeus*
Blue-winged Teal	*Anas discors*
Brown-headed Cowbird	*Molothrus ater*
Black Brant	*Branta b. nigricans*
Black Phoebe	*Sayornis nigricans*
Black Rail	*Laterallus jamaicensis*
Black Scoter	*Melanitta americana*
Black Turnstone	*Arenaria melanocephala*
Black-necked Stilt	*Himantopus mexicanus*
Bonaparte's Gull	*Chroicocephalus philadelphia*

Common name	Scientific name
Brewer's Blackbird	*Euphagus cyanocephalus*
Brown Creeper	*Certhia americana*
Bufflehead	*Bucephala albeola*
Burrowing Owl	*Athene cunicularia*
Bushtit	*Psaltriparus minimus*
Cackling and Canada Goose	*Branta hutchinsii and B. canadensis*
Cactus Wren	*Campylorhynchus brunneicapillus*
California and Canyon/Brown Towhee[#]	*Melozone crissalis and M. fuscus*
California Gull	*Larus californicus*
California Quail	*Callipepla californica*
Canvasback	*Aythya valisineria*
Canyon Wren	*Catherpes mexicanus*
Caspian Tern	*Hydroprogne caspia*
Cassin's Finch	*Haemorhous cassinii*
Cattle Egret	*Bubulcus ibis*
Cedar Waxwing	*Bombycilla cedrorum*
Chestnut-backed Chickadee	*Poecile rufescens*
Chipping Sparrow	*Spizella passerina*
Chukar	*Alectoris chukar*
Cinnamon Teal	*Anas cyanoptera*
Clapper Rail	*Rallus crepitans*
Clark's Nutcracker	*Nucifraga columbiana*
Clark's and Western Grebe[§§§]	*Aechmophorus clarkii and A. occidentalis*
Common Goldeneye	*Bucephala clangula*
Common Ground-Dove	*Columbina passerina*
Common Loon	*Gavia immer*
Common Merganser	*Mergus merganser*
Common Moorhen	*Gallinula galeata*
Common Murre	*Uria aalge*
Common Raven	*Corvus corax*
Common Yellowthroat	*Geothlypis trichas*
Cooper's Hawk	*Accipiter cooperii*
Dark-eyed Junco	*Junco h. hyemalis*
Double-crested Cormorant	*Phalacrocorax auritus*
Downy Woodpecker	*Picoides pubescens*
Dunlin	*Calidris alpina*
Eared Grebe	*Podiceps nigricollis*
Eastern and Spotted Towhee[‡‡]	*Pipilo erythrophthalmus and P. maculatus*
Eastern and Western Screech-Owl[¶¶¶]	*Megascops asio and M. kennicottii*
European Starling	*Sturnus vulgaris*
Evening Grosbeak	*Coccothraustes vespertinus*
Ferruginous Hawk	*Buteo regalis*
Forster's Tern	*Sterna forsteri*
Fox Sparrow	*Passerella iliaca*
Gadwall	*Anas strepera*

Common name	Scientific name
Gambel's Quail	*Callipepla gambelii*
Glaucous Gull	*Larus hyperboreus*
Glaucous-winged Gull	*Larus glaucescens*
Golden Eagle	*Aquila chrysaetos*
Golden-crowned Kinglet	*Regulus satrapa*
Golden-crowned Sparrow	*Zonotrichia atricapilla*
Gray Jay	*Perisoreus canadensis*
Great Blue Heron	*Ardea herodias*
Great Egret	*Ardea alba*
Great Horned Owl	*Bubo virginianus*
Greater Roadrunner	*Geococcyx californianus*
Greater Scaup	*Aythya marila*
Greater White-fronted Goose	*Anser albifrons*
Greater Yellowlegs	*Tringa melanoleuca*
Green Heron	*Butorides virescens*
Green-tailed Towhee	*Pipilo chlorurus*
Green-winged Teal	*Anas crecca*
Hairy Woodpecker	*Picoides villosus*
Harlequin Duck	*Histrionicus histrionicus*
Harris's Sparrow	*Zonotrichia querula*
Hermit Thrush	*Catharus guttatus*
Herring Gull	*Larus argentatus*
Hooded Merganser	*Lophodytes cucullatus*
Horned Grebe	*Podiceps auritus*
Horned Lark	*Eremophila alpestris*
House Finch	*Haemorhous mexicanus*
House Sparrow	*Passer domesticus*
House Wren	*Troglodytes aedon*
Hutton's Vireo	*Vireo huttoni*
Iceland and Thayer's Gull §	*Larus glaucoides and L. thayeri*
Inca Dove	*Columbina inca*
Juniper and Oak Titmouse##	*Baeolophus ridgwayi and B. inornatus*
Killdeer	*Charadrius vociferus*
Ladder-backed Woodpecker	*Picoides scalaris*
Lapland Longspur	*Calcarius lapponicus*
Lark Sparrow	*Chondestes grammacus*
Least Bittern	*Ixobrychus exilis*
Least Sandpiper	*Calidris minutilla*
Lesser Goldfinch	*Spinus psaltria*
Lesser Scaup	*Aythya affinis*
Lesser Yellowlegs	*Tringa flavipes*
Lewis's Woodpecker	*Melanerpes lewis*
Lincoln's Sparrow	*Melospiza lincolnii*
Little Blue Heron	*Egretta caerulea*
Loggerhead Shrike	*Lanius ludovicianus*

Common name	Scientific name
Long-billed Dowitcher	*Limnodromus scolopaceus*
Long-eared Owl	*Asio otus*
Long-tailed Duck	*Clangula hyemalis*
Marbled Godwit	*Limosa fedoa*
Marbled Murrelet	*Brachyramphus marmoratus*
Marsh Wren	*Cistothorus palustris*
Merlin	*Falco columbarius*
Mew Gull	*Larus canus*
Mountain Bluebird	*Sialia currucoides*
Mountain Chickadee	*Poecile gambeli*
Mourning Dove	*Zenaida macroura*
Nashville Warbler	*Oreothlypis ruficapilla*
Northern Cardinal	*Cardinalis cardinalis*
Northern Goshawk	*Accipiter gentilis*
Northern Harrier	*Circus cyaneus*
Northern Flicker	*Colaptes a. cafer*
Northern Mockingbird	*Mimus polyglottos*
Northern Pintail	*Anas acuta*
Northern Pygmy-Owl	*Glaucidium gnoma*
Northern Saw-whet Owl	*Aegolius acadicus*
Northern Shoveler	*Anas clypeata*
Northern Shrike	*Lanius excubitor*
Orange-crowned Warbler	*Oreothlypis celata*
Osprey	*Pandion haliaetus*
Palm Warbler	*Setophaga palmarum*
Pelagic Cormorant	*Phalacrocorax pelagicus*
Peregrine Falcon	*Falco peregrinus*
Pied-billed Grebe	*Podilymbus podiceps*
Pileated Woodpecker	*Dryocopus pileatus*
Pine Siskin	*Spinus pinus*
Pinyon Jay	*Gymnorhinus cyanocephalus*
Prairie Falcon	*Falco mexicanus*
Purple Finch	*Haemorhous purpureus*
Pygmy Nuthatch	*Sitta pygmaea*
Red Crossbill	*Loxia curvirostra*
Redhead	*Aythya americana*
Red Knot	*Calidris canutus*
Red-breasted Merganser	*Mergus serrator*
Red-breasted Nuthatch	*Sitta canadensis*
Red-necked Grebe	*Podiceps grisegena*
Red-shouldered Hawk	*Buteo lineatus*
Red-winged Blackbird	*Agelaius phoeniceus*
Ring-billed Gull	*Larus delawarensis*
Ring-necked Duck	*Aythya collaris*
Ring-necked Pheasant	*Phasianus colchicus*

Common name	Scientific name
Rock Sandpiper	*Calidris ptilocnemis*
Rock Wren	*Salpinctes obsoletus*
Ross's Goose	*Chen rossii*
Rough-legged Hawk	*Buteo lagopus*
Royal Tern	*Thalasseus maximus*
Ruby-crowned Kinglet	*Regulus calendula*
Ruddy Turnstone	*Arenaria interpres*
Rufous-crowned Sparrow	*Aimophila ruficeps*
Sanderling	*Calidris alba*
Sandhill Crane	*Antigone canadensis*
Savannah Sparrow	*Passerculus sandwichensis*
Say's Phoebe	*Sayornis saya*
Semipalmated Plover	*Charadrius semipalmatus*
Sharp-shinned Hawk	*Accipiter striatus*
Short-billed Dowitcher	*Limnodromus griseus*
Short-eared Owl	*Asio flammeus*
Snow Goose	*Chen caerulescens*
Snowy Egret	*Egretta thula*
Snowy Plover	*Charadrius nivosus*
Song Sparrow	*Melospiza melodia*
Sora	*Porzana carolina*
Spotted Sandpiper	*Actitis macularius*
Steller's Jay	*Cyanocitta stelleri*
Surfbird	*Calidris virgata*
Surf Scoter	*Melanitta perspicillata*
Swamp Sparrow	*Melospiza georgiana*
Townsend's Solitaire	*Myadestes townsendi*
Townsend's Warbler	*Setophaga townsendi*
Tree Swallow	*Tachycineta bicolor*
Tricolored Heron	*Egretta tricolor*
Tundra Swan	*Cygnus columbianus*
Turkey Vulture	*Cathartes aura*
Varied Thrush	*Ixoreus naevius*
Verdin	*Auriparus flaviceps*
Vermilion Flycatcher	*Pyrocephalus rubinus*
Vesper Sparrow	*Pooecetes gramineus*
Virginia Rail	*Rallus limicola*
Western Bluebird	*Sialia mexicana*
Western Meadowlark	*Sturnella neglecta*
Western Scrub-Jay	*Aphelocoma californica*
Whimbrel	*Numenius phaeopus*
White-breasted Nuthatch	*Sitta carolinensis*
White-crowned Sparrow	*Zonotrichia leucophrys*
White-tailed Kite	*Elanus leucurus*
White-throated Sparrow	*Zonotrichia albicollis*

Common name	Scientific name
White-winged Dove	*Zenaida asiatica*
White-winged Scoter	*Melanitta fusca*
Wild Turkey	*Meleagris gallopavo*
Willet	*Tringa semipalmata*
Williamson's Sapsucker	*Sphyrapicus thyroideus*
Wilson's Snipe	*Gallinago delicata*
Wilson's Warbler	*Cardellina pusilla*
Winter Wren	*Troglodytes hiemalis*
Wood Duck	*Aix sponsa*
Yellow-bellied Sapsucker	*Sphyrapicus varius*
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*
Yellow-rumped Warbler	*Setophaga coronata*

Notes:

Since the Cackling and Canada Goose (*Branta hutchinsii* and *B. canadensis*) were not distinguished in CBC counts until after 1966, the two species were lumped for trend analyses.

§ Since the Iceland and Thayer's Gull (*Larus glaucoides and L. thayeri*) were not distinguished in CBC counts until after 1966, the two species were lumped for trend analyses.

¶ Since the Arctic and Pacific Loon (*Gavia arctica* and *G. pacifica*) were not distinguished in CBC counts until after 1966, the two species were lumped for trend analyses.

Since the California and Canyon/Brown Towhee (*Melozone crissalis* and *M. fuscus*) were not distinguished in CBC counts until after 1966, the two species were lumped for trend analyses.

‡‡ Since the Eastern and Spotted Towhee (*Pipilo erythrophthalmus* and *P. maculatus*) were not distinguished in CBC counts until after 1966, the two species were lumped for trend analyses.

†† Since the Bell's and Sagebrush Sparrow (*Amphispiza belli* and *A. nevadensis*) were not distinguished in CBC counts until after 1966, the two species were lumped for trend analyses.

Since the Juniper and Oak Titmouse (*Baeolophus ridgwayi* and *B. inornatus*) were not distinguished in CBC counts until after 1966, the two species were lumped for trend analyses.

‡‡‡ Since the Blue-headed, Cassin's, and Plumbeous Vireo (*Vireo solitarius*, *V. cassini*, and *V. plumbeus*) were not distinguished in CBC counts until after 1966, the three species were lumped for trend analyses.

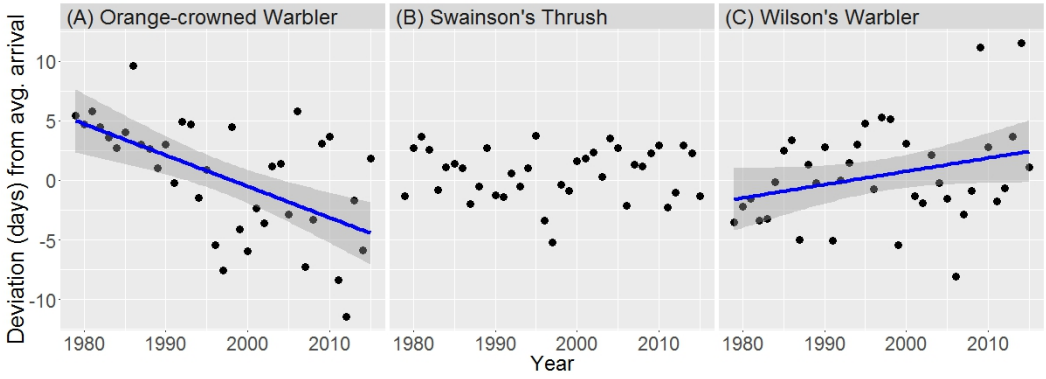
§§§ Since the Clark's and Western Grebe (*Aechmophorus clarkii* and *A. occidentalis*) were not distinguished in CBC counts until after 1966, the two species were lumped for trend analyses.

¶¶¶ Since the Eastern and Western Screech-Owl (*Megascops asio* and *M. kennicottii*) were not distinguished in CBC counts until after 1966, the two species were lumped for trend analyses.

4.11 Migratory Bird Arrivals (No Update)

Migratory songbird species are showing a diversity of changes in arrival dates. Of the three species studied that arrive at a coastal California site in the spring, two are showing opposite trends in timing (one shows no significant change). Of the four species that arrive in the fall, two have been arriving earlier over the past 36 years, while one has been showing a trend toward earlier arrival since 1995. The fourth species shows no significant change.

Figure 4.11.1. Annual Arrival Dates, 3 Spring Migrant Species at Palomarin Field Station, 1979–2015.



Orange-crowned Warbler



Swainson's Thrush



Wilson's Warbler



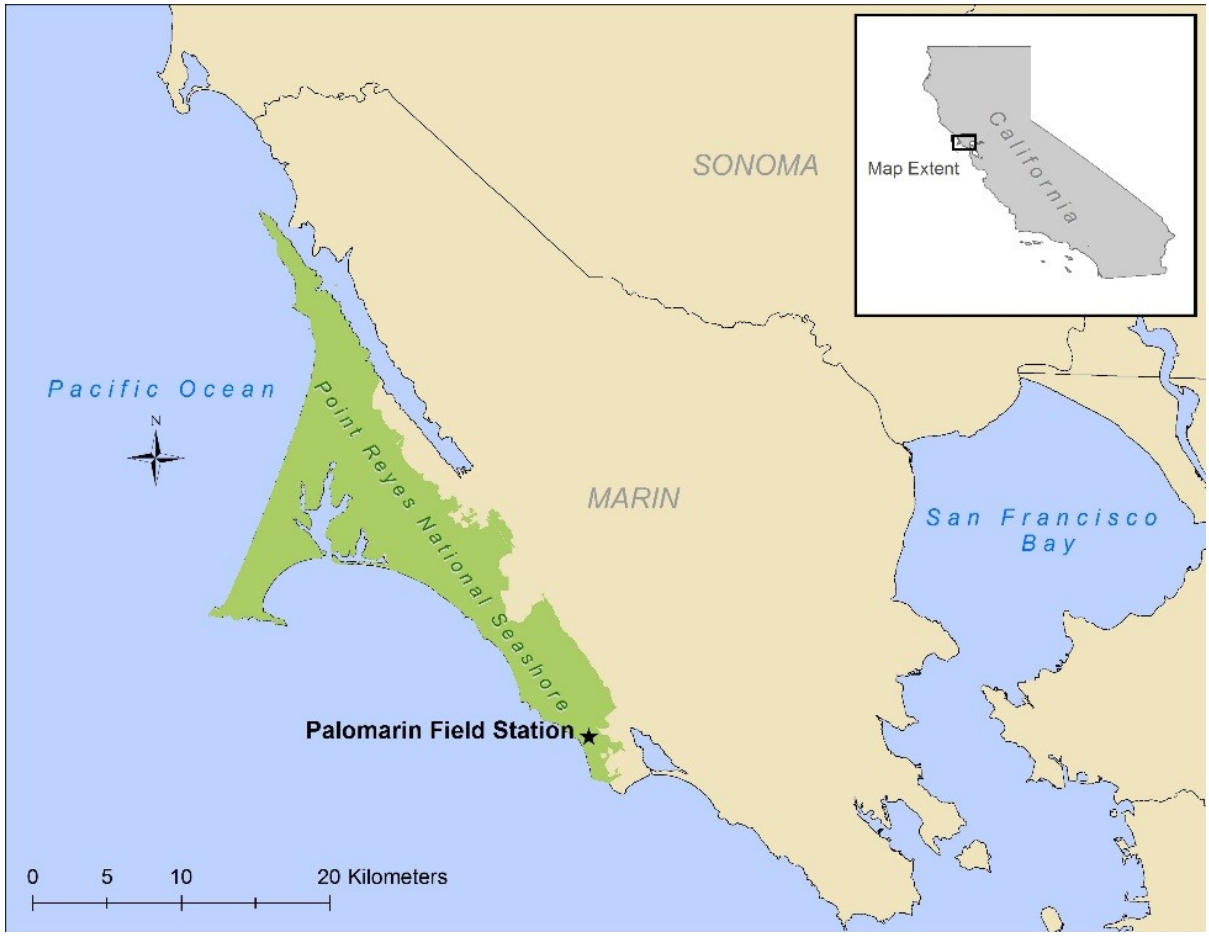
Deviation (in days) from the overall mean spring arrival date for that species is shown for each year. Significant linear trend shown for (A) and (C); shading shows confidence interval. No significant trend in (B).

Photo credits (left to right): Rich Stallcup, Point Blue; Ian Tait, Point Blue; Rich Stallcup

What does the indicator show?

Trends in spring and fall arrival dates of birds migrating to their breeding grounds in the spring (**Figure 4.11.1**) and their wintering grounds in the fall (**Figure 4.11.3**) differ among seven species of songbirds that spend part of the year at the Point Blue Conservation Science's Palomarin Field Station in Point Reyes National Seashore, Marin County, California (see **Figure 4.11.2**). Arrival dates are based on a 36-year record of observations at this location, where the habitat is a mix of coastal scrub and mixed-evergreen hardwood forest with encroaching Douglas-fir forest.

Figure 4.11.2. Map Showing Location of Palomarin Field Station.



Source: Point Blue Conservation Science (2016)

As shown in **Figure 4.11.1**, of the spring species migrating to their breeding grounds, the Wilson's Warbler (*Wilsonia pusilla*) has been arriving later (1.1 days later per decade), while the Orange-crowned Warbler (*Oreothlypis celata*) has been trending towards earlier arrivals (2.6 days earlier per decade) over the past 36 years. No significant trend was observed for the Swainson's Thrush (*Catharus ustulatus*).

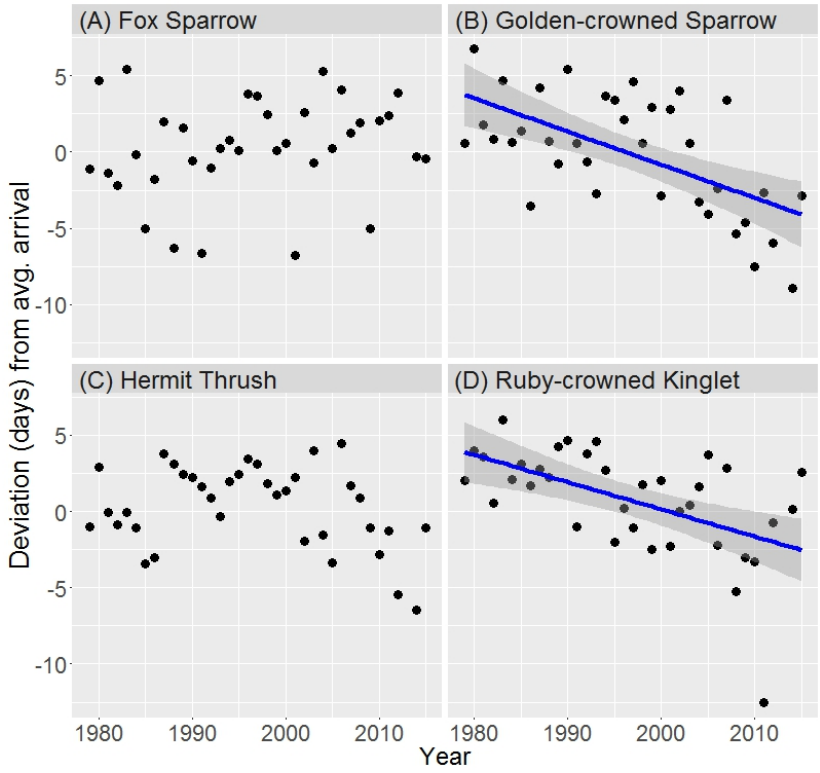
Figure 4.11.3 shows that, among species migrating to their wintering grounds in the fall, the Ruby-crowned Kinglet (*Regulus calendula*) and the Golden-crowned Sparrow (*Zonotrichia atricapilla*) have been arriving earlier (1.8 and 2.1 days per decade, respectively) since 1980. The overall linear trend over the 36-year period is not significant for the Hermit Thrush (*Catharus guttatus*); however, the data show a trend toward earlier arrival beginning in 1995. This response is similar to that of the Golden-crowned Sparrow, which has been arriving at increasingly earlier dates (the data show a significant acceleration in the past two decades). The Fox Sparrow (*Passerella iliaca*) shows no significant linear trend.

Globally, a general trend of earlier arrival of birds migrating in the spring has been reported, associated with warming temperatures and the earlier onset of spring and with it, the emergence of the plant and insect resources the birds rely on (Hurlbert and Liang, 2012; Parmesan, 2006; Usui et al., 2007). However, there is considerable variation, with different species (or even populations of the same species) exhibiting both earlier and later timing of spring migration. While there are less data on fall migration, some studies have indicated shifts to later arrivals (Jarjour et al., 2017).

Why is this indicator important?

Tracking changes in migratory bird arrivals adds to the body of evidence of how terrestrial species have responded to regional changes in climate. A growing number of studies have examined changes in the timing of migration in recent decades across the Northern Hemisphere. Changes in the timing of spring migration (MacMynowski et al., 2007; Marra et al., 2005; van Buskirk et al., 2009; Ward et al., 2015) and, to a lesser extent fall migration, have been documented (Cotton, 2003; Jenni and Kéry, 2003; Mills, 2005).

Figure 4.11.3. Annual Arrival Dates, 4 Fall Migrant Species at Palomarin Field Station, 1979–2015.



Fox sparrow

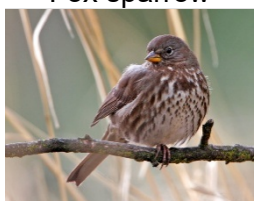


Photo Credit: Tom Munson

Golden-crowned sparrow



Photo Credit: Kim Savides and Rick Clark

Hermit thrush



Photo Credit: Rick Lewis

Ruby-crowned Kinglet



Photo Credit: Point Blue

Deviation (in days) from the overall mean fall arrival date for that species is shown for each year. Significant linear trend shown for (B) and (D); shading shows confidence interval. No significant linear trend in (A) and (C).

The timing of bird arrivals on breeding territories and wintering grounds is a key determinant of reproductive success and survival (Cotton, 2003). To the extent that migrating birds species are adapted to arrive at the optimum stage in the growth season — thus maximizing the availability of resources — shifts in migration timing can be expected to be disadvantageous (Travers et al., 2015). An analysis of changes in spring arrival dates among 48 bird species and the emergence of vegetation (spring "green-up" dates) across North America from 2001–2012 found that both have changed over time, usually in the same direction; however, arrival of eastern species increasingly lagged behind greenup, while in the west, where green-up typically shifted later, birds arrived increasingly earlier (Mayor et al., 2017). These findings highlight mismatches in timing that may potentially lead to adverse consequences on bird populations.

Knowledge of how migratory birds are responding to changing climatic conditions is critical in assessing and projecting the impacts of those changes on bird populations. Of particular concern are species or populations that are unable to modify their arrival times; reduced genetic variability due to a decline in their population size could limit their ability to adapt to climate change, potentially hastening further population declines (Hurlbert and Liang, 2012). A study of changes in spring migration timing among 100 European bird species found that population declines occurred in species that did not advance their spring migration in the period 1990–2000; those with stable or increasing populations advanced their migration considerably (Møller et al., 2008).

This indicator illustrates the value of long-term data, gathered in a systematic way, in revealing trends in spring and fall arrival dates of migratory songbirds. It adds California and western North American observations to the growing body of data describing temporal patterns in bird migration patterns (Seavy et al., 2018). Such regional information helps improve the scientific understanding of factors that may be influencing the timing of migration and how these factors may be reflected in global trends. The data presented can serve as a baseline with which to compare future observations and to develop long-term projections under future climate change scenarios. While there is no definitive explanation for why the responses of the seven species differ, this

information can also help inform studies that seek to elucidate the mechanisms and consequences of these phenological changes — particularly studies that examine whether shifts in timing are synchronous with changes in the timing of optimal conditions in breeding or wintering grounds.

What factors influence this indicator?

Bird migrations are seasonal movements between wintering and breeding grounds that allow individuals to take advantage of abundant resources, or to avoid predators or exposure to harsh conditions. As environmental conditions change over time, birds can potentially adjust the timing of migration — a response that reflects the interactions among several intrinsic and extrinsic factors. Migratory birds exhibit seasonal physiological changes in preparation for migration, triggered by environmental cues such as photoperiod (the length of day or night) and temperature (Hurlbert and Liang, 2012).

Researchers have investigated the association between changes in migration timing and a number of factors. Species that migrate more slowly and over short distances, and that occupied broader climatic niches (that is, habitats with a wider range of physical and biological resources) were found to have advanced arrival dates the earliest in a study of 18 common bird species in eastern North America (Hurlbert and Liang, 2012). An analysis of over 70 published studies on the timing of spring migration of 413 species across five continents found that, correlated with warmer spring conditions on arrival grounds, short distance migrants advanced their arrival dates by more than long distance migrants; no relationship was found between species' habitat or diet and arrival time (Usui et al., 2017). In contrast, a study of 19 songbird species in Quebec, Canada from 2005 to 2015 found a significant association between changes in migration timing and feeding habits: 10 of 14 insectivores, and only one of five granivores showed evidence of a shift in migration (Jarjour et al., 2017); overall spring arrival dates shifted earlier, while fall departure dates varied considerably.

As fall temperatures increase, insects and plants may be available as food for longer, delaying fall departure as individuals improve their condition to increase survival during migration (Jarjour et al., 2017). Similarly, some species may be shifting their spring

arrival timing in response to climatic conditions at their wintering grounds, which has been shown to affect the physiological condition of migrants and thus their departure dates (Marra et al., 2015).

Environmental conditions in the wintering or breeding grounds, stopover locations along the migration route, or in the final settling location — all of which affect arrival times — may, in turn be affected by factors operating on multiple spatial scales. The variety of factors and the multiplicity of temporal and spatial scales at which birds operate during migration undoubtedly contribute to the considerable inter-annual variation in arrival dates.

The earlier arrival of the Orange-crowned Warbler at Palomarin is not surprising. Earlier onset of spring conditions has been documented over much of the Northern Hemisphere (Parmesan, 2006; Root et al., 2003). This can influence the timing of migration and breeding (Gordo, 2007; Møller et al., 2010; Seavy et al., 2018). However, Both and Visser (2001) found that changes in conditions on the breeding grounds influenced laying date but did not lead to changes in spring arrival dates for a long-distance migrant. The contrasting arrival patterns of the two warbler species — both small, insectivorous songbirds in the same taxonomic family — presents a paradox, however, and indicates the need for further research.

In contrast, less research has investigated fall arrival patterns of birds to their wintering grounds (Gallinat et al., 2015). Trends in fall arrival dates likely relate, in part, to spring breeding ground conditions elsewhere: If breeding conditions persist later in the season, fall arrivals could be delayed; if breeding conditions support earlier breeding or if drier conditions result in earlier cessation of breeding, fall arrivals could advance.

The species described here migrate to the Point Reyes area from different wintering or breeding locations. Among the spring arrivals to the Point Reyes area, Swainson’s Thrushes (which show no trend in arrival dates) winter predominantly in western Mexico (Cormier et al., 2013); Wilson’s Warblers, which have been arriving later, winter in a larger area covering Baja California as well as western Mexico (Ruegg et al., 2014). Baja California and western Mexico are characterized by different wintering habitats that may influence departure timing from the wintering grounds. The migratory pathways of

Orange-crowned Warblers have not been documented; while their wintering range includes areas farther north than the other species (Gilbert et al., 2010), the wintering location of the population migrating to Palomarin is unknown.

The four species that arrive in the fall migrate from temperate regions. The Golden-crowned Sparrow (arriving earlier) and Fox Sparrow (no change in arrivals) both breed predominantly in the Gulf of Alaska (Cormier et al., 2016; Point Blue unpublished data; Seavy et al., 2012). The difference in these species' arrival patterns suggests that either conditions on the breeding grounds are not having a direct effect on timing of arrival or that the species are responding differently. Hermit Thrush, whose pattern is similar to Golden-crowned Sparrows (tendency to earlier arrival), breed in the Pacific Northwest, in particular, coastal British Columbia and the Olympic Peninsula of Washington (Nelson et al., 2016). It is not known where the population of Ruby-crowned Kinglets breed, although subspecies-related plumage patterns at Palomarin (Point Blue unpublished data) suggest that the majority are likely from either or both of the above two regions (Pacific Northwest and Gulf of Alaska), with some originating from interior Alaska or Canada (Swanson et al., 2008). Thus it is possible that either finer-scale differences in conditions at breeding grounds or along migratory stopover sites, or differential responses to shared conditions, may be influencing their arrival timing on their wintering grounds.

Technical considerations

Data characteristics

The data for this analysis consists of banding records of individual birds captured and marked as part of a constant-effort mist-netting program at the Palomarin Field Station (Point Blue, 2016; Ralph et al., 1993). Although mist-netting was initiated in 1966, the period of analyses was restricted to 1979, when constant-effort mist netting became fully standardized, through fall 2015. Fall 2013 was excluded due to a 15-day October hiatus in banding operations resulting from the federal government shutdown. This provides a 36-year dataset for spring arrivals and 36 years for fall arrivals.

The dataset was restricted to the first capture of each individual in each season. In spring, newly fledged birds were excluded from the analysis, thus all individuals

analyzed were approximately 1 year or older; in the fall, all age classes were included, including immature birds that fledged earlier in the year (during the breeding season immediately preceding fall arrival).

The species selected for this analysis were chosen for their migratory status and high capture rates. These species differed somewhat from the previous iteration of this report (OEHHA, 2009), by including analyses of three species not previously reported, namely Hermit Thrush, Golden-crowned Sparrow and Orange-crowned Warbler, and the removal of three species due to modest sample sizes: Black-headed Grosbeak, Warbling Vireo, and Yellow Warbler.

The distribution of first capture dates for each species was assessed to determine species-specific “arrival windows.” The beginning of the arrival window was determined by the first captures; the end of the arrival period was determined by the date at which first captures had declined to relatively low “baseline” levels (see Nur et al., 2017 for details). Any further captures after the arrival window’s end-date were determined to be individuals that likely had been present in the study area but had avoided capture until then. Thus, the arrival window encompassed the first wave of captures during the season in its entirety.

Arrival window dates are as follows:

- Swainson’s Thrush: 6 April – 8 June
- Wilson’s Warbler: 12 March – 29 May
- Orange-crowned Warbler: 20 February – 19 May
- Ruby-crowned Kinglet: 8 September – 15 November
- Hermit Thrush: 13 September – 15 December
- Fox Sparrow: 29 August – 5 November
- Golden-crowned Sparrow: 6 September – 30 November

Of these species, two occur in the region in small numbers year-round. In addition to the overwintering population in this study, a small number of Hermit Thrushes also breed in the region and migrate south in the fall (Phillips, 1991); however, the small number of post-breeding individuals from this population that were captured in early fall did not

overlap in time with the window for arrivals from the north. Similarly, in addition to the breeding population of Orange-crowned Warblers studied here, a relatively small number of individuals winter in the region; again, the capture window allowed those few breeding individuals to be excluded from this study.

None of the species in this study are passage migrants at the Palomarin Field Station; rather, Palomarin is the final stopping location (either for breeding or wintering) for all 7 species. In addition, the arrival window was set to exclude individuals that may have been present at the location for some period of time to better identify the timing of the wave of migrants as they first arrive on their wintering or breeding grounds.

The 25th percentile of capture dates during the arrival window was used to track the initial wave of arrival of migrants. Linear models were then fit to the capture dates for each species to analyze a linear-only trend (reported in **Figure 4.11.1** and **Figure 4.11.3**). To better analyze changes in trend, quadratic models were also fit to the same data (depicted as blue lines in **Figure 4.11.1** and **Figure 4.11.3**). Details on data processing and analysis are provided in the companion Technical Report (Nur et al., 2017).

One concern was that a change in population size could result in fewer captures which could affect measures of arrival date. Reduced sample size will bias the metric of the very earliest arrival date (Miller-Rushing et al., 2008). To provide a more robust metric, not biased by sample size, the 25th percentile value was used, though other quantiles could have been used, e.g., the median.

Strengths and limitations of the data

These data provide a long-term record of bird migration phenology. There was sufficient data to analyze these seven migrant songbirds, including both fall and spring migrants; species included came from four taxonomic families, thus providing taxonomic breadth. The time series is extensive for biological monitoring: 37 years as of 2015.

Monitoring efforts have been strictly standardized since 1979. In general, sampling efforts and net hours per season (where each “net hour” equals a single net open for one hour) have remained relatively stable during the period included in these analyses. Frequency of mist netting was generally three days per week (April through

Thanksgiving) or 6 days per week (May through Thanksgiving), weather permitting; one significant change in effort was a switch from banding 6 days/week to 3 days/week in the month of April starting in 1989. This change, as well as the generally small variation in effort in other months due to weather and other variables, was addressed by standardizing the analysis regarding bird captures per 1000 net hours (a full banding day at Palomarin results in 120 net hours) and pooling captures into 5-day periods.

The 2013 *Indicators of Climate Change in California* Report provided results for four of the seven species analyzed here, using the long-term mist-netting data from the Palomarin Field Station. For one of the species, Swainson's Thrush, previous results are very similar to what is presented here. However, for the other three species (Wilson's Warbler, Ruby-crowned Kinglet, and Fox Sparrow) there were noticeable differences in trends. The principal reason for the differences was that the earlier analysis used 1971–1978 (which, as noted earlier, were excluded here because mist-netting was not fully standardized until 1979), while the current analysis included the years 2006–2015. These more recent years made a substantial difference in characterizing the trend. The bottom line is that most species analyzed demonstrate both year-to-year variability and a trend over time that is not constant over the entire time series and, therefore, two different time intervals can produce two different trend values.

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Introduction

Human-caused climate change has led to more frequent and intense climate extremes, warming temperatures, and altered precipitation patterns which have had widespread, pervasive impacts on human health and well-being (IPCC, 2023). Climate change affects health directly through exposures to extreme heat and wildfires, and indirectly through exacerbated health threats, such as higher levels of air pollutants and shifting ranges of disease vectors (Ebi and Hess, 2020; USGCRP, 2023; de Souza and Weaver, 2024).

Health impacts from heat exposure are an ongoing and increasingly prevalent issue in California, while still being likely underreported. Reported cases of Valley fever have reached record highs, workers' compensation claims for heat-related illness have more than doubled, and warming temperatures continue to expand the geographic range and season of disease vectors. Across all five indicators, surveillance systems are known to capture only a portion of the true burden — a structural limitation that affects the comparability of reported figures to actual health impacts. Climate change has also altered the conditions under which infectious diseases spread, shifting the seasonality, distribution, and behavior of disease vectors. These exposures do not act in isolation: co-exposure to extreme heat and wildfire smoke worsens cardiovascular and respiratory outcomes and is associated with adverse birth outcomes, while wildfires can disperse fungal spores into new geographic areas. The communities most exposed to heat, smoke, and infectious disease vectors, including California tribes, are frequently the

same communities with the least access to healthcare, air conditioning, and early warning resources.

The five chapters that follow – Heat-related Illnesses and Deaths, Occupational Heat-related Illnesses, Wildfire Smoke and Human Health, Valley Fever, and Vector-borne Diseases – describe the current state of climate-related human health impacts in California and the efforts underway to address them. Since the 2022 edition of this report, several of these indicators have worsened, and new monitoring and regulatory tools have been introduced, including mandatory indoor heat illness protections and an OEHHA early warning tool for dangerous heat events.

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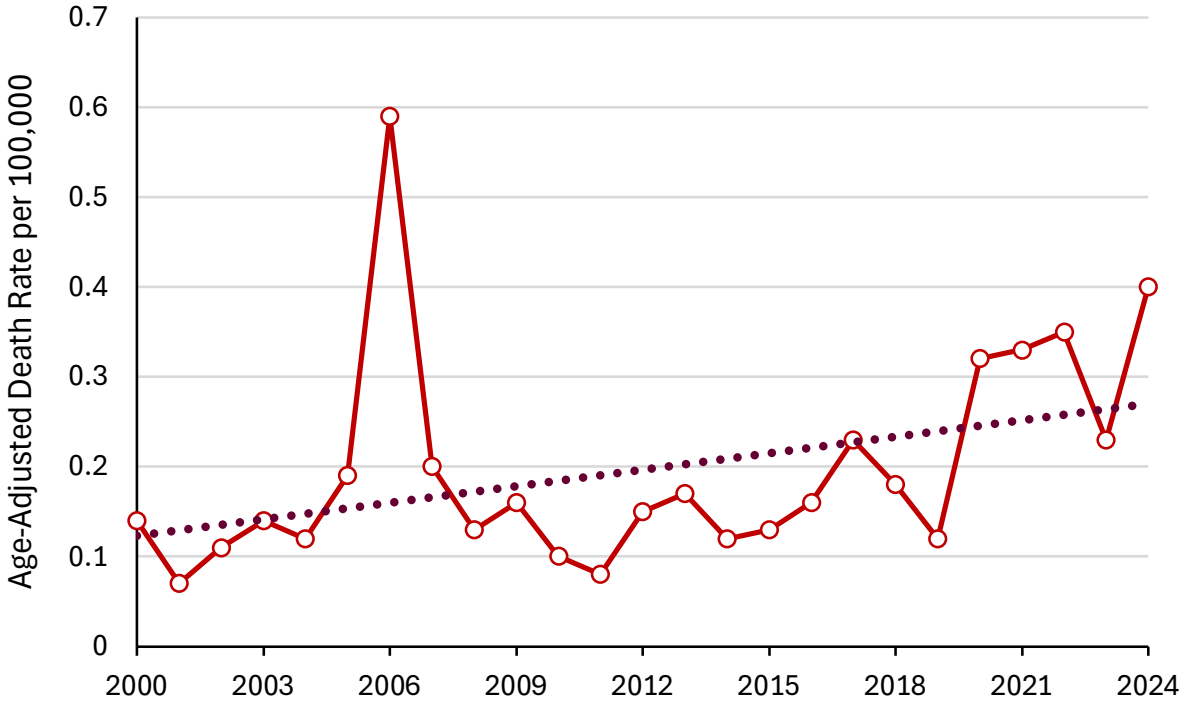
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5.1 Heat-Related Deaths and Illnesses

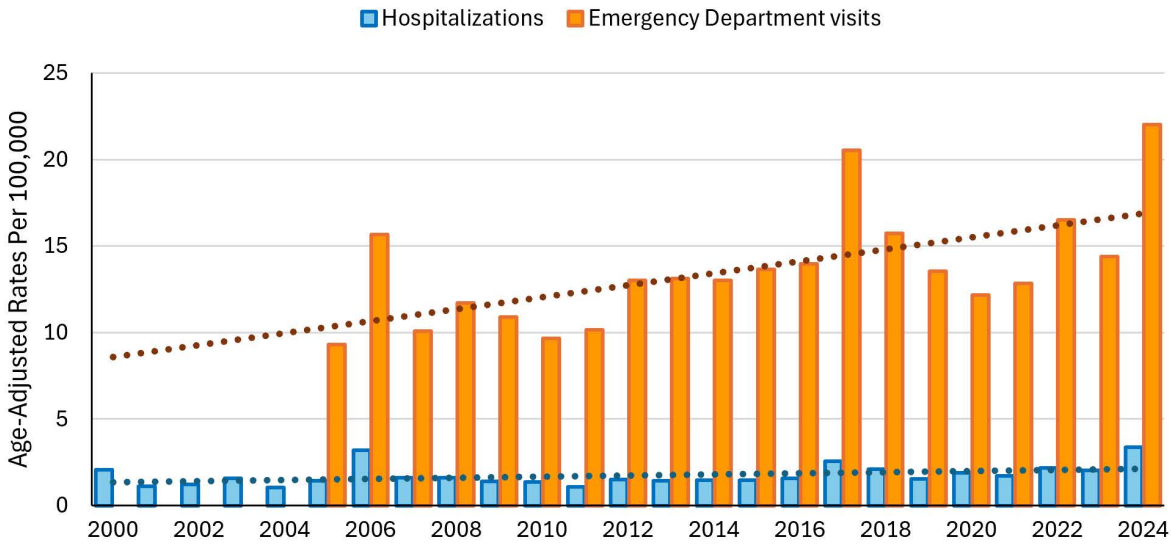
In years with especially high summertime temperatures, heat-related deaths in California have spiked. During these same periods, emergency department (ED) visits and hospitalizations due to heat-related illnesses have increased as temperatures rise statewide. Because many heat-related cases are unrecognized and thus underreported, the actual number of heat-related illnesses and deaths is likely higher.

Figure 5.1.1. Heat-Related Deaths in California.



The figure shows reported deaths in the warm season (May to September) from 2000 to 2024 due to heat exposure as a primary or contributing cause. Mortality rates peaked in 2006, coinciding with an unprecedented statewide heat wave. Year-to-year variability in deaths likely reflects differences in summertime temperature intensity and duration across years. The solid red line represents the annual values, and the dotted brown line is the linear trend. Source: Tracking California and the Dept of Health Care Access and Information (2026)

Figure 5.1.2. Heat-Related Illnesses in California.



The figure shows reported heat-related hospitalizations and ED visits during the warm season (May to September), from 2000 to 2024, with trendlines represented by dotted lines. Data for ED visits became available starting in 2005. Fluctuations across years likely correspond to variability in summertime heat conditions, including the frequency and severity of extreme heat events.

Note: Health cases related to heat are often unrecognized and thus underreported. In addition, people without adequate access to healthcare may not seek treatment. As a result, the true magnitude and health burden of heat-related illnesses and deaths in California are likely much higher than what is shown.

Source: Tracking California and the Dept of Health Care Access and Information (2026)

What does the indicator show?

Health impact from heat exposure is an ongoing and increasingly prevalent issue in California. Heat-related illnesses occur when a person is exposed to high temperatures or intense sunlight and their body's ability to cool itself becomes strained or overwhelmed, which can sometimes lead to death. Symptoms and illnesses include:

- Dehydration
- Heat exhaustion

- Heat cramps
- Heat rash
- Heat syncope (fainting)
- Heat stroke, which can be fatal

The trends in California align with nationwide trends. A recent assessment found 21,518 heat-related deaths in the US from 1999-2023, with an average of 861 deaths per year (Howard et al., 2024). Heat-related mortality in the United States has been increasing, on average, by 16.8% per year since 2016 and reached a record high of 2,325 deaths in 2023, the hottest year on record.

Figure 5.1.1 presents California's annual age-adjusted heat-related deaths from 2000 to 2024. Heat-related mortality rates peaked in 2006 due to the unprecedented heat wave that year, declining between 2007 and 2010 and have since trended upward. The number of reported deaths attributed to heat exposure nearly tripled in 2024 compared to 2000.

Figure 5.1.2 shows annual age-adjusted heat-related hospitalizations (2000 to 2024) and ED visits (2005 to 2024) in California. Relative to the early 2000s, when hospitalization rates ranged from 1.0 to 1.5 per 100,000 people, rates during peak heat years were significantly higher. In 2006 and 2017, hospitalization rates increased to approximately 2-3 per 100,000 – about a 50-100% increase above an average summer. Despite ongoing statewide adaptation efforts, rates of both heat-related ED visits and hospitalizations show an upward trend, consistent with rising temperatures and record-breaking heat events.

While data from past decades demonstrate significant health impacts from heat, many heat-related illnesses and deaths often go unreported. This is partly because heat exposure exacerbates many health conditions that might not be reported as heat related. In fact, warmer temperatures have been linked to:

- Increased cardiovascular and respiratory deaths
- Greater health care usage for a wide range of diagnoses, including electrolyte imbalance, diabetes, and renal, cardiovascular, and respiratory diseases

- Adverse birth outcomes such as preterm birth, stillbirth, and low birth weight
- Increased ED visits for mental health-related outcomes, such as for psychiatric conditions and self-harming or aggressive behaviors
- Increased ED visits for amphetamine, cocaine and opioid use or overdose

During the 2006 California heat wave, for instance, over 16,000 excess ED visits and 1,100 excess hospitalizations were observed. These were much larger than the 2,134 ED visits and 538 hospitalizations officially identified as heat-related, so many were not explicitly diagnosed as heat illnesses (Knowlton et al., 2009).

Why is this indicator important?

Extreme heat (see the *Extreme Heat Events* chapter) causes hundreds of deaths, thousands of injuries, and billions of dollars in economic losses in California, even though heat-related illnesses and deaths are generally preventable (CDI, 2024; Luber et al., 2014; NOAA, 2026).

Assessing changes in frequency of heat-related deaths and illnesses over time provides a measure of how climate change-related temperature shifts are impacting human health. Despite heat-related illness and mortality counts being underreported, tracking the number of deaths and illnesses attributed either wholly or in part to heat can provide an indication of the trend in health impacts related to climate change.

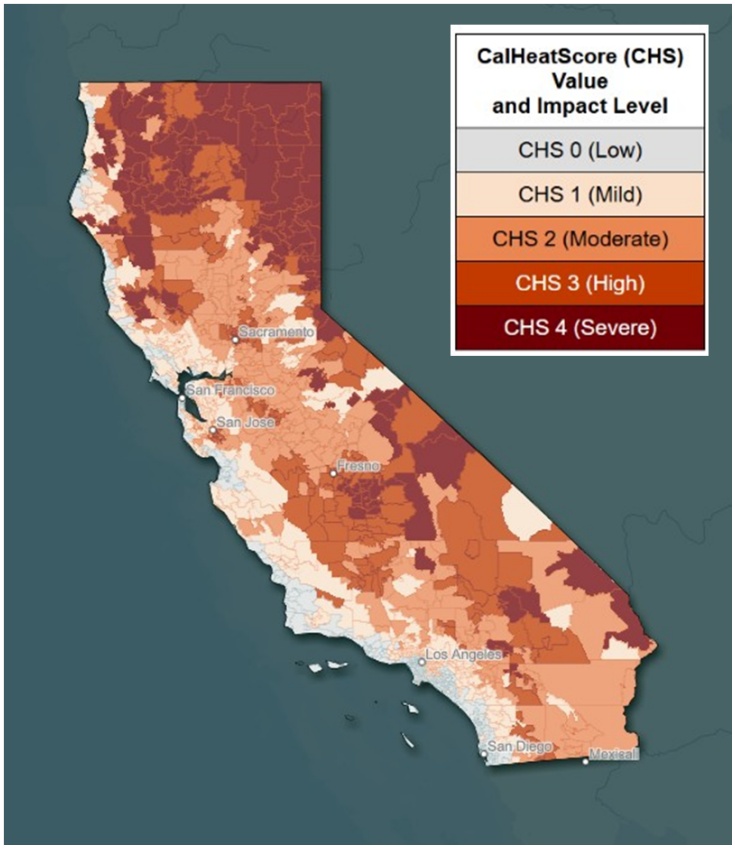
Tracking trends in heat-related illnesses and deaths provides critical information for developing adaptation plans and evaluating their success, especially in relation to heatwaves. This information will become even more important as periods of warmer temperatures and heatwaves are expected to rise in frequency, duration, and intensity over the next century (IPCC, 2021; Luber et al., 2014), placing an even greater public health burden on California.

In response to the health risks posed by extreme heat, California has invested $404 million through the state's Extreme Heat Action Plan, with many initiatives already underway, including strengthening community services and response, increasing resilience of the environment, and utilizing nature-based solutions (CDPH, 2023a).

Tracked heat-related illness and deaths will serve as a metric to evaluate the effectiveness of these initiatives.

In early 2025, California's Office of Environmental Health Hazard Assessment (OEHHA) launched CalHeatScore: a public health tool that provides near real-time daily, health-relevant heat rankings at the zip code level. CalHeatScore was developed to serve as a public early warning system for California communities to reduce heat-related illnesses and deaths (**Figure 5.1.3**). In addition to heat-risk rankings, the tool provides public-facing resources, including information on local cooling centers, recommended protective actions, and signs and symptoms of heat-related illnesses.

Figure 5.1.3. Screenshot of the CalHeatScore Map on July 14, 2025.



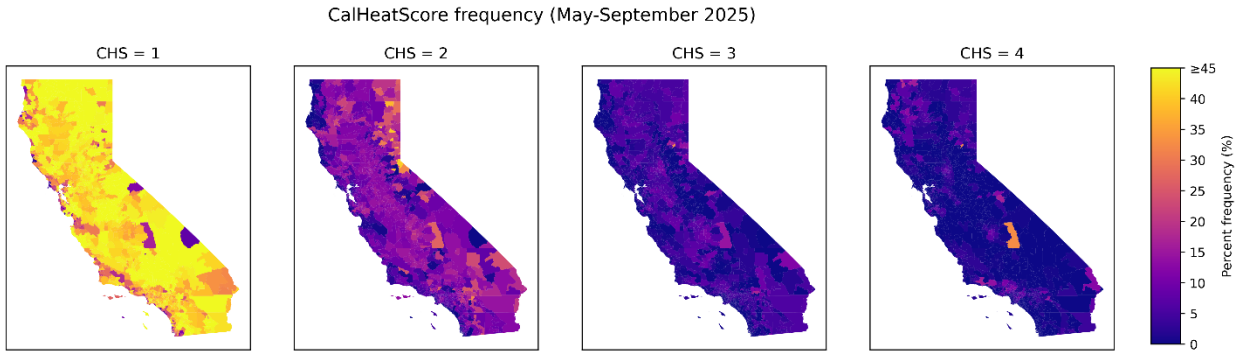
Source: CalHeatScore (2025)

The ranking system uses historical relationships between climate conditions and heat-related illnesses to translate upcoming daily weather forecasts into easy-to-understand scores, ranging from 0 to 4 to indicate increasing levels of human health risk from extreme heat impacts. CalHeatScore is updated daily, using temperature forecasts for the next 7 days to anticipate upcoming heat events.

Data from the first year of CalHeatScore (May – September 2025) showed that the majority of daily CalHeatScore (CHS) ranks were 1 (mild, 39.5%) followed by 2 (moderate, 9.8%). Ranks 3 (high) and 4 (severe) were least frequent, occurring approximately 3.2% and 2% of the time, respectively. Because these higher-impact days were relatively rare, they provide clear opportunities to focus preparedness and response efforts when risks are most elevated.

These frequencies varied by location (**Figure 5.1.4**) and time (**Figure 5.1.5**). Looking across time, there were distinct patterns in the rank distribution across the summer period as well.

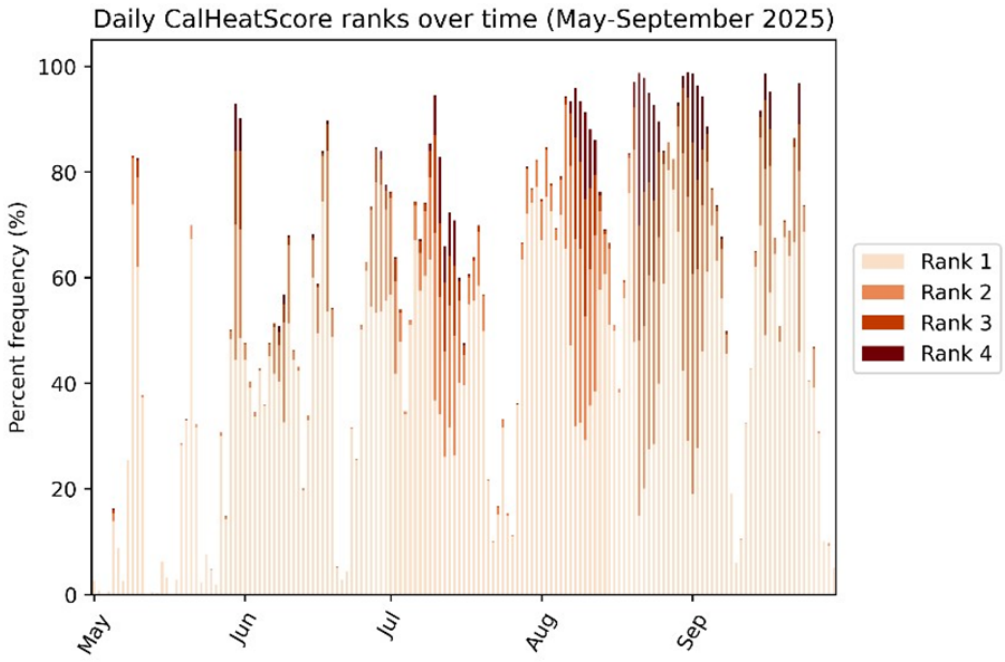
Figure 5.1.4. Spatial Distribution of CalHeatScore Rankings.



The maps show the frequency of CalHeatScore ranks in the summer of 2025.
Source: CalHeatScore (2025)

Figure 5.1.5 shows that CalHeatScore ranks of 3 (high impact) and 4 (severe) increased in frequency later in the summer of 2025 which reflected the relatively mild start of the 2025 heat season. Once the late summer period was reached, there were multi-day stretches across the summer where higher CalHeatScore ranks were seen.

Figure 5.1.5. Daily Distribution of CalHeatScore Rankings.



The graph shows daily ranks over time in the summer of 2025.

1=mild, 2=moderate, 3=high, 4=severe

Source: CalHeatScore (2025)

As global temperatures continue to warm, increases in extreme heat and concurrent increases in community health risk driven by exposure to heat can be expected. OEHHA will continue to refine CalHeatScore's methodology to ensure the accurate reflection of localized heat-health risk. CalHeatScore will be informed by input from community organizations, tribes, local governments, health professionals, emergency responders, researchers, and the public.

What factors influence this indicator?

The association between exposure to high temperatures and increased illnesses or deaths is well established. Even short periods of extreme heat are associated with adverse health impacts (Gasparrini and Armstrong, 2011; Sherbakov et al., 2018).

Key factors influencing heat-related health outcomes in California include intensity and duration of the heat events, frequency of exposure (e.g., how often events occur and when they occur during the year), location of exposure (e.g., geographic location, acclimation to heat, air quality in the area), and population characteristics (e.g., age, health condition, socioeconomic status, occupation, access to protective measures, etc.) These factors are further discussed below.

Heat Wave Characteristics

The intensity, duration, frequency and spatial extent of heat events all play a role in whether people will experience heat-related effects and how severe those effects can be. Longer lasting heat waves are associated with higher mortality, ED visits, and hospitalizations in California. Heatwaves that span larger geographic areas of populated regions can have more significant health impacts, particularly when they affect vulnerable populations.

Specific characteristics of heat events further influence the impact of these heat-related health effects. Elevated nighttime temperatures during heat waves can exacerbate health impacts by preventing recovery from high daytime temperatures (Gershunov et al., 2009). Heatwaves accompanied by high humidity are also especially dangerous, as rising humidity can prevent evaporation of sweat, which impairs the body from regulating temperature. Heatwaves occurring outside the typical hot season, either early in the spring or late in the fall, could cause greater health burdens as people are less prepared for heat risks.

Health disparities

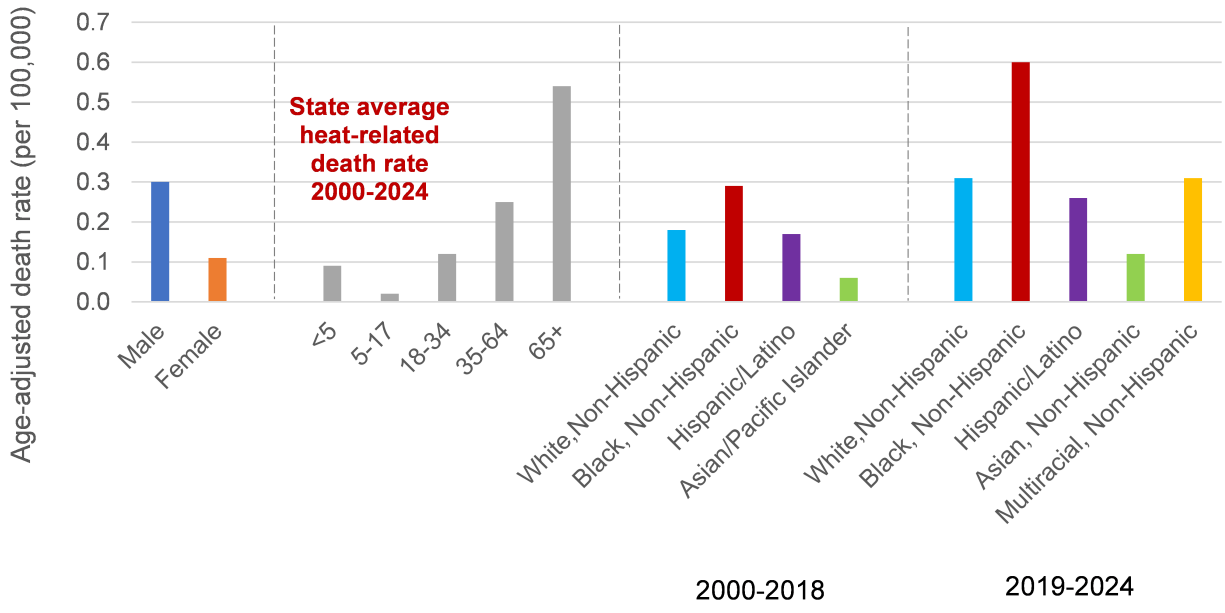
Although anyone can experience heat exposure impacts, some populations face higher risk. **Figure 5.1.6** and **Figure 5.1.7** show reported deaths, ED visits, and hospitalizations from May to September with heat exposure as a main or contributing cause, with greater risks of heat illnesses among males (likely driven in part by occupational exposure), adults aged 65 and older, and the non-Hispanic Black demographic. These groups have consistently higher rates of heat-related deaths, ED visits and hospitalizations than those in other comparable demographic groups. A more detailed analysis by race revealed higher risks of heat-related illnesses among the

Pacific Islander demographic (**Figure 5.1.7b**). A separate analysis by the California Department of Insurance (CDI, 2024) examined seven extreme heat events in California from 2013 to 2022 and found substantial health impacts, including an estimated:

- Higher mortality rates in disadvantaged communities (SB535 census tracts) than non-disadvantaged communities, with heat-related mortality rates 14-30% higher in SB535 tracts across six of seven extreme heat events evaluated statewide.
- Blacks, Native Americans, and Hispanic populations experienced disproportionately higher adverse health outcomes than White and Asian populations, with heat-attributable mortality rates up to approximately two times higher during several extreme heat events.
- People over 65 had disproportionately more adverse health outcomes than younger age groups, with mortality rates of approximately 16-29 deaths per 1,000,000 compared with about 1 death per 1,000,000 among those under age 65.

Factors such as age, race/ethnicity, and socioeconomic status (including homelessness or inadequate access to air conditioning) could all interact with each other to worsen disparities. Racial and ethnic disparities are directly linked to the inequitable distribution of social, political, and economic power and the subsequent health burden and disadvantaged living conditions (CDPH, 2023b). The following figure shows heat-related death rates in California by sex, age, and race/ethnicity for 2000 to 2024. Rates are age-adjusted for all groups except the rates of different age groups (**Figure 5.1.6**).

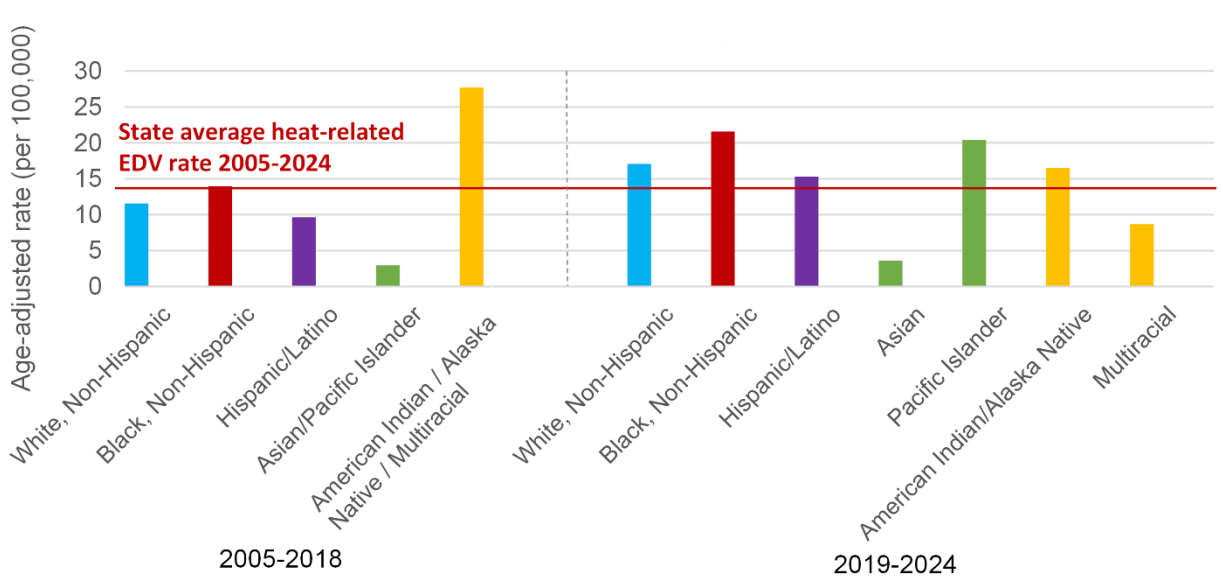
Figure 5.1.6. Heat-Related Death Rates in California, by Sex, Age, and Race/Ethnicity (2000-2024).



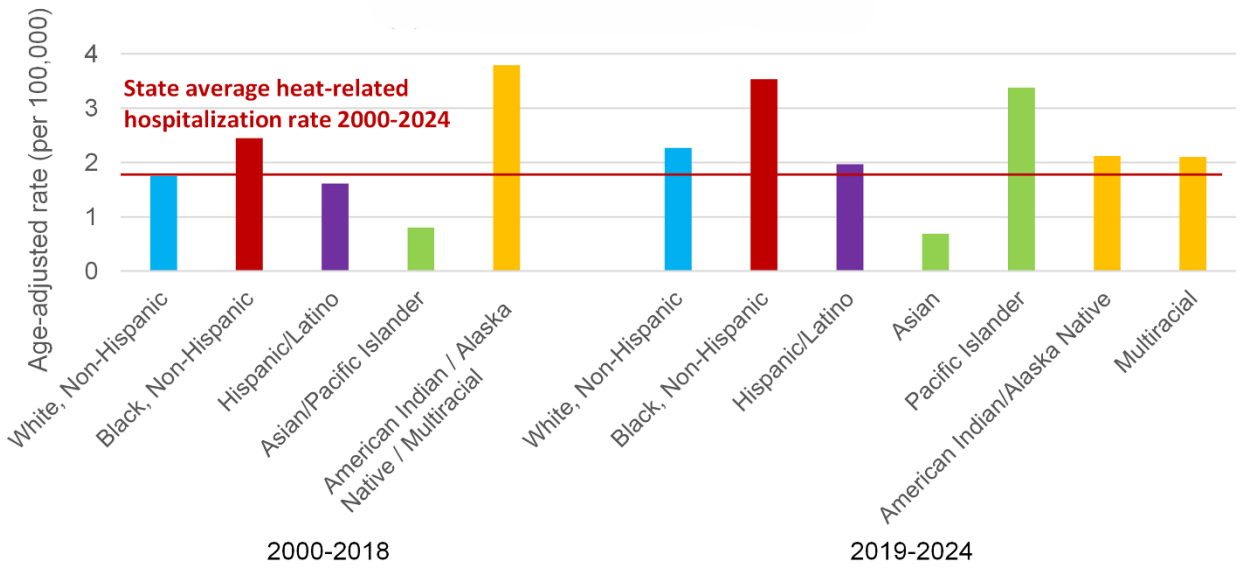
Less than 1% of the deaths were excluded from the sex- and age-stratification due to missing dates of birth needed to calculate age-adjusted rates, and the impact to the overall distribution was minimal. Source: Tracking California and the Dept of Health Care Access and Information (2026).

Figure 5.1.7. Heat-Related Illness Rates in California, by Race/Ethnicity.

(A) Heat-related Emergency Department Visits



(B) Heat-related Hospitalizations



American Indian/Alaska Native and Multiracial demographics are reported separately beginning 2019. Their relatively large rates in 2000-2018 may be reflective of their small sample size.
Source: Tracking California and the Dept of Health Care Access and Information (2026).

A study of pediatric hospitalizations and ED visits in California from 2005 to 2019 found that children in communities with lower incomes, lower education levels, less access to insurance, less access to air conditioning, and higher percentages of Black, Hispanic, and Pacific Islander residents were most vulnerable to extreme heat events (Ndovu et al., 2025).

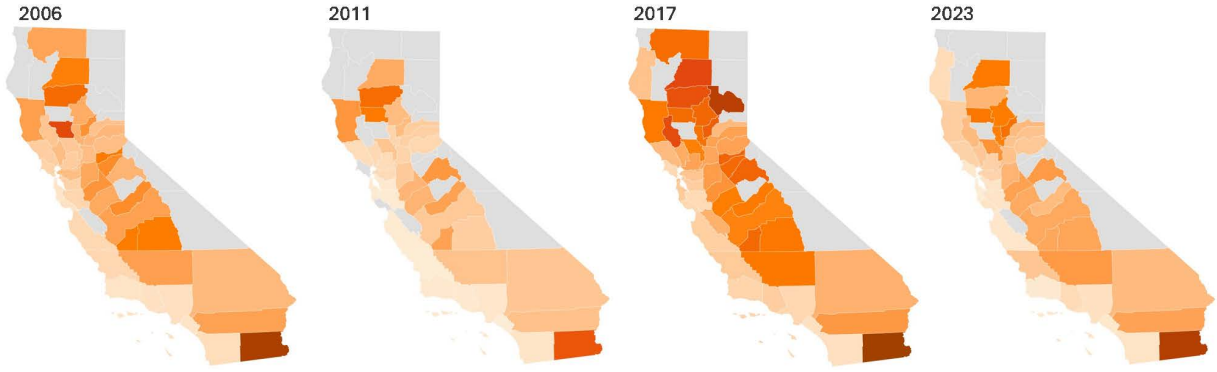
Furthermore, people engaged in extended outdoor activities during hot days, such as workers in construction, agriculture, delivery service, and firefighting are also at risk. Over the past two decades, reported occupational heat-related illnesses have increased in California (see *Occupational Heat-Related Illnesses* chapter). Athletes, hikers, tourists, and those who spend a lot of time outdoors on hot days are also subject to higher risks. Heat-related illness is one of the leading causes of death of teenage athletes in the US (Adams, 2019; Kerr et al., 2013).

Regional differences

Some California regions face greater challenges than others due to differences in climate, infrastructure, and population characteristics. A statewide analysis of hospital admissions from 2004 to 2013 found substantial heat burdens in the Central Valley and a high variation in heat-related hospitalizations in coastal cities. The Central Valley and the southern inland areas consistently observe higher summer daytime temperatures than the state average. Daytime heat events had the greatest impact in the Central Valley, while nighttime heat events drove burdens in the southeastern desert regions (Hansen et al., 2024). Meanwhile, coastal populations tend to be less acclimated to higher temperatures and have lower rates of air conditioner ownership.

Figure 5.1.8 shows heat-related ED visit rates across California in 2006 (extended summer heat wave), 2011 (cool summer season), 2017 (exceptionally hot summer), and 2023 (relatively warm summer). Darker colors indicate higher heat-related illness rates. The Central Valley, northern inland, southeastern desert, and northwest coast always appear as high-risk areas. Note the distinction between 2006 and 2017 and which counties are most impacted.

Figure 5.1.8. ED visits by County Due to Heat Illness, Selected Years.



Source: Tracking California (2025)

Urban residents may experience higher temperatures than those in surrounding suburban and rural areas due to the urban heat island effect, in which built environments retain and generate heat. Urban heat islands are created by a combination of:

- Heat-absorbing surfaces (such as dark pavement and roofing)
- Heat-generating activities (such as engines and generators)
- Absence of vegetation (which provides evaporative cooling)

Average daily summer temperatures in urban areas were warmer than those for nearby rural areas by the following magnitudes:

- Smaller urban areas: Up to 5°F (3°C) warmer
- Moderately large urban areas: Up to 9°F (5°C) warmer
- Very large urban areas: Up to 19°F (11°C) warmer (southern California)

Urban heat islands also strongly influence nighttime temperatures. Warmer nights limit the body's ability to cool down and recover before temperatures begin to climb again the next day, increasing the risk of illness and fatalities (CalEPA, 2015). Most of the urban areas are concentrated along the coast, Sacramento Valley, and San Joaquin Valley.

Air pollution

High temperatures and heat waves can worsen air quality and amplify the health effects of air pollutant exposures and thus pose a threat to public health (Nolte et al., 2018; O'Lenick et al., 2019). Heat accelerates the formation of ground-level ozone and traps ozone, particulate matter and other harmful air pollutants. Exposure to these pollutants has been linked to adverse respiratory, cardiovascular, mental health, and reproductive outcomes (Bekkar et al., 2020; Nguyen et al., 2021; US EPA, 2019).

Air pollution often acts synergistically with extremely high temperatures to exacerbate adverse cardiovascular, respiratory and other health effects (Anenberg et al., 2020; Schwarz et al., 2021). Communities burdened by high air pollution levels may be more likely to experience adverse health effects during heat events.

Emerging research suggests that the health impacts of co-exposure to extreme heat and air pollution (particularly wildfire smoke) can produce greater health impacts than in isolation. This has been observed in studies on mortality (Rahman et al., 2022), cardiorespiratory hospitalizations (Chen et al., 2024), and preterm births (Ha et al., 2024). The risk of preterm birth from combined exposure to heat and wildfire smoke is highest for Black, Hispanic, Asian, and American Indians/Alaskan Native populations.

Along with outdoor air pollution, heat can significantly influence indoor air quality. Sources of indoor air pollution include building materials, gas appliances, cleaning products, personal care products, and furniture. Exposure to indoor air pollutants is associated with adverse health effects, such as eye and throat irritation, asthma and other respiratory diseases, and cancer (California Air Resources Board, 2025). Heat can accelerate the release of volatile chemicals from household products (Beel et al., 2023) and materials and increase the rate of indoor chemical reactions. As outdoor levels of ozone rise on hot and sunny days, ozone can infiltrate buildings through cracks and gaps in buildings. Once indoors, ozone can react chemically with components of buildings and building furnishings, as well as some indoor air pollutants, to form air pollutants like formaldehyde and ultrafine particles that can pose a hazard to human health (Berkeley Lab Indoor Air Quality, 2025). Moreover, when people use air conditioning, they often close doors and windows, which may trap pollutants indoors,

potentially worsening allergies and respiratory issues. These combined indoor and outdoor pathways further contribute to heat-related health burdens, particularly during prolonged heat waves.

Technical considerations

Data characteristics

Heat-related hospitalizations and ED visits were identified for the months of May to September (2000–2023) by Tracking California (https://trackingcalifornia.org), a program of the Public Health Institute, in partnership with the California Department of Public Health, and formerly the Centers for Disease Control.

Cases were included when heat stress was explicitly listed, as either the primary or contributing cause of diagnosis. Heat-related diseases were identified using International Classification of Diseases (ICD-9 for 2000-2015, ICD-10 for 2015-2024) codes for: heat stroke and sunstroke; heat syncope; heat cramps; heat exhaustion; heat fatigue; heat edema; other specified heat effects; unspecified effects of heat and light; and exposure to excessive natural heat or sunlight. Illnesses that were due to a man-made source of heat were excluded. Hospitalization data were available from 2000 to 2024, with ED visit data from 2005 to 2024.

Tracking California also identified heat-related deaths for the months of May to September from 2000 to 2023, using ICD-10 codes for the following as the main or contributing causes of death: heat stroke and sun stroke, heat syncope, heat cramps, heat exhaustion, heat fatigue, heat edema, other specified heat effects, unspecified effects of heat and light, and exposure to excessive natural heat, and sunlight. Again, deaths due to a man-made source of heat were excluded. More information about data and methods, including rate calculations, can be found at Tracking California.

Strengths and limitations of the data

As noted earlier, the available data on heat-related death and illnesses likely underestimate the full health impacts of heat exposure. Heat-related deaths from coroners' reports rely on deaths coded as "heat-related" without universally applied classification of these diseases and often require knowledge of the circumstances

surrounding the death to be communicated by other parties. Consequently, heat is infrequently listed as a primary cause of death, even when it contributes substantially to fatal outcomes (English et al., 2009). It is likely that there were three to four times as many deaths in the July 2006 heatwave than reported (Ostro et al., 2009; Joe et al., 2016). Similarly, for the 2022 heatwave, the estimated number of all-cause excess deaths was significantly higher than the number coded as heat-related on death certificates (395 vs. 20) (CDPH, 2023a). Recent studies of annual heat-related deaths in the US also support that the number of deaths is substantially larger than what has been previously reported (Weinberger et al., 2020; Vaidyanathan et al., 2020).

Non-fatal outcomes may similarly be undercounted. Heat-related health effects can manifest in several clinical outcomes, including urinary tract infection, renal failure, septicemia, hypotension, cardiac dysrhythmia, ischemic stroke, ischemic heart disease, diabetes, and mental health conditions (Basu et al., 2012; Green et al., 2010; Sorensen and Hess, 2022). Heat exposure has also been associated with preterm birth, low birth weight, and stillbirth (Bekkar et al., 2020). People with chronic health problems are more susceptible to heat effects compared to healthy individuals. However, these cases are usually unrecognized and not reported as heat-related in the current reporting system, unless they happened during or right after a heat event. It is often difficult to determine whether an illness is heat-related when it involves multiple organ systems, and there is no standardized training among healthcare providers to make these determinations (Madrigano et al., 2015).

Outpatient visits are generally not considered in reported cases of heat-related illnesses, and the California Department of Insurance found that the 2022 Coastal Inland Heat wave (August 31-September 13) and 2017 Full Coastal Heat wave (August 27-September 8) each resulted in tens of thousands of excess outpatient visits (around 55,000 and 35,000, respectively) and more than $10 million in excess medical costs (CDI, 2024). Therefore, the full magnitude of health impacts from heat exposure could be much greater than indicated by hospitalization and ED visit data alone.

For hospitalizations and ED visits, ambiguity in diagnosis classifications of heat-related visits due to the transition from ICD-9 to ICD-10 in the 4th quarter of 2015 may also

impact observed patterns in those indicators. Also, only ED visits and hospitalizations for California residents are reported. Out-of-state residents and unhoused patients with no recorded address are excluded from the rates (Tracking California, 2025), suggesting that the number of heat-related visits may be higher.

Furthermore, due to the requirement for age-adjusted mortality and morbidity calculations, records without valid dates of birth were excluded from the analytical dataset. This exclusion accounted for approximately 1% of mortality records and a negligible fraction of morbidity records. Sensitivity analyses of the omitted records demonstrated minimal deviation in distributional patterns, including within low-frequency racial groups.

Despite these known limitations, heat-related ED visits, hospitalizations and deaths can be used to document trends, monitor vulnerable areas, and assess local climate-adaptation strategies. These metrics are tracked at the national level as part of the National Environmental Public Health Tracking Network, enabling comparisons across states. This tracking provides a better understanding of risks to specific groups and helps with designing interventions and communication efforts (CDC, 2026).

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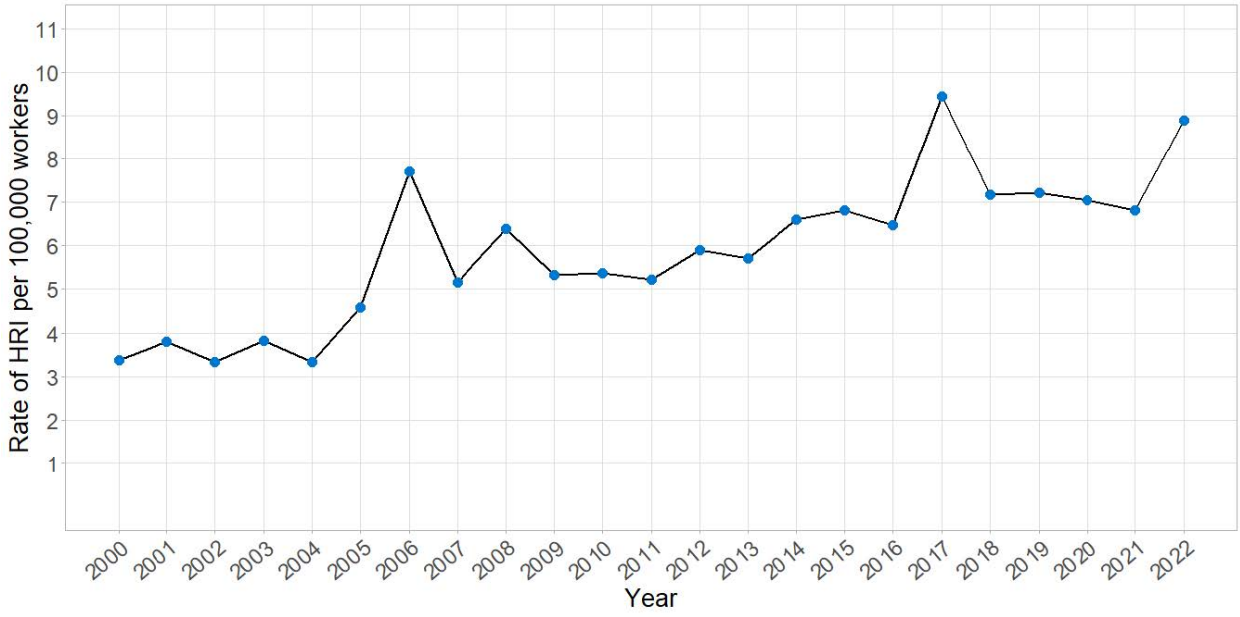
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5.2 Occupational Heat-Related Illnesses

Californians are increasingly exposed to extreme heat due to climate change. In 2024, California experienced its hottest July on record. Workers are uniquely vulnerable to extreme heat due to occupational conditions and sustained exposure during work activities. Although heat-related illnesses are preventable, they remain a significant source of occupational (work-related) illness and death. In California, workers' compensation insurance claims for heat-related illnesses more than doubled from 2000 to 2022, underscoring the growing health burden of heat on the workforce.

Figure 5.2.1. Occupational Heat-related Illnesses in California.



Rates of heat-related illnesses are based on workers' compensation insurance claims from January 1, 2000, to December 31, 2022. HRI, heat-related illnesses. Source: CDPH (2025a)

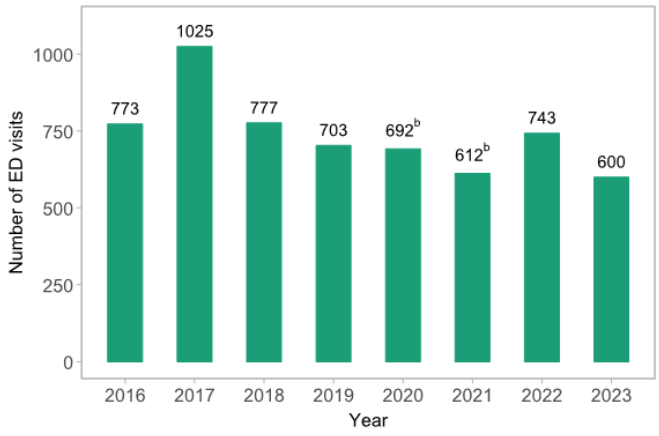
What does the indicator show?

The yearly rate of occupational heat-related illness workers' compensation insurance claims more than doubled between 2000 and 2022. **Figure 5.2.1** presents annual rates of occupational heat-related illness claims per 100,000 California workers from 2000 to 2022 based on an analysis of workers' compensation claims data. Between 2000 and 2022, a total of 20,564 heat-related illness claims were reported in California. This

represents an average annual rate of 5.9 heat-related illness claims per 100,000 workers. Most heat-related illness cases reported in California occurred during the summer: July had the highest number of cases, followed by August, then June (not shown). Heat-related illnesses were relatively high in 2006, 2017, and 2022 when summertime temperatures were exceptionally warm.

Figure 5.2.2 shows the annual number of emergency department (ED) visits for occupational heat-related illness from 2016 to 2023. Over this period, occupational exposures accounted for 5,925 (12.5%) of the 47,223 ED visits with a heat-related illness diagnosis among people 16-84 years old. ED utilization declined during 2020 and 2021 due to the COVID-19 pandemic, suggesting that the reported visit counts during those years may underestimate the true burden of occupational heat-related illness.

Figure 5.2.2. ED visits for Occupational Heat-Related Illness, 2016–2023[a].



[a]2016–2021 counts may differ from the previous version of this data brief due to an error in identifying severe HRI cases that has been corrected.

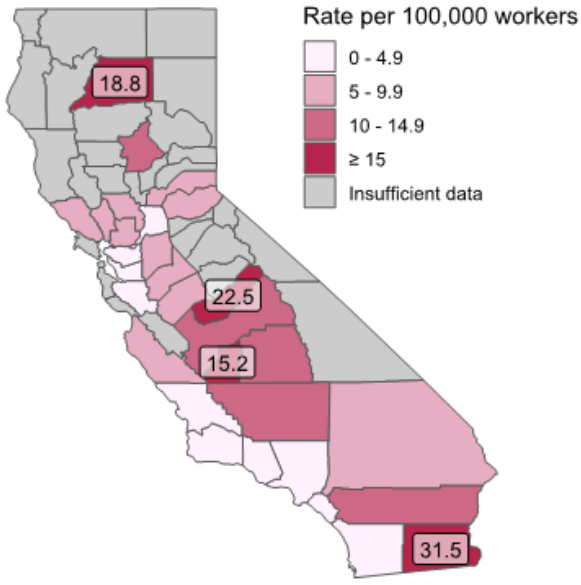
[b]2020–2021 data subject to bias caused by reduced emergency department utilization during the COVID-19 pandemic.

Source: CDPH (2025b)

The highest rate of occupational heat-related illness ED visits is seen in Imperial County, with Kings, Madera and Shasta Counties also having high rates (**Figure 5.2.3**). **Figure 5.2.3** shows the rate of occupational heat-related illness visits per 100,000

workers by patient's county of residence, averaged over the eight years of data. Imperial County experiences the hottest temperatures in California (for daytime and nighttime/overnight) and agriculture is one of its major industries – potentially explaining the high rate of workers' ED visits for heat-related illness. It is possible that the high rate in Shasta County was caused by overlapping wildfire and heat events. Counties shown in gray reported relatively few total ED visits, so reliable rate estimates could not be determined.

Figure 5.2.3. ED Visit Rates per 100,000 Workers for Occupational Heat-Related Illness, 2016–2023.



Source: CDPH (2025b)

Why is this indicator important?

Heat-related illness among workers has been well-documented for several decades. Tracking these illnesses among workers is an integral part of public health planning, to mitigate and prevent the effects of extreme heat on the most vulnerable populations. As the climate warms, Californians are increasingly exposed to extreme heat. Workers are particularly vulnerable to heat exposure because they typically have little control over

working conditions and environments, with limited ability to adapt when faced with extreme heat conditions (Gibb et al., 2024).

> *"I worked in a skilled nursing facility without air conditioning, standing the entire shift. I experienced heat-related illnesses, including fainting, not knowing it was heat-related illnesses. My employer did not tell us about the importance of taking breaks, drinking water, and resting when working in hot conditions. Even if I knew about my right to file a workers' compensation claim for my illnesses, I would have been afraid to."*
>
> *-Alyssa*, former skilled nursing facility worker*
> **Name changed to protect privacy*
> *CDPH 2025(a)*

As climate change intensifies, average daily temperatures and the frequency and intensity of extreme heat events, as well as occupational heat-related illnesses and deaths, are projected to increase (ILO, 2019). A study of U.S. crop workers estimates that, at the current pace of climate change, occupational heat-related illnesses could double by the middle of the 21st century (Tigchelaar et al., 2020). As more workers are placed at risk, additional strategies and interventions will be needed to protect workers from heat-related illnesses. Such strategies include adjusted work schedules and more frequent and longer breaks with access to water and shade. OEHHA's CalHeatScore, released in 2025, helps employers track local heat events and identify cooling centers to support preparedness when extreme heat events arise.

Rising workplace temperatures also have broader economic implications. Borg et al. (2021) reviewed 20 studies to estimate the past and potential future global economic burden of workplace heat exposure. They estimated substantial heat stress-related expenses from lost productivity, decreased work efficiency, and healthcare costs, and highlighted the need for workplace heat management policies to minimize future economic burden. A study of workers' compensation claims for heat exposure in California estimated financial costs for heat-related injuries at between $525 and $875 million per year, considering health care expenditures, lost wages and productivity, and disability claims (Park et al., 2021). A study of heat-related workers'

compensation insurance claims in weather-exposed industries during seven extreme heat events from 2013 to 2022 estimated approximately $527 million in work-time losses (CDI, 2024).

Exposure to elevated workplace temperatures may also exacerbate trends in labor market inequality. Park et al. (2021) report that lower-wage workers are more likely to live and work in places with greater heat exposure and experience larger increases in heat-related risk on hotter days. People in the state's lowest household income tier are approximately five times more likely to be affected by heat-related illnesses or injuries on the job than those in the top income tier. These injuries among low-income workers can lead to high healthcare costs and long-term wage losses, potentially affecting future earnings.

What factors influence this indicator?

Warmer temperatures and more frequent extreme heat events such as those seen during the summers of 2006, 2017, and 2022 are becoming the new normal (see *Air Temperature* and *Extreme Heat Events* chapters). These warming trends coincide with an increase in reported cases of worker heat-related illnesses, as shown in **Figure 5.2.1**. Exposure to heat can lead to heat-related illnesses, including heat exhaustion, heat cramps, and heat stroke (a life-threatening medical emergency that can lead to death if not treated promptly).

Heat exposure during work restricts a worker's physical functions and leads to loss of productivity (ILO, 2019). When workers are exposed to heat, they are more likely to experience heat-related illnesses, make mistakes, become irritable, and sustain injuries due to impaired cognitive and physical performance. Extreme heat can also exacerbate chronic or underlying illnesses and injuries (Gibb et al., 2024). On average, workplace temperatures above 75-79 degrees Fahrenheit (˚F) (24-26 degrees Celsius (˚C)) are associated with reduced labor productivity. At 91-93˚F (33-34˚C), a worker operating at moderate work intensity loses approximately 50% of their work capacity. These temperature thresholds are even lower for workers who wear personal protective equipment (PPE), such as for pesticide applications. In California, a comparison of workers' compensation claims with local weather data from 2001 to 2018 showed that

on days with a high temperature above 90˚F (32˚C), workers have a 6 to 9% greater risk of any injuries than on days with high temperatures of 50 to 60˚F (10 to 16 ˚C) (Park et al., 2021). When temperatures top 100˚F (38˚C), the risk of injuries increases by 10 to 15%. However, the temperature at which heat exposure adversely affects a worker's health varies widely and is influenced by multiple interacting factors. Individual characteristics, working conditions, and broader environmental or living conditions can all lower the temperature threshold at which occupational heat exposure becomes harmful. In particular, workers who are not heat-acclimatized - such as those newly exposed to hot conditions or returning after time away - are at increased risk of heat-related illness. **Figure 5.2.4** presents some examples of individual, occupational, and environmental factors that influence susceptibility to heat-related illness and helps explain variability in health outcomes among workers exposed to similar ambient temperatures. Further information is discussed below.

Figure 5.2.4. Examples of Individual, Occupational, and Environmental Factors that Affect Heat-Related Illness.



Source: Gibb et al. (2024)

Individual worker factors

Certain demographic groups have higher rates of occupational heat-related illnesses than others, as shown in **Tables 5.2.1**-**5.2.3**. In California, occupational heat-related illnesses are more common among Hispanic individuals, younger workers, and men (CDPH, 2025b). Workers who are socially isolated or economically disadvantaged, have chronic illnesses, or lack health insurance are especially vulnerable to heat-related illness; these workers are often from communities of color (OEHHA, 2026; US Global Change Research Program, 2023). Additional factors are shown in **Figure 5.2.4**.

Table 5.2.1. Total Number and Average Yearly Rates of Occupational Heat-Related Illness Claims by Age in California, 2000–2022.

Age (years)*	Number and percent of total worker claims	Claims per 100,000 workers per year
16-24	3,830 (18.7%)	7.7
25-34	5,761 (28.1%)	6.3
35-44	4,462 (21.7%)	4.8
45-54	3,924 (19.1%)	4.5
55-64	2,080 (10.1%)	3.8
65+	475 (2.3%)	2.7

*Age was missing for 32 claims
Source: CDPH (2025a)

Table 5.2.2. Total Number and Average Yearly Rates of Occupational Heat-Related Illness Claims by Sex in California, 2000–2022.

Sex**	Number and percent of total worker claims	Claims per 100,000 workers per year
Male	14,715 (72.2%)	6.8
Female	5,672 (27.8%)	3.2

Source: CDPH (2025a)

Table 5.2.3. Race and Ethnicity of Occupational Heat-Related Illness Emergency Department Patients, California, 2016–2023.

Race and ethnicity	**Number and percent of emergency department visits**
Hispanic, any race	2,661 (45%)
White, non-Hispanic	2,313 (39%)
Black, non-Hispanic	365 (6.2%)
Other or multiracial, non-Hispanic	295 (5.0%)
Asian or Pacific Islander, non-Hispanic	179 (3.0%)
Race/ethnicity unknown	112 (1.9%)

Source: CDPH (2025b)

Younger workers may be more likely to work in industries or occupations with a higher risk of heat exposure, undertake more physically demanding work, and/or lack work experience and adequate acclimatization to hotter temperatures. New workers are considered those who are new to or returning to a job and lack acclimatization to the heat. New workers are at risk for occupational heat illness because they may not be accustomed to the physical demands and environmental conditions of their job (Gibb et al., 2024).

Working conditions

Workers who perform physically demanding or strenuous tasks and/or work outdoors are particularly vulnerable to heat-related illnesses (Heinzerling et al., 2020; Gibb et al., 2024). Occupations posing the highest risk of heat illness include those working outdoors in hot climates, such as agriculture, construction, mining, and landscaping, as well as those in non-climate-controlled indoor settings, including production work (machine operators and food packers). Workers in these occupations are typically at

risk due to their exposure to hot environments, labor-intensive tasks, and lack of access to cooling resources, such as shade, air conditioning, and fans (Gibb et al., 2024). Outdoor workers are often exposed to the sun, and many farmworkers require extra clothing to protect themselves against pesticides and abrasive vegetation such as thorns or rough foliage. Research on heat-related illnesses among indoor workers remains limited. Indoor workers who use heat-generating equipment, particularly in poorly ventilated settings or non-climate-controlled environments, such as warehouses and food production facilities, may be at risk of heat-related illnesses (CDPH, 2023; Gibb et al., 2024).

The occupational group with both the highest number and rate of heat-related illnesses is “protective services”, which includes police and firefighters (**Table 5.2.4**; CDPH, 2025a). Heat-related illness was also commonly reported among workers in farming, fishing, and forestry; construction; and transportation and material moving occupations, though at lower rates than in protective services.

High ambient temperatures challenge the body’s ability to regulate internal temperature through evaporative cooling. Anything that limits sweat from evaporating, such as PPE or clothing, impairs the body’s ability to cool down (Gubernot et al., 2014), which in turn increases the risk of heat-related illness. Firefighting presents significant challenges for heat illness prevention, given the high heat exposure and exertion involved, as well as the heavy PPE required (West et al., 2020, **Figure 5.2.4**). Heat-related illnesses among firefighters have risen from 2001 to 2020 (Murray et al., 2024; **Figure 5.2.5**). The risk of heat-related illnesses in this group, especially among wildland firefighters, is expected to continue increasing as wildfires grow larger and more severe, and as fire seasons lengthen (see *Wildfires* chapter). Other occupations that may require heat-restrictive equipment or clothing include farmwork for pesticide applications (see *Farmwork Exposure to Pesticides* chapter) and construction, further increasing heat-related illness risk during periods of extreme heat.

Table 5.2.4. Total Number and Average Yearly Rates of Heat-Related Illness Claims for the 10 Highest Occupation Groups, California, 2000-2022.

Occupation Group	Number and percent of total claims*	Claims per 100,000 workers per year
Protective service occupations**	3,776 (22.4%)	50.2
Farming, fishing, and forestry occupations	1,928 (11.5%)	37.0
Construction occupations	2,114 (12.6%)	12.4
Transportation and material moving occupations***	2,115 (12.6%)	8.7
Building and grounds cleaning and maintenance occupations	1,028 (6.1%)	7.6
Installation, maintenance, and repair occupations	802 (4.8%)	7.5
Production occupations****	711 (4.2%)	4.1
Arts, design, entertainment, sports, and media occupations	226 (1.3%)	3.5
Architecture and engineering occupations	250 (1.5%)	3.1
Personal care and service occupations	189 (1.1%)	2.7

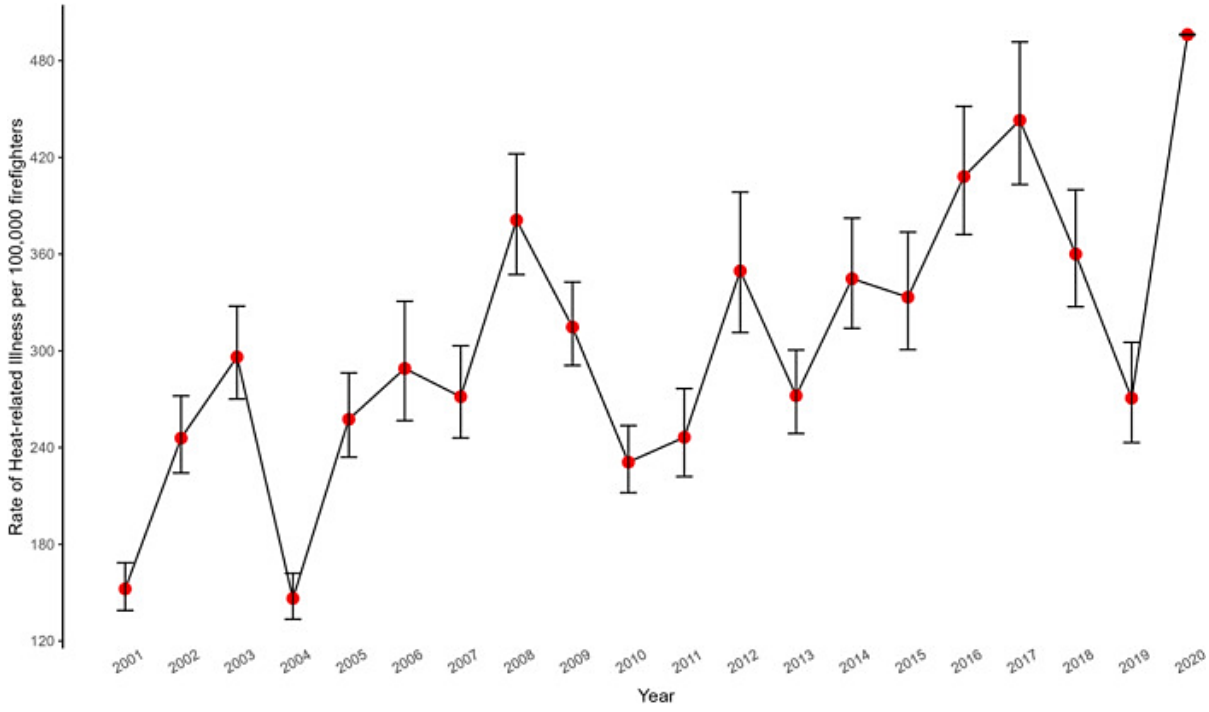
* Total number of claims = 20,564

** Includes firefighters, police officers, and correctional officers

*** Includes transportation workers, refuse collectors, and hand packers

**** Includes machine operators, assemblers, welders, and food packers Source: CDPH (2025a)

Figure 5.2.5. Rates of Heat-Related Illnesses in California Firefighters, 2001-2020.



The graph shows estimates of heat-related illnesses (red points) and 90% confidence intervals. Source: Murray et al. (2024).

Heat-related illnesses are also common among farmworkers (**Table 5.2.4**; CDPH, 2025a). The majority of farmworkers in California are immigrants who work long days during the summer season and have limited control over their work schedule and job tasks (ILO, 2019). Immigrant and migrant workers have high overall rates of occupational injuries; they often have extended work hours, poor working conditions, and limited safety training in comparison to their non-migrant counterparts. Language barriers can also interfere with health and safety training (Gibb et al., 2024). A study of heat strain in California farmworkers found an increased risk of acute kidney injury after a day of work, particularly among female workers who were paid by the amount they picked or harvested (Moyce et al., 2017).

In a California Heat Illness Prevention Study, core body temperature and work rate (monitored using a personal accelerometer) over a work shift were used to monitor

heat-related illness risk in 587 farmworkers (Langer et al., 2021). About 58,000 workers were at risk of elevated core body temperatures greater than or equal to 101.4°F, (38.6°C). Despite consuming more water compared to less active workers, many of those at risk still became dehydrated (15.7% of men and 3.3% of women). The study concluded that the risk of heat-related illness was exacerbated by both work rate and environmental temperature, despite farms adhering to Cal/OSHA heat-related illness regulations.

Incarcerated workers are also vulnerable to heat stress and often do not receive the same level of protection as many other workers. They perform various indoor and outdoor jobs, including firefighting, construction, cooking, cleaning, laundry, and manufacturing, many of which are at high risk for heat-related illnesses. The extent of the impact of heat exposure on incarcerated workers is unknown, as they are typically excluded from data sources that characterize occupational heat illness, which are limited to noninstitutionalized populations (Gibb et al., 2024).

Worker living conditions

The hazards created by extreme heat in the workplace are affected by the context in which workers live. Cities are often warmer than surrounding rural areas due to heat-absorbing materials such as concrete used for roads and buildings, without adequate shade. This phenomenon is called the urban heat island effect. Urban heat islands, combined with substandard worker housing, can prevent overnight cooling periods, which are crucial for reducing the risk of heat-related illnesses (Gibb et al., 2024).

Prevention

Heat-related illnesses are preventable, with well-established strategies to protect workers (Heinzerling et al., 2020). Two regulations enforced by the California Division of Occupational Safety and Health (Cal/OSHA) protect workers from heat-related illnesses. Since 2006, all employers with outdoor workers have been required to comply with the regulation for heat illness prevention in outdoor work, Title 8 CCR Section 3395. This requires employers to implement protections, including adequate shade, water, and rest breaks, as well as training, recordkeeping, and additional procedures for exposure to extreme heat. Beginning in fall 2024, employers with indoor workers have been required to comply with Title 8 CCR Section 3396, which mandates similar

protections for these workers. The California Department of Industrial Relations maintains information about both standards on their website: Cal/OSHA Heat Illness Prevention Guidance and Resources. Evidence suggests that these heat-safety regulations help mitigate some of the risk that outdoor workers face (Alahmad et al., 2025; Fomenko et al., 2025). After implementing Title 8 CCR Section 3395 in 2005, the rate of heat-related work injuries in California declined by approximately 30%, and heat-related deaths may have been reduced by as much as 43% after Cal/OSHA updated and strengthened the requirements in 2015 (Dean and McCallum, 2025).

Technical considerations

Data characteristics

When workers are injured or become ill on the job, a workers' compensation claim may be filed with their employer's workers' compensation insurance carrier. This occupational heat-related illnesses indicator is based on analyses by CDPH, which uses workers' compensation claims and ED visits to estimate the burden of heat-related illnesses in California. Findings of the workers' compensation analysis are presented in **Figure 5.2.1** and **Tables 5.2.1** through **5.2.3** (CDPH, 2025a). Findings of the emergency department analysis are presented in **Figure 5.2.2** and **Table 5.2.4** (CDPH, 2025b).

The Workers' Compensation Information System (WCIS), managed by the California Department of Industrial Relations, collects information on work-related illnesses and injuries that result in more than one day of lost work time or require treatment beyond first aid. Most, but not all workers are eligible for workers' compensation and workers may decline to file a claim for various reasons (CDPH, 2025a). Claims were identified as heat-related if the nature or cause of injury was heat-related, or if heat-related illness keywords were included in the injury description. Employment data from the US Bureau of Labor Statistics Current Population Survey was used to calculate rates of heat-related illnesses per 100,000 workers by sex, age, and occupation (CDPH, 2025a).

Each claim contains a description of the worker's occupation at the time of the claim. The National Institute for Occupational Safety and Health (NIOSH) Industry and Occupation Computerized Coding System was used to assign standard occupation

codes to individual occupations. To compare occupations with many versus few workers, average yearly rates of heat-related illnesses were calculated per occupation group, using the same classification system as NIOSH. Occupations employing fewer than 1,000 workers annually in California are excluded. WCIS data does not include information on the worker's race or ethnicity (CDPH, 2025a).

All state licensed emergency departments in California are required to submit summary information for each visit to the Department of Health Care Access and Information. These data include codes for the diagnoses received by the patient, as well as information about the patient, including age, race and ethnicity, and county of residence. CDPH searched these data for the years 2016–2023 for ED visits with heat-related illness diagnostic codes that were accompanied by either a code indicating a work-related event or that the medical bill was expected to be paid by Workers' Compensation Insurance. The diagnostic codes included heat-related illness included heat exhaustion, heat stroke, heat fatigue, heat syncope (fainting), heat cramps, and heat edema (swelling of extremities). The Occupational Health Branch followed CDPH guidelines on data de-identification and did not include identifying information in any results presented in this chapter (CDPH, 2025b).

Strengths and limitations of the data

Rates of reporting may also differ by industry and occupation. Some occupations, such as those with barriers to obtaining healthcare or struggle to file workers' compensation claims, are likely to be underrepresented. Other barriers to filing a workers' compensation claim include fear of retaliation (for example, getting hours reduced or being fired); vulnerability due to immigration status (for example, migrant farmworkers); and a lack of accessible information about rights when injured at work. Conversely, individuals who work in occupations with a high level of organized labor may face fewer barriers to filing a workers' compensation claim. Analyses of heat-related illness rates among incarcerated individuals were not included in this analysis due to the lack of available data on the total number of incarcerated people working in the state (CDPH, 2025a).

Additionally, the COVID-19 pandemic is likely to have affected workers' ability to seek care and may have resulted in lower rates of heat-related illnesses; therefore, caution must be used when comparing data from 2000–2019 to later years (CDPH, 2025a).

Milder heat-related cases, such as those treated at home, in the workplace, or in non-medical settings, would not be included in the data. In addition, there are likely to be occupational heat-related cases that were missed because any hospital records that did not include a work-related diagnostic code or list Workers' Compensation insurance as the payer would be excluded (CDPH, 2025b).

OEHHA acknowledges the expert contribution of the following to this report:

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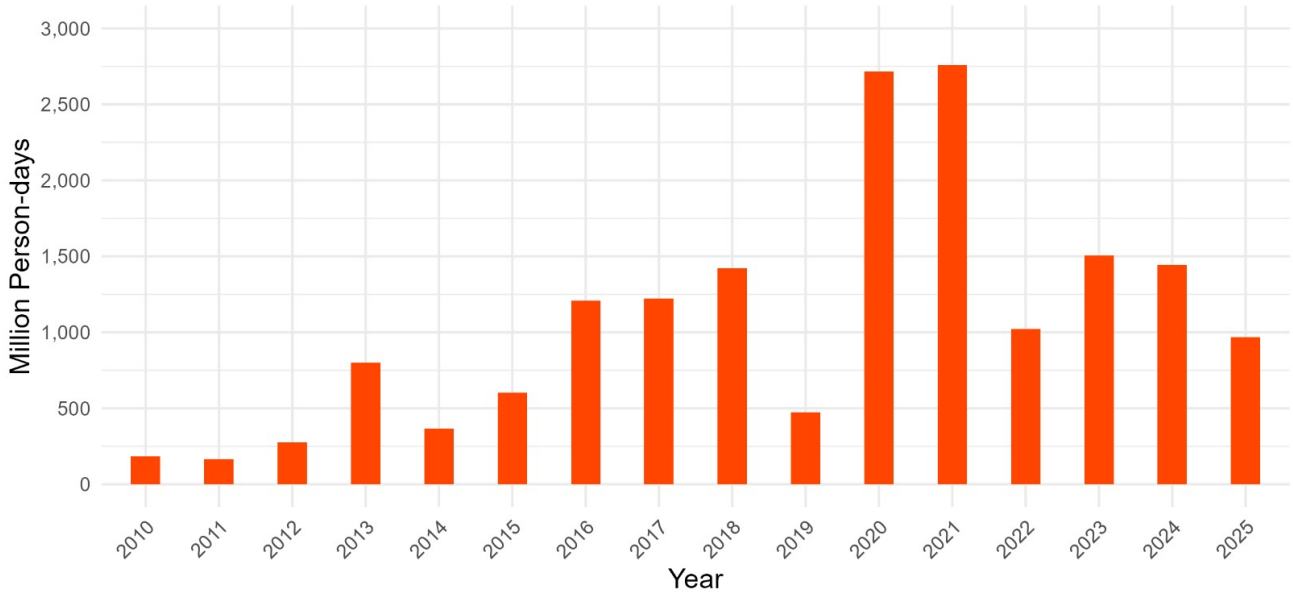
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5.3 Wildfire Smoke and Human Health

Wildfire smoke has become an increasingly important climate-related hazard to air quality and public health in California. Climate change contributes to more frequent, intense, and severe wildfires, causing regions across the state to experience longer-lasting smoke impacts that extend far beyond the fire perimeter. Because wildfire smoke affects populations across broad geographic areas and contributes to the state's growing burden of climate-related illness, this indicator examines two complementary measures: a smoke metric, which tracks population impacts from wildfire smoke and related fine particulate matter exposure, and a health metric, which tracks associated respiratory health impacts over time. Together, these metrics provide a more complete picture of the statewide impacts of wildfire smoke.

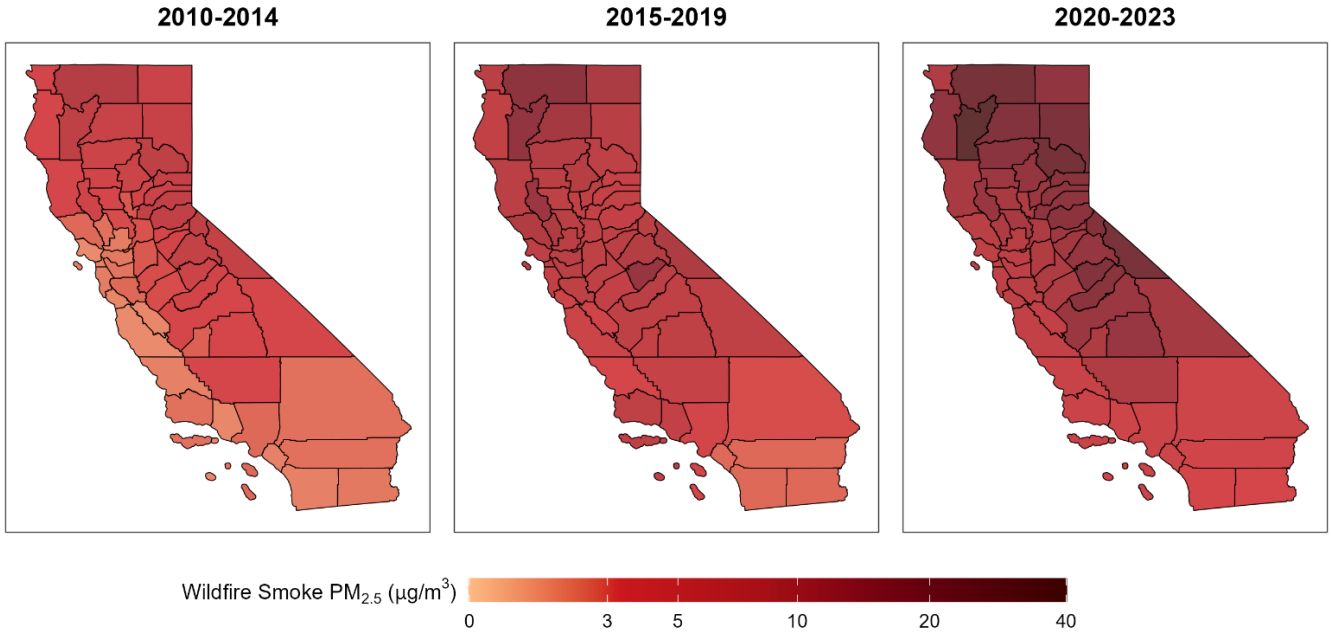
Figure 5.3.1. Statewide Population Impacts from Wildfire Smoke, 2010-2025.



This graph shows annual "person-days" of wildfire smoke, which represents the estimated number of people living in California in areas where smoke plumes were present, multiplied by the number of days plumes were present, for each year from 2010-2025. Estimates are based on the presence of smoke plumes over populated areas and may not reflect smoke impacts at ground-level where people breathe. Source: CDPH (2026), NOAA Hazard Mapping System, U.S. Census Bureau Centers of Population[1]

[1] California Department of Public Health (CDPH), Environmental Health Investigations Branch;

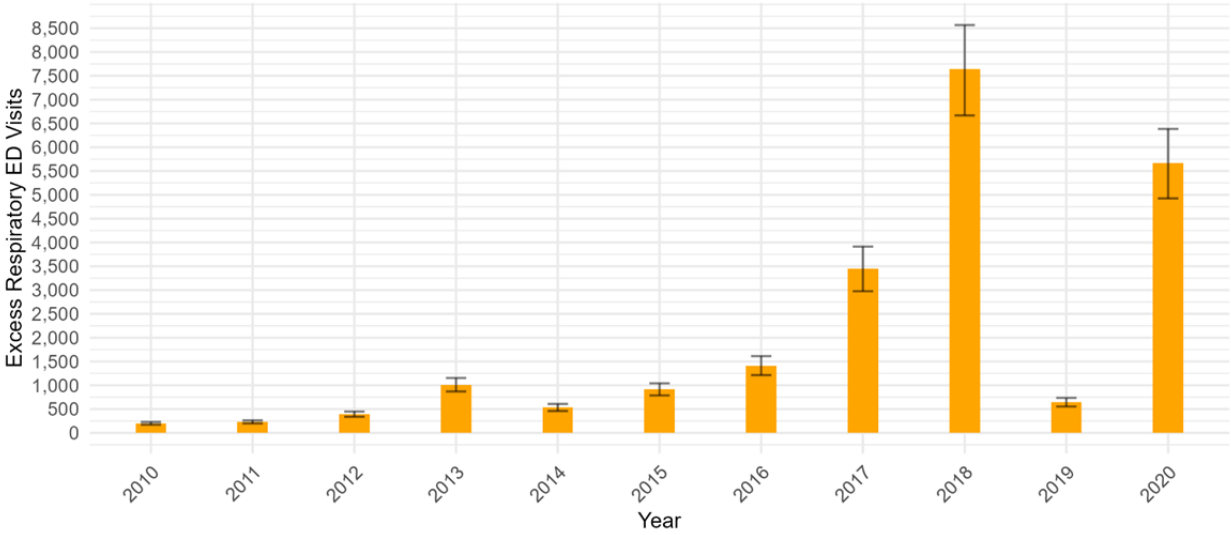
Figure 5.3.2. Average Annual Wildfire Smoke $PM_{2.5}$ Concentrations by County, 2010-2014, 2015-2019, and 2020-2023.



The maps show county-level average annual wildfire-specific $PM_{2.5}$ (WF-$PM_{2.5}$; fine particulate matter specifically attributed to wildfire smoke emissions) in micrograms per cubic meter ($\mu g/m^3$), based on daily average estimates. County averages are summarized as 5-year averages for 2010-2014 and 2015-2019, and as a 4-year average for 2020-2023. Source: Childs et al. (2025) Updated v2.0 preprint data, made available through the Stanford Environmental Change and Human Outcomes Lab.

National Oceanic and Atmospheric Administration (NOAA), Hazard Mapping System, Smoke Product; U.S. Census Bureau, Centers of Population by Block Group

Figure 5.3.3. Statewide Wildfire Smoke $PM_{2.5}$-Attributable Respiratory Emergency Department (ED) Visits, 2010-2020.



Total Excess Respiratory ED Visits (2010-2020): 22,096 (95% CI: 19,161-24,953)

This graph presents the estimated number of annual respiratory-related ED visits that were associated with WF-$PM_{2.5}$ exposure during a wildfire seasonal period (May-November) from 2010-2020. The "attributable number" represents the estimated excess number of respiratory ED visits beyond what would have been expected had there been no WF-$PM_{2.5}$. The 95% confidence interval (CI) represents the degree of uncertainty around the estimate. Source: Analysis by the California Department of Public Health (CDPH) (2026), Environmental Health Investigations Branch

What does the indicator show?

Smoke metric

Population impacts from wildfire smoke in California have risen substantially since 2010 (**Figure 5.3.1**). From 2010–2014, annual person-days of smoke were relatively low (168–800 million). By the mid-to-late 2010s, annual person-days increased to 475 million–1.4 billion. The highest annual person-days occurred in 2020 and 2021, when record-breaking wildfires led to unprecedented smoke impacts across the state, reaching approximately 2.7 billion person-days in each year. During 2022-2025, when wildfire activity was less severe, annual person-days of smoke remained elevated above pre-2015 levels, ranging from approximately 968 million to 1.5 billion.

Average annual concentrations of wildfire smoke $PM_{2.5}$ (WF-$PM_{2.5}$), or fine particulate matter less than 2.5 microns in diameter derived from wildfire smoke emissions, have also increased, both in the magnitude of concentrations and in geographic extent (**Figure 5.3.2**). During 2010-2014, the highest average annual concentrations were limited primarily to the northern and eastern parts of the state, while WF-$PM_{2.5}$ remained relatively low (below 3.0 µg/m^3) across much of California. During 2015-2019, over half of California counties experienced annual average WF-$PM_{2.5}$ concentrations of 3.5 to 6.0 µg/m^3 (52%), while some counties in the northern region reached concentrations up to 11.4 µg/m^3. During 2020-2023, annual average WF-$PM_{2.5}$ concentrations increased substantially, reflecting the severe smoke impacts of 2020 and 2021. Several highly impacted counties, particularly in the northern and eastern regions, including Mono, Siskiyou, Plumas, and Trinity, experienced annual average WF-$PM_{2.5}$ concentrations above 24.0 µg/m^3, with Trinity County reaching 40.0 µg/m^3.

Health metric

Across wildfire seasons (May-November) from 2010-2020, an estimated 22,096 excess respiratory emergency department (ED) visits (95% CI: 19,161-24,953) were attributable to WF-$PM_{2.5}$ exposure (**Figure 5.3.3**). Annual excess respiratory ED visits increased over time, from about 200 in 2010 to over 5,500 in more recent years. The largest increases occurred in 2017, 2018, and 2020, during severe wildfire seasons that included major fires such as the Thomas Fire, Camp Fire, and August Complex Fire. In 2020, the estimated number of WF-$PM_{2.5}$ attributable respiratory ED visits (5,667) was lower than in 2018, likely reflecting the sharp decline in ED utilization during the onset of the COVID-19 pandemic. Overall, the upward trend in WF-$PM_{2.5}$ attributable respiratory ED visits indicates that wildfire smoke became an increasing contributor to the statewide respiratory health burden over time, particularly during years with more severe smoke impacts.

Why is this indicator important?

Smoke Metric

Wildfire smoke is an increasingly important air quality concern in California. As the frequency, intensity, and duration of wildfire smoke events has increased, smoke

emissions have begun to offset improvements in air quality achieved over past decades (Deng et al., 2026; Jaffe et al., 2026; Jaffe et al., 2020). Recent research suggests that wildfire smoke now contributes up to 50% of ambient fine particulate matter ($PM_{2.5}$) in the western U.S., underscoring its growing influence on regional air quality (Burke et al., 2022). Wildfire smoke has become an increasingly important driver of harmful $PM_{2.5}$ pollution exposure in California and is no longer limited to isolated air quality events during the most severe fire seasons.

Wildfire smoke is a complex mixture of fine particles and gases, and its composition can vary depending on the types of vegetation or material burned, fire behavior and intensity, and weather conditions. $PM_{2.5}$ is the most studied component of wildfire smoke and among the most harmful to health, because these particles can remain in the air for extended periods and travel long distances. $PM_{2.5}$ can penetrate deep into the lungs, enter the bloodstream, and affect the heart and other organs. Wildfire smoke also contains other hazardous pollutants, including carbon monoxide, nitrogen oxides, volatile organic compounds, polycyclic aromatic hydrocarbons, and metals. Some of these pollutants, such as benzene and formaldehyde, are known carcinogens.

In addition to smoke generated from burned vegetation, fires that burn in the wildland-urban interface (WUI) – areas where built structures and developed landscapes intermix with wildland vegetation – can produce a more complex mixture of toxic pollutants from building materials, household products, vehicles, and other synthetic sources. These emissions can create more hazardous air pollution than smoke from wildfires that burn primarily vegetation. A recent analysis reported that large wildfires that burned more structures produced smoke containing toxic heavy metals such as lead and zinc (CARB, 2021).

More generally, wildfire smoke can infiltrate indoor environments like schools, workplaces, and homes, affecting the air people breathe indoors. Smoke can enter through doors, windows, ventilation systems, or other openings if not properly sealed, contributing to unhealthy indoor air. As people spend most of their time indoors, smoke that infiltrates buildings can become an important source of smoke exposure during wildfire events, especially when sheltering indoors (Liang et al., 2021).

Wildfire smoke can also interact with other air pollutants and climate-related exposures. Across the western U.S., smoke emissions have been associated with increasing co-occurrence of hazardous $PM_{2.5}$ and ground-level ozone concentrations, particularly during summer months when strong UV light and higher temperatures can promote ozone formation (Kalashnikov et al., 2022). Over the last two decades, these overlapping events have contributed to greater population exposure to multiple harmful air pollutants (Kalashnikov et al., 2022).

As wildfire seasons become longer and more severe, wildfire smoke is also increasingly co-occurring with extreme heat, which is also becoming more frequent in California (see the *Extreme Heat Events* chapter). When wildfire smoke and extreme heat occur at the same time, this compound climate hazard may pose greater health risks than either exposure alone (Chen et al., 2024a; Jones-Ngo et al., 2025a; Rahman et al., 2022). These co-occurring exposures also create additional challenges related to cooling, air filtration, and other resources used to reduce smoke and heat exposure. In 2020, extreme heat and high concentrations of wildfire-related $PM_{2.5}$ co-occurred at least once across 68% of California's land area, occurring an average of 2.5 times across affected areas. An estimated 16.5 million people, or 42% of the state's population, were exposed to at least one such compound event (Rosenthal et al., 2022).

Health Metric

Exposure to wildfire smoke is an increasingly important contributor to respiratory-related morbidity, as well as other adverse health impacts that are experienced disproportionally across populations and regions of the state. Epidemiologic and toxicological studies of wildfire smoke-related health effects have focused primarily on wildfire smoke $PM_{2.5}$, while less is known about the health effects associated with gaseous components of wildfire smoke (Chen et al., 2021; Chen et al., 2024b; Kim et al., 2018). Some studies also suggest that wildfire smoke $PM_{2.5}$ may pose greater adverse health effects than $PM_{2.5}$ from other ambient sources due to its complex pollutant mixture and toxicity (Aguilera et al., 2021). The strongest and most consistent evidence on the health effects of wildfire smoke relates to short-term respiratory outcomes associated with exposure on the day of a smoke event and over the following several days (Gould et al., 2024; Reid et al., 2016). Wildfire smoke has been associated with asthma exacerbation, reduced lung function,

chronic obstructive pulmonary disease, pneumonia, and heart conditions, such as congestive heart failure and cardiac events (Cascio, 2018; US EPA, 2019). Evidence for cardiovascular-related impacts has been reported, although findings are generally less consistent compared to respiratory outcomes (Chen et al., 2021; Reid et al., 2016; Thilakaratne et al., 2023). These health impacts are often tracked and studied using healthcare utilization data, such as emergency department visits and hospitalizations, as well as other health indicators that allow researchers to quantify how the health burden of wildfire smoke changes over time and across populations.

Evidence is expanding beyond respiratory and cardiovascular-related health effects and increasingly includes adverse birth outcomes, cognitive and neurodegenerative effects, premature mortality, and mental health effects, including anxiety, depression, psychotic episodes, and suicidal behavior (Cleland et al., 2022; Connolly et al., 2024; Eisenman and Galway, 2022; Elser et al., 2025; Heft-Neal et al., 2022; Jung et al., 2025; Ma et al., 2024; Qiu et al., 2025; Zhu et al., 2024). However, research on health effects beyond acute impacts remains limited and continues to develop with advancements in data availability and methodological approaches.

Concerns are growing about the health effects of repeated and long-term wildfire smoke exposure (Casey et al., 2024; Hao et al., 2026; Jin et al., 2025; Schwarz et al., 2025). More frequent multi-day smoke events and shorter intervals between events (recovery periods) may limit the ability of communities to fully recover between periods of hazardous air quality (Jones-Ngo et al., 2025b). Emerging evidence also suggests that repeated and long-term wildfire smoke exposure may contribute to chronic diseases such as diabetes, dementia, and stroke, as well as all-cause and cause-specific mortality (Connolly et al., 2024; Elser et al., 2025; Hao et al., 2026; Ma et al., 2024; Zhang et al., 2026). Additional research is needed to better understand how these changing exposure patterns may affect long-term health.

Some populations and communities may be more affected by wildfire smoke than others. Identifying who is most affected and where public health impacts are most severe is important for prioritizing public health actions and protective resources across the state. Infants, children, older adults, pregnant people, individuals with pre-existing health

conditions, unhoused populations, outdoor workers, wildland firefighters, and communities facing environmental, socioeconomic, and racial inequities may be disproportionately affected by wildfire smoke (Cascio, 2018; Casey et al., 2024; Gould et al., 2024). These unequal health burdens reflect differences in both exposure and vulnerability to wildfire smoke, which are influenced by the conditions in which people live and work. Current evidence indicates that several populations experience disproportionate exposure to wildfire smoke; studies have also reported differential health effects across sociodemographic groups, although this evidence remains less consistent (Casey et al., 2024; Heaney et al., 2022; Kondo et al., 2019; Reid et al., 2016; Stowell et al., 2025).

Tribal Connection 5.3.1

California Native American Tribes also face disproportionate impacts due to the legacy of genocide and forced relocation, which continues to perpetuate health and economic inequities today. For example, a member of the Big Pine Paiute Tribe in the Owens Valley writes: *"As our people no longer travel to the mountains to live during the hotter summer months, they are routinely exposed to higher temperatures in the summer. Summer is typically dry and windy, with exposure to smog from tourist vehicles and smoke from California wildfires. During the 2020 fire season, residents of the Owens Valley were forced to remain indoors for many months straight. It should be noted that during this time there was little wind, which allowed the smoke to settle over the town of Big Pine; many people commented about how unusual it was. Not all households own air conditioners or swamp coolers, so many people are left in houses that are too hot to safely occupy."* (Big Pine, 2026)

Assessing the health burden of wildfire smoke provides critical information to support emergency preparedness and response, strengthen adaptive capacity, and reduce population exposure during smoke events. Mitigating smoke-related health impacts requires timely smoke and health data, accessible public health communications, and expanded access to protective resources. Improved data can support situational

awareness and inform state and local response activities, while clear, actionable, culturally and linguistically appropriate guidance delivered through multiple channels can help communities take recommended protective actions. More equitable access to resources such as Clean Air Centers, N95 respirators, and portable air cleaners can further support efforts to reduce smoke exposure.

What factors influence this indicator?

Several factors contribute to wildfire smoke exposure and related health impacts across California, including wildfire activity and smoke intensity, geographic and community characteristics, health inequities, access to protective resources, individual protective behaviors, and other contextual factors that may affect emergency department utilization or healthcare-seeking behavior.

Wildfire Activity and Smoke Intensity

Wildfire smoke-related $PM_{2.5}$ concentrations vary widely across California due to differences in the characteristics of landscape fires and the specific conditions that influence how smoke is generated, transported, and experienced by communities in different regions of the state year to year. The location and size of a wildfire, the intensity of the burning, the types of vegetation and materials burned, how dry (or moist) the vegetation is, and the rate at which an area burns all influence the amount of WF-$PM_{2.5}$ emitted into the atmosphere (Reid et al., 2016). Fires that are larger, more intense, and longer-lasting are often due to hotter and drier burn conditions, or accumulated vegetation, and typically generate higher WF-$PM_{2.5}$ emissions and wider geographic impacts (Williamson et al., 2016).

Meteorological and topographic characteristics, including wind speed and direction, temperature, humidity, and atmospheric inversions, further influence how smoke is transported and dispersed (Jaffe et al., 2020). In regions of California prone to temperature inversions, such as the Central Valley and mountain basins, smoke can remain trapped at ground-level for extended periods, increasing the duration of population exposure (Gao et al., 2023). Additionally, as smoke disperses in the atmosphere, its chemical composition and toxicity can transform through interactions with other pollutants, contributing to both regional and compositional differences in pollution

mixtures (Altshuler, 2020; Jaffe et al., 2020). Together, these factors contribute to significant geographic and seasonal variations in WF-$PM_{2.5}$ concentrations across the state.

Geographic and Community Characteristics

Geographic and community characteristics influence both population exposure and vulnerability to wildfire smoke across California. Rural and more remote communities often face disproportionate smoke impacts due to their proximity to wildfire-prone areas. These regions may also face additional vulnerabilities that affect adaptive capacity, such as longer travel times to seek healthcare services, fewer local resources to mitigate smoke exposure, or limited access to timely information during smoke events. As wildfire activity intensifies and expands across the state, fires occurring in WUI areas may increasingly affect more densely populated communities (Alshehri et al., 2023; Krasovich Southworth et al., 2025). Similarly, changing patterns in California's population growth, mobility, and migration, such as expanded development in WUI areas, may further contribute to geographic variations in wildfire smoke exposure and related health impacts by changing where people and housing are located relative to wildfire activity.

In addition, community characteristics such as age distribution, underlying health status, occupational conditions such as outdoor or emergency response work, and housing conditions can contribute to differences in wildfire smoke exposure and associated health outcomes (D'Evelyn et al., 2022; Do et al., 2024). Communities with a higher prevalence of chronic conditions such as asthma, heart disease, or diabetes may experience greater wildfire smoke-related health impacts (Reid et al., 2023; Liu et al., 2015). Together, these characteristics influence population-level and regional variations in wildfire smoke exposure and health impacts and point to important inequities in community capacity to prepare for and respond to smoke events.

Health Inequities, Access to Resources, and Protective Actions

Health inequities are often reflected in social determinants of health, such as income, education, occupation or workplace conditions, access to healthcare, and housing quality, which shape both vulnerability and the ability to mitigate exposure to wildfire smoke (Kramer et al., 2023; Weheba et al., 2024). These inequities are rooted in historical and ongoing environmental injustice, housing, and land use policies that concentrate social

and environmental burdens in specific neighborhoods and populations across California, contributing to greater smoke and health impacts (Casey et al., 2024; D'Evelyn et al., 2022; Jung et al., 2024; Lane et al., 2022).

For many of these communities, wildfire smoke can act as a threat multiplier, adding to existing environmental burdens, including poor air quality, multiple sources of pollution, low housing quality, and other environmental hazards further compounded by frequent smoke events (Davies et al., 2018; Reid et al., 2023). These overlapping burdens can increase vulnerability during smoke events, particularly for communities and individuals that already face barriers in managing underlying health conditions or accessing protective resources such as air conditioning, indoor air filtration, well-sealed indoor environments, or other health-protective resources (Jaffe et al., 2020).

Individual behavioral responses and protective actions during wildfire smoke events influence the extent of exposure and risk of health impacts (Burke et al., 2022). People may evacuate, temporarily relocate, reduce outdoor activity, wear N95 respirators, use indoor air filtration, or take other actions to reduce exposure to smoke. However, the ability to adopt these health-protective behaviors varies across communities in California and may be limited by the inequities and resource constraints described above.

Interpretation of Emergency Department (ED) Utilization in 2020

The WF-$PM_{2.5}$-attributable respiratory burden estimated for 2020 should be interpreted in the context of significant changes in healthcare utilization patterns and pandemic-related behaviors during the COVID-19 pandemic. The ED visit data showed a substantial decline in respiratory ED visits from all causes during 2020, reflecting reduced utilization and general avoidance of healthcare services during the early period of the pandemic. Moreover, widespread adoption of health-protective behaviors, such as spending more time indoors, masking, and using indoor air filtration, may have altered the conditions under which respiratory health impacts attributable to wildfire smoke were estimated. In addition, changes in COVID-19-specific ICD-10 coding practices during this period may have influenced how respiratory ED visits were recorded or classified in administrative health data. Consequently, these pandemic-related factors complicated direct

comparisons between 2020 and earlier wildfire seasons and limited the ability to fully characterize the wildfire smoke-attributable respiratory burden for 2020.

Technical considerations

Data sources

Smoke Metrics

Population impacts from wildfire smoke were estimated using daily smoke plume data from the National Oceanic and Atmospheric Administration (NOAA) Hazard Mapping System (HMS) Smoke Product and population data from the U.S. Census Bureau Centers of Population by Block Group. HMS is a satellite-based smoke product that maps the spatial extent of visible smoke plumes across North America over 24-hour periods. Block group centers of population from the 2010 Census were used for 2010-2019, and 2020 Census centers of population were used for 2020-2025.

Annual person-days of smoke were estimated using HMS smoke polygons, which were intersected with block group centers of population to identify areas and populations potentially impacted by smoke each day. For each year, population counts in smoke-affected areas were multiplied by the total number of days smoke was detected. Person-days were then summed across all impacted areas to estimate total annual person-days of smoke across California.

Daily wildfire-specific $PM_{2.5}$ concentrations were obtained from high-resolution wildfire smoke $PM_{2.5}$ datasets by Childs et al. The health impact assessment used the Childs et al. (2022) dataset, which provides modeled daily (24-hour average) concentrations of fine particulate matter derived specifically from wildfire smoke across the contiguous United States from 2006 to 2020. WF-$PM_{2.5}$ concentrations were estimated using a data fusion and machine-learning modeling framework that integrates ground-based air quality monitoring data, satellite observations, smoke dispersion modeling, and meteorological data. Daily WF-$PM_{2.5}$ estimates were generated at a 10-km gridded resolution and subsequently downscaled to the ZIP Code Tabulation Area (ZCTA) level using population- and area-of-intersection-weighted averaging.

The county-level WF-$PM_{2.5}$ concentrations shown in **Figure 5.3.2** were estimated using the updated v2.0 preprint dataset from Childs et al. (2025), which extends the period

through 2023. Daily WF-$PM_{2.5}$ estimates were extracted for California ZCTAs from 2010-2023 and aggregated to the county level. County-level daily estimates were then averaged annually and summarized for the 2010-2014, 2015-2019, and 2020-2023 periods.

Health Metric

Statewide emergency department (ED) visit records were obtained from the California Department of Health Care Access and Information (HCAI), which maintains administrative records of all ED visit encounters in California. Respiratory-related ED visits were identified using principal diagnosis codes from the *International Statistical Classification of Diseases, Ninth* and *Tenth Revisions* (ICD-9 and ICD-10), with respiratory diseases defined using diagnosis codes 460-519 (ICD-9) and J00-J99 (ICD-10). Daily ED visit counts were aggregated to the ZCTA level for each May-November period from 2010-2020 and restricted to encounters with a residential ZIP code in California. The daily ED visit counts were then linked with the WF-$PM_{2.5}$ data by residential ZIP code and date.

A health impact assessment framework was used to estimate the excess number of respiratory ED visits attributable to WF-$PM_{2.5}$ exposure in California from 2010-2020 (Gasparrini & Leone, 2014). This assessment used a previously published health effect estimate, which represents the association between short-term WF-$PM_{2.5}$ exposure and respiratory-related ED visits, and applied the corresponding concentration-response function (CRF) to calculate the population-level health burden attributable to wildfire smoke. The CRF describes how changes in daily WF-$PM_{2.5}$ concentrations relate to corresponding changes in respiratory ED visits.

Specifically, a published health effect estimate from Stowell et al. (2025) was used. This health effect estimate reflects the cumulative change in risk of respiratory-related ED visits over seven days following WF-$PM_{2.5}$ exposure in California (2012-2019). For this indicator, the cumulative 7-day risk estimate was converted into a CRF that reflects the proportional change in respiratory ED visit risk per $\mu g/m^3$ increase in WF-$PM_{2.5}$. The wildfire season was defined as the period from May through November each year, as this

exposure window captures the months when wildfire activity and WF-$PM_{2.5}$ concentrations are most common in California.

The attributable number, or the estimated number of respiratory ED visits associated with wildfire smoke was calculated to compare wildfire smoke-attributed respiratory impacts across years. Daily ZCTA-level WF-$PM_{2.5}$ estimates were used to assign exposure values to corresponding ED visit counts by residential ZIP code and date. WF-$PM_{2.5}$ attributable ED visits were estimated for each ZCTA-day in which WF-$PM_{2.5}$ concentrations were above 0 μg/m^3. These ZCTA-day estimates were then summed across all impacted days within each year to quantify the number of respiratory ED visits associated with wildfire smoke during each May-November wildfire season from 2010-2020.

A concentration limit of 100 μg/m^3 was applied to reduce the potential for overestimation at very high WF-$PM_{2.5}$ concentrations. For any ZCTA-day in which WF-$PM_{2.5}$ exceeded 100 μg/m^3, concentrations were set to 100 μg/m^3 before estimating the WF-$PM_{2.5}$ attributable number of ED visits (affecting <1% of data). This approach attempted to adjust daily attributable ED visit estimates that may be disproportionately affected by a small portion of ZCTA-days with severe smoke impacts, particularly in 2017, 2018, and 2020, when several areas of California experienced extreme levels of WF-$PM_{2.5}$. By excluding exposures above 100 μg/m^3, this indicator provides more conservative estimates of wildfire smoke-attributable respiratory health impacts during the most severe smoke events.

Metric Formula:

Attributable Number = *Observed ED Visits* $x\left(1-\frac{1}{RR_{\Delta WF-PM2.5}}\right)$

Where:

Observed ED Visits = the total number of respiratory ED visits from all causes for a given ZCTA-day

RR = the relative risk associated with the WF-$PM_{2.5}$ concentration on that ZCTA-day, based on the concentration-response relationship reported in Stowell et al. (2025)

$\Delta WF\text{-}PM_{2.5}$ = the WF-$PM_{2.5}$ concentration on that ZCTA-day, relative to a counterfactual of no wildfire smoke exposure (WF-$PM_{2.5}$ = 0)

Strengths and limitations

Smoke Metric

The HMS Smoke Product is publicly available, updated daily, and covers all of North America, providing consistent and timely observations of smoke plume detections derived from satellite imagery and validated by human analysts. HMS is valuable for producing geographically relevant indicators of fire-related smoke plumes for characterizing smoke impacts across space and time. However, HMS smoke detections should be interpreted as an indicator of potential population exposure rather than a direct measure of ground-level air quality conditions or individual-level exposure. While HMS detects visible smoke in the atmosphere, it cannot determine the height of smoke plumes or whether smoke was near ground level where people breathe. Satellite-based smoke detections can also be influenced by cloud cover, daylight availability, and the timing of observations over a given area. Smoke plumes can shift rapidly and may not be fully captured by detections, which may impact the coverage and accuracy of HMS data.

Person-days of smoke should also be interpreted within this context. This metric is based on residential population locations and does not account for mobility, evacuation, time spent indoors, use of air filtration, or other protective measures. Additionally, because person-days are calculated by multiplying smoke days by number of people in an affected area, the metric gives greater weight to smoke events occurring in more densely populated areas and may understate impacts in less populated rural areas that may experience more frequent smoke but contribute fewer total person-days.

The WF-$PM_{2.5}$ exposure metric is derived from modeled daily ZCTA-level estimates of wildfire-specific $PM_{2.5}$. The model provides fine-scale estimates of wildfire smoke intensity across California, particularly in areas where stationary monitors or air quality sensors are sparse or unavailable. This allows wildfire-specific $PM_{2.5}$ concentrations to be characterized across space and time in ways that would not be possible using monitoring data alone. Although the model is well validated and demonstrated strong performance, WF-$PM_{2.5}$ estimates may be less certain at very high concentrations, which may introduce exposure measurement error in high-impact locations. The WF-$PM_{2.5}$ estimates reflect wildfire-derived $PM_{2.5}$ only and do not account for potential exposure to other pollutants, co-pollutant mixtures, or co-occurring exposures such as extreme heat and wildfire

smoke, all of which may modify respiratory-related health effects associated with WF-$PM_{2.5}$ exposure.

Health Metric

The health indicator applied a well-validated health impact assessment approach using a peer-reviewed, California-specific health effect estimate that reflects the cumulative respiratory effects of wildfire smoke over a seven-day exposure period. The indicator also used established data sources, consistent with those applied in Stowell et al. (2025), to integrate modeled WF-$PM_{2.5}$ estimates with statewide emergency department data, providing strong generalizability across the 2010-2020 study period.

The use of respiratory ED visit encounters (identified by ICD-9/10 diagnostics codes), a well-established health outcome in air quality and wildfire smoke health studies, provided a valid and standardized measure of respiratory impacts at the population-level. The health data captured more than five million respiratory ED visits over an 11-year period, enabling the characterization of statewide trends in wildfire smoke-related health impacts across more than a decade of wildfire seasons in California. Lastly, the characterization of population-level health impacts using the attributable number provides a clear and interpretable measure of estimated wildfire smoke-related health impacts in California.

However, the health indicator is based on administrative emergency department visit data, and therefore only captured respiratory health events that resulted in an ED visit encounter. This excludes urgent care visits, outpatient care, hospital admissions, and subclinical respiratory symptoms that may have also resulted from wildfire smoke exposure. The indicator does not include differences in health impacts by age, race-ethnicity, sex or gender identity, socioeconomic status, health status, or other factors that may result in disproportionate health impacts among specific subpopulations. Finally, behavioral responses to smoke and health-protective actions, such as mask use, indoor air filtration, access to clean air spaces, and other adaptive strategies, are not captured in the available data, though may substantially protect individuals from exposure and associated health outcomes. Taken together, these strengths and limitations provide important context for interpreting the smoke and health indicators presented in this chapter.

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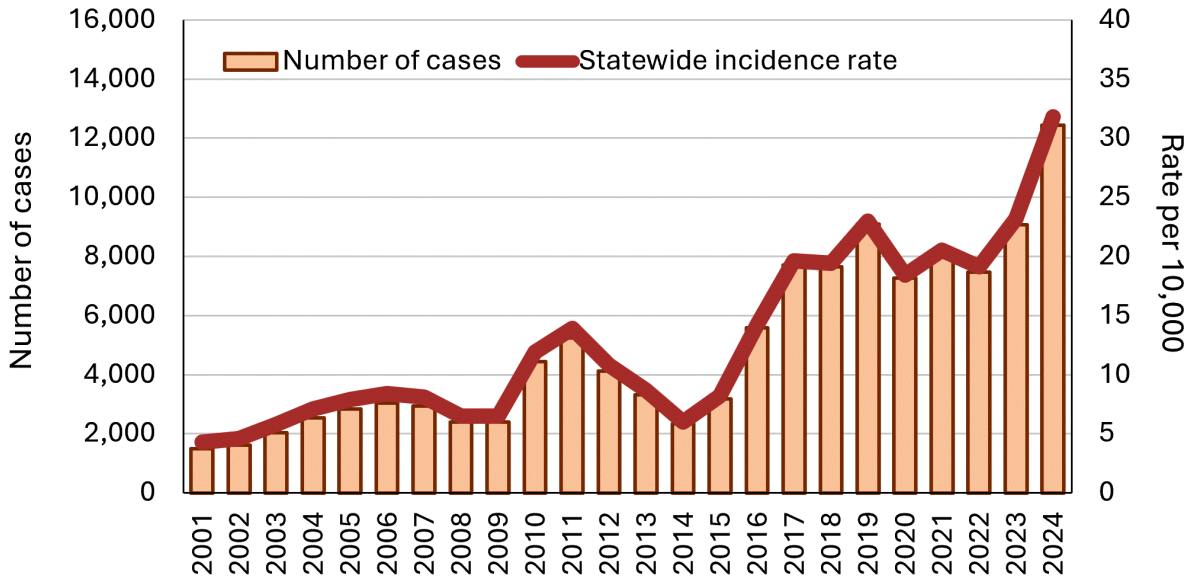
Zhang S, Wang Y, Wei J, Benmarhnia T, Liu Y, et al. (2026). Impact of long-term cumulative exposure to wildfire smoke $PM_{2.5}$ on cardiovascular hospital admissions among older adults in the United States: A Population-Based Cohort Study. *Journal of the American College of Cardiology* S0735-1097(**25**)10660-8. Advance online publication.

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5.4 Valley Fever

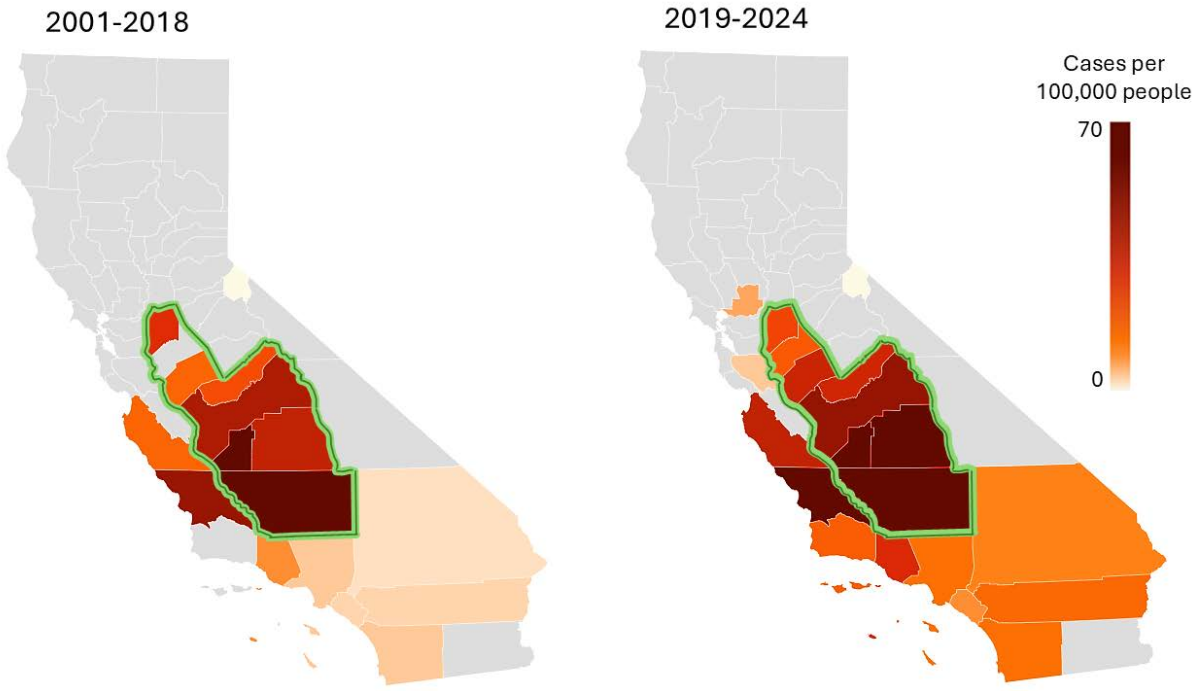
The incidence of Coccidioidomycosis, commonly known as Valley fever, has increased over the past 20 years. Valley fever is caused by inhaling spores of the *Coccidioides* fungus that is endemic to the soil in parts of southwestern United States. Approximately 97% of Valley fever cases in the United States are reported in California and Arizona. The fungus usually infects the lungs, causing respiratory symptoms. Pets and other animals can also be infected. Valley fever is impacted by climatic changes and is an increasing public health burden.

Figure 5.4.1. Valley Fever Annual Number of Cases and Incidence Rates (2001-2024).



Source: CDPH Valley Fever Dashboard (2026)

Figure 5.4.2. Valley Fever Incidence Rates by County.



The figure above shows average historical (2001-2018) and recent (2019-2024) incidence rates (cases per 100,000 people) by county in California. Counties in the historically endemic Central Valley are outlined by the green border. Darker colors indicate higher rates. Grey areas represent counties where there are too few cases to calculate reliable rates.
Source: CDPH Valley Fever Dashboard (2026)

What does the indicator show?

The number of Valley fever cases in California has greatly increased in recent years. As shown in **Figure 5.4.1**, the annual incidence of reported cases of Valley fever has increased fivefold from 2001 (with a rate of 4.3 cases per 100,000 people) to 2024 (rate of 31.8 cases per 100,000 people). Notably, Valley fever cases tripled from 2014–2018, and from 2018–2022, between 7,000 and 9,000 cases were reported each year. In 2024, the number of new cases reported was the highest on record.

The geographic range of Valley fever appears to be expanding. Valley fever is named after the Central Valley, where most cases have been consistently reported. Kern County reported the highest number of new cases in 2023, with 3,012 cases. However,

over the last decade, increasing cases have been detected in surrounding counties, such as Monterey and San Joaquin (**Figure 5.4.2**; Sondermeyer Cooksey et al., 2020) and even more northerly locations like Washington state (Johnson et al., 2014).

A regional analysis of surveillance data from 2000 to 2018 suggested that, despite the consistently high rates of Valley fever in the Southern San Joaquin Valley, the largest increases in incidence have occurred outside of that region, primarily in Northern San Joaquin Valley, Central Coast, and Southern Coast regions (Sondermeyer Cooksey et al., 2020). From 2020 to 2024, the largest increases were seen in the northern San Joaquin Valley (253% increase, Merced, San Benito, San Joaquin, Stanislaus counties) and the Central Coast (107% increase, Monterey, San Luis Obispo, Santa Barbara, Santa Cruz, and Ventura counties).

Why is this indicator important?

Each year in California, around 80 deaths and over 1,000 hospitalizations are attributed to Valley fever. Valley fever can develop into a potentially debilitating disease. Inhaling only a few spores of the fungus may lead to infection, so even limited exposure, such as passing through dusty environments in the endemic regions, could result in infection. Although antifungal medications are available for treatment when it is clinically indicated, no vaccine currently exists (CDPH, 2015). Most people recover fully from Valley fever, experiencing only mild symptoms, but up to 10% exhibit more serious health consequences including severe respiratory disease and disseminated disease outside the lungs (Ampel et al., 2010; CDPH, 2015). Symptoms of disseminated disease include skin lesions, bone or joint pain, and severe headaches.

The financial burden is significant. From 2000 to 2011, reported Valley fever hospitalizations in California cost a total of $2.2 billion in charges, with a median hospital stay of six days at $6,800 per day (Sondermeyer et al., 2013). Lifetime costs in 2017 from Valley fever in California were estimated to be $94,000 per hospitalized person – with $58,000 in direct costs (including diagnosis, treatment, and follow-up) and $36,000 in indirect costs (including productivity losses) – totaling $700 million for the state (Wilson et al., 2019). In a 2025 interview, Dr. Manish Butte, of the Allergy and Immunology Department from the UCLA School of Medicine, estimated that California

spent around $1 billion a year taking care of patients with Valley fever and disseminated disease (UCLA Health, 2025). The true impact of Valley fever on the economy and health is likely underestimated, as mild cases (which manifest as a mild self-limited respiratory illness or pneumonia) are less likely to be diagnosed and reported but can result in missed work and reduced productivity (Thompson et al., 2015).

Valley fever disproportionately affects historically marginalized communities in California, particularly outdoor workers and those who live or work in the San Joaquin Valley. Regions with relatively high rates of Valley fever cases, like the San Joaquin Valley and Central Coast, are home to large populations of low-income agricultural and construction workers, many of whom are Hispanic, immigrants, or undocumented. Farmworkers often lack adequate health insurance, paid sick leave, and legal protections (Rios, 2018; PPIC, 2022). Additionally, outbreaks have also arisen in endemic areas in prisons, and legal action has been taken against the state for failing to protect vulnerable incarcerated individuals—particularly Black and older adults—who are more susceptible to serious complications from the disease (Wheeler et al., 2015).

Understanding the dynamics among climatic, ecological niche, lifestyle, and demographic factors could help improve early detection and diagnosis of disease (Pearson et al., 2019). Tracking the incidence and geographic distribution of Valley fever provides valuable information to inform public health decisions, particularly given projected changes in climate-related factors. Since there is no commercially available test to determine whether the fungus is growing in an area's soil, the current understanding of the geographic risk for infection is largely based on human surveillance data.

What factors influence this indicator?

The rise in and geographic expansion of Valley fever cases is likely due to a combination of climatic, environmental, and human-related factors that impact *Coccidioides*. Climate-related phenomena such as drought, dust storms, aridity, and wildfires can affect the spread of and eventual infection with Valley fever (Pearson et al., 2019) and are projected to increase in frequency and severity with climate change

(Abatzoglou and Williams, 2016; Cook et al., 2015; Prein et al., 2016; Seager et al., 2007; Tong et al., 2017).

Drought

Valley fever cases are initially suppressed during droughts and then spike in the following years (Head et al., 2022). Limited winter precipitation suppresses fungal proliferation in the soil. However, droughts may allow heat-resistant *Coccidioides* spores to outlast their less-hardy competitors. When rain returns, the fungus can proliferate in the soil with less competition for moisture and nutrients (Coates and Fox, 2018; Fisher et al., 2000; Kirkland and Fierer, 1996; Zender et al., 2006). When dry, hot conditions follow, the fungus is released into air when soil is disturbed (Gorris et al., 2018; Johnson et al., 2014; Lewis et al., 2015).

Aridity

Valley fever incidence is greater in warm, dry areas (Gorris et al., 2018), such as Antelope Valley, a desert in southern California where the fungal pathogen was detected in 40% of soil samples (Colson et al., 2017).

Dust Storms

Increased winds linked to global climate change (Tong et al., 2017) could also drive Valley fever infections. Dust storms, particularly those attributed to Santa Ana winds in southern California during the fall, could help spread the spores to farther locations. Evidence shows that a dust storm in 1978 in the Central Valley carried the pathogen hundreds of miles, infecting individuals in Sacramento County, for example (Williams et al., 1979). Santa Ana winds and the ensuing dust storm after the 1994 Northridge earthquake have been linked to distributing *Coccidioides* spores to local communities, triggering a Valley fever outbreak in Simi Valley (Schneider et al., 1997). In Arizona, researchers found a moderate correlation ($r = 0.51$) between frequency of dust storms and Valley fever incidence in Maricopa County (Tong et al., 2017).

Wildfires

With the increasing risk of wildfires (see *Wildfires* chapter), researchers have begun investigating the potential influence of wildfires on Valley fever. The link between Valley fever and wildfires is not yet well understood. Anecdotal evidence and interviews with firefighters have provided insight into this relatively new area of research. Santa Ana

winds, which occur in the fall, coincide with Valley fever's seasonality and when fire danger is also highest, particularly in coastal Central and Southern California. The creation of fire lines by firefighters and post-wildfire cleanup and construction may disturb the soil and disperse *Coccidioides* spores through the air.

Valley fever incidences significantly increased in the San Joaquin Valley following three wildfires (2006 Midway Fire in San Joaquin, 2015 Park Hill Fire in San Luis Obispo, and 2011 Canyon Fire in Kern) where there were relatively large adjacent populations, high transmission before the fire, and a burn area exceeding 5,000 acres (Phillips et al., 2023). Valley fever outbreaks have also occurred among wildland firefighters, particularly among those involved in soil disruptive activities used to contain wildfires (Laws et al., 2021), in regions with historically high incidence of Valley fever, and among those who do not wear adequate respiratory protection (Donnelly et al., 2022).

Seasonality

Valley fever surveillance data in California are primarily based on reports from positive laboratory tests and assigned to the date when the test was conducted. While cases identified seem to peak between September and November, the end of California's dry season, it is important to note that the incubation period for Valley fever (i.e., time from infection to symptom onset) is typically 1-3 weeks and delays in diagnosis are common. Patients may not be tested for weeks after becoming sick, and with those delays, the peak seen in Valley fever cases in the fall is likely indicative that most people are infected in the summer and early fall months. As mentioned, drought temporarily dampens seasonal peaks but leads to spikes once rain returns (Head et al., 2022). With climate change experts predicting an earlier start to summer and a later beginning for fall/winter (Wang et al., 2021), there is the potential for an extension of Valley fever season, leaving residents and summer visitors in endemic areas more vulnerable to infection for more extended periods.

Sensitive populations

Certain groups are more likely to develop severe disease if infected, including pregnant women, adults over 65, immunocompromised individuals, and people who are Black or Filipino (CDPH, 2022; CDPH, 2026). Although most people develop immunity after a primary illness, Valley fever is complex and not fully understood. Even people who have

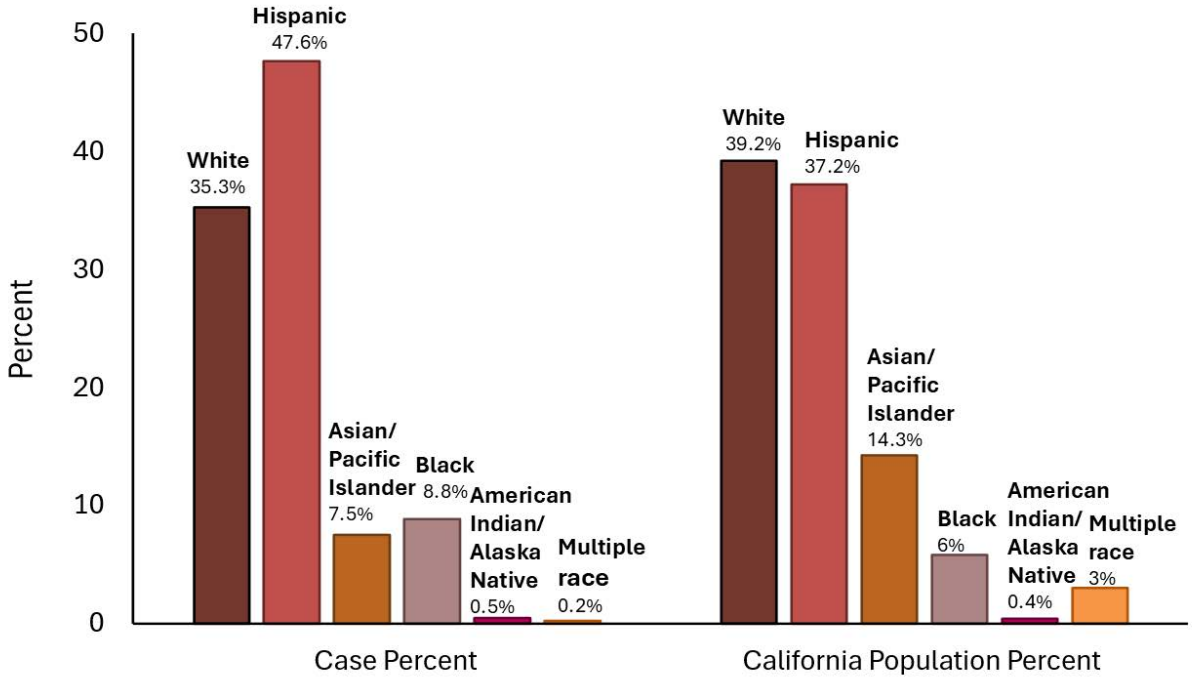


lived in highly endemic areas for years can develop diseases. Compromised immunity, due to age, comorbidities, or certain medications, can lead to reactivation of disease (i.e. developing symptoms again later) (CDPH, 2018).

Work or recreational activities that disturb the soil increase the chance of inhaling fungal spores. Outbreaks have most often been linked to jobs like construction, military service, firefighting, archaeology, and corrections – where high attack rates have been seen even among relatively young people. ("Attack rates" refers to the proportion of people in a population who experience an acute health event during a limited period, such as during an outbreak.)

Racial-ethnic disparities in Valley fever cases are not well understood and are likely due to a variety of factors, including occupation, genetics, underlying health conditions, and social determinants of health such as access to healthcare and socioeconomic status. To better evaluate the breakdown of racial/ethnic groups among Valley fever case-patients in California, **Figure 5.4.3** shows Valley fever cases and statewide population distributions by racial and ethnic groups. A high percentage of cases (35.4%) are reported without racial/ethnic information, so data from this graph should be interpreted with caution. The proportion of Valley fever cases that reported Black race/ethnicity (8.8%) was substantially higher than would be expected given that only 6% of the California population report Black race/ethnicity. Additionally, a higher proportion of Hispanics are reported among Valley fever cases. Hispanics make up 47.6% of reported Valley fever cases from 2001 to 2024 despite comprising only 37.2% of the total population. Cases of Valley Fever were more prevalent in Hispanic populations in San Joaquin Valley (Fresno, Kern, Kings, Madera, Tulare, Merced, San Benito, San Joaquin, and Stanislaus counties), and among Black populations across all regions in California (Sondermeyer Cooksey et al., 2020).

Figure 5.4.3. Coccidioidomycosis, Cases and Population by Race/Ethnicity, 2001-2024.



Source: CDPH Valley Fever Dashboard (2026)

Incarcerated individuals are also at higher risk for Valley fever. Outbreaks among incarcerated individuals imprisoned in endemic areas have been ongoing during the last twenty years. Prisons include a continual rotation of new inmates who may have no previous exposure to Valley fever. In one outbreak, exposure likely stemmed from fugitive dust from building construction near where prisoners were housed or engaging in outdoor physical activity; despite mitigation efforts, such as planting vegetation, high Valley fever attack rates continued (Wheeler et al., 2015). The prison population includes a disproportionate number of Black people (Lofstrom et al., 2020) – a group identified above as bearing a disproportionately poor outcome burden from Valley fever, as Black race/ethnicity is a risk factor for disseminated disease. In addition, many inmates engage in wildland firefighting (comprising approximately 30% of California's firefighting workforce), which puts them at a greater risk of exposure.

Technical considerations

Data characteristics

The California Department of Public Health (CDPH) Infectious Diseases Branch maintains a statewide reporting system for Valley fever and other communicable diseases. From 2001 to 2018, confirmed cases required both clinical and laboratory evidence for reporting. Since 2019, laboratory confirmation alone has been sufficient. Data was from CDPH's Valley Fever in California Year-end Data Dashboard. Data in this dashboard were quality checked with only the first report of Valley fever per person included.

Strengths and limitations of the data

The number of reported cases of Valley fever likely underestimates the true magnitude of the disease. Factors contributing to underreporting include ill people who do not seek health care, misdiagnoses, not ordering diagnostic tests, and limited reporting by clinicians and laboratories. Factors that may enhance disease reporting include increased exposure and disease severity, recent media or public attention, and active surveillance activities.

In addition, race/ethnicity information was missing or incomplete for 35.4% of all cases, so that incidence rates for race/ethnicity couldn't be calculated. Case data are assigned to the patient's county of residence, which may not reflect the location of exposure or diagnosis. Reporting delays and differences in data definitions over time may affect year-to-year comparisons.

OEHHA acknowledges the expert contributions of the following to this report:

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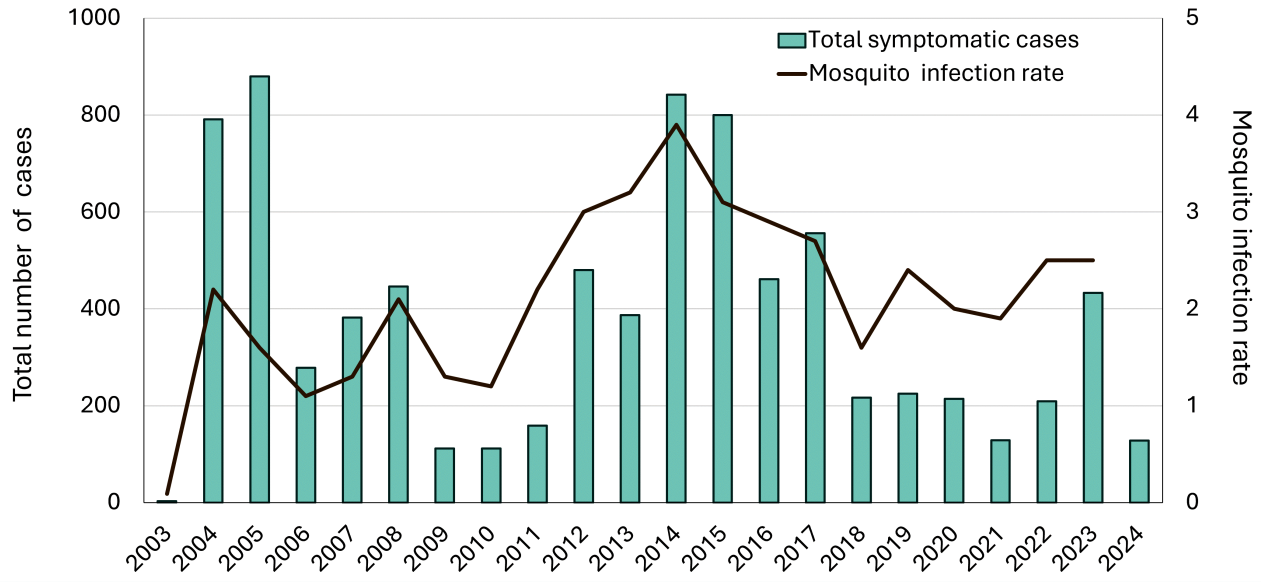
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5.5 Vector-Borne Diseases

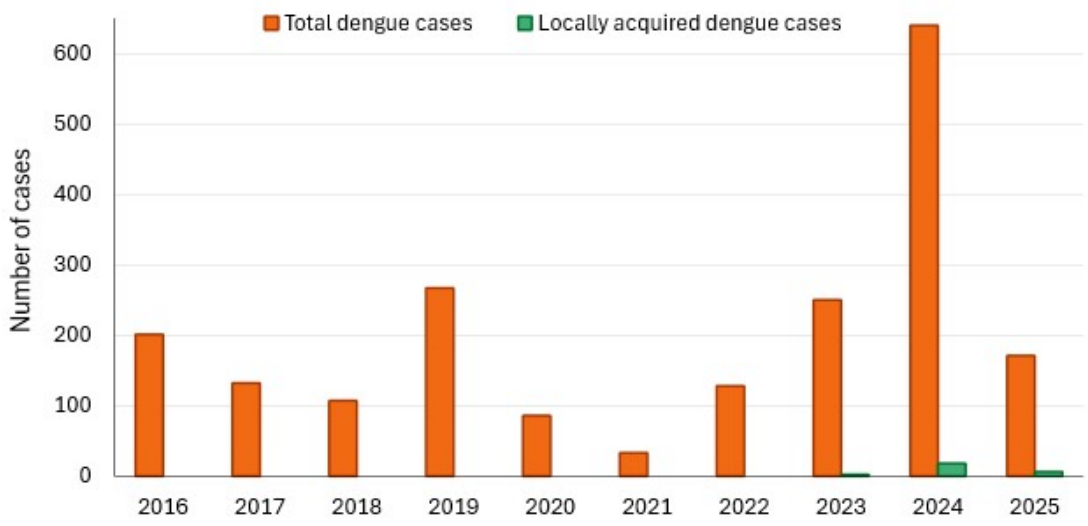
A changing climate alters the conditions under which vector-borne diseases spread. Such diseases are transmitted to people and animals by the bites of infected arthropods, such as mosquitoes and ticks, whose life cycles are strongly influenced by environmental conditions. Monitoring vector-borne diseases will become increasingly important as climate change reshapes their risk and burden, both within and beyond California.

Figure 5.5.1. West Nile Virus (WNV).



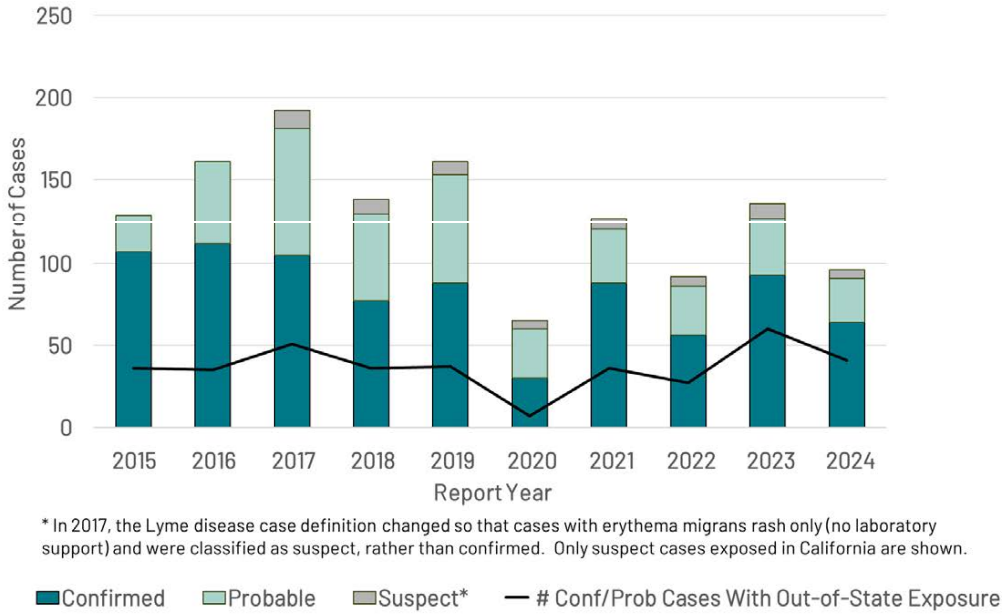
Human WNV cases and minimum infection rates in mosquitoes in California, 2003-2024.
Source: CDPH West Nile Virus Website (2025c).

Figure 5.5.2. Dengue.



Travel-associated and locally acquired dengue cases in California, 2016-2025. Source: [CDPH Dengue Webpage](#) (2025a).

Figure 5.5.3. Lyme Disease.



Reported Lyme disease cases in California, 2015-2024. Source: CDPH (2024).

What does the indicator show?

Vector-borne diseases are caused by pathogens that are transmitted to people and other animals through the bites of infected arthropods, known as vectors, including mosquitoes and ticks. The abundance and distribution of vectors and animals that can act as reservoirs, as well as transmission of pathogens carried by vectors, are affected by climate-driven environmental changes in temperature and precipitation patterns.

Many cases of vector-borne diseases go unreported, largely because their reporting depends on people seeking medical care and receiving appropriate diagnostic testing. Asymptomatic infections are common for some of these diseases, and symptoms such as fatigue and headaches are often mild and nonspecific, making them difficult to distinguish from other common illnesses. Severe cases are rare but can result in serious health complications and even death.

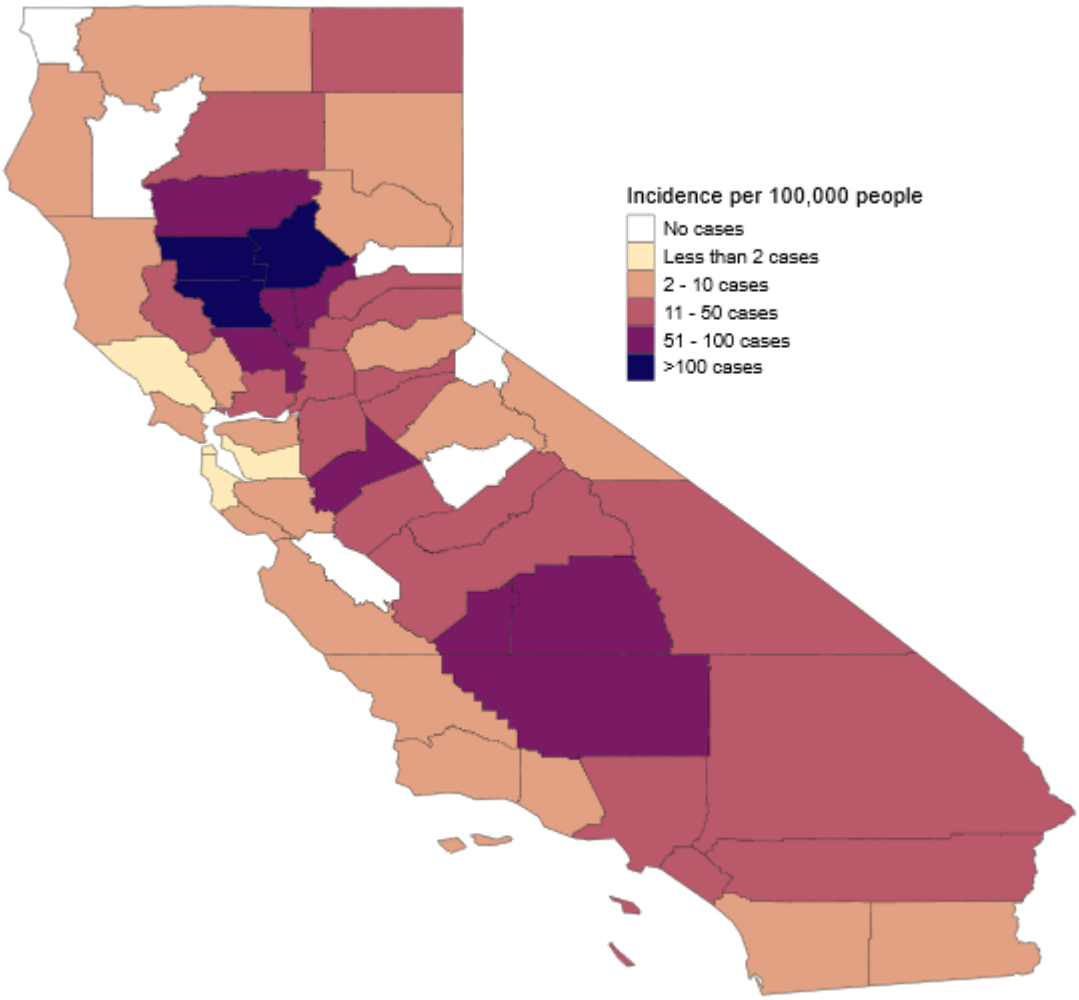
Mosquito-borne diseases

Mosquito-borne diseases under surveillance in California include endemic diseases, such as West Nile virus (WNV) and St. Louis encephalitis virus (SLEV). These viruses are carried by *Culex* mosquito species found throughout much of the state. Additional cases of diseases such as those caused by dengue, chikungunya, and Zika viruses, are typically associated with international travel, although invasive populations of *Aedes* mosquitoes in California make local transmission of these viruses possible. The transmission of all mosquito-borne diseases is influenced by temperature, which regulates the rate of mosquito development, frequency of biting and the time required for a mosquito to become infectious after biting an infected host.

For most Californians, WNV poses the greatest vector-borne disease threat (Snyder et al., 2020). This virus circulates primarily among birds, which act as reservoirs, and *Culex* mosquito vectors and has caused human disease in California every year since it was first detected in 2003. Most infections are asymptomatic, with 20% of infected people developing fever and flu-like symptoms, and less than 1% developing severe, and sometimes fatal neurological illnesses (CDC, 2021). Approximately 10% of the severe cases are fatal (CDC, 2025b).

Statewide, the number of West Nile virus cases varies from year to year. Symptomatic infections peaked in 2004-2005 and 2014-2015, with a smaller uptick in 2023. Infection rates in *Culex* mosquitoes (minimum infection rate, or MIR; see *Technical Considerations*) follow similar year-to-year fluctuations as human cases (**Figure 5.5.1**). WNV was first detected in the state in 2003, when three human cases were reported: one each in Imperial, Orange, and Riverside counties. WNV transmission quickly expanded across the state, with most counties (46 of 58) reporting at least one case and nearly all (54 of 58) detecting viruses in the environment by 2005 (CDPH, 2005). Spatially, hot spots of West Nile virus infection in mosquitoes have often been detected in the Los Angeles metropolitan area and the Central Valley, typically in the same areas that experience a high burden of human disease (Bayles et al., 2024). However, the highest incidence (cases per 100,000 people) typically occurs in the northern Central Valley, a sparsely populated part of the state where rice agriculture supports significant mosquito production in the summer months (**Figure 5.5.4**).

Figure 5.5.4. WNV Cases by County.



Cumulative incidence of symptomatic WNV cases by county in California, 2003 – 2025. Source: CDPH (2026a).

Cases of WNV in California are predicted to rise over the next 20 years with increasing temperatures due to climate change (Parker, 2024). WNV cases are driven in part by the proportion of *Culex* mosquitoes infected with WNV, as measured by the MIR. The MIR typically increases as temperatures rise due to the shortened incubation period in the mosquito vector and more frequent feeding on hosts by the mosquito (see *What factors influence this indicator?*). MIR along with mosquito abundance levels at local

scales are used to evaluate human risk and inform the response of local vector control agencies as outlined in the California Mosquito-Borne Virus Surveillance and Response Plan (CDPH, 2026b). In areas without human WNV cases reported, and where mosquito testing is conducted, the mosquito MIR provides a measure of transmission risk in the environment.

Because most vector-borne infections are asymptomatic or mild, patients may not seek treatment or diagnostic testing. As a result, severe cases of WNV, which involve neurological symptoms, are more likely to be detected and reported than mild febrile illness or asymptomatic infections. For every neuroinvasive case reported, there are an estimated 30 to 70 cases of febrile illness (Mostashari et al., 2001). Given that most human WNV infections are not detected or reported, mosquito infection rates provide a robust indication of WNV activity in the environment.

Before WNV was introduced to the state, endemic mosquito-borne pathogens such as western equine encephalomyelitis virus (WEEV) and SLEV were regularly detected in California. After the introduction of West Nile virus, the detection of both viruses declined, with the last environmental detection of WEEV in 2007 (MVCAC, 2008). SLEV re-emerged in California in 2015 after more than a decade without detection (Danforth et al., 2022; White et al., 2016). Since 2015, SLEV has been detected annually through environmental surveillance and has caused 63 cases of symptomatic illness (CDPH, 2024).

Additional mosquito-borne viruses of concern in California include those that are typically associated with international travel: dengue, chikungunya, and Zika. Of these, dengue causes the greatest burden of disease globally. Like WNV, most people infected with dengue virus experience no symptoms, but severe cases can become life-threatening within hours. Because there are four different strains of the dengue virus, a person can contract dengue more than once in their lifetime and those with a history of dengue infection are more likely to experience severe dengue if they are infected again (CDPH, 2025a).

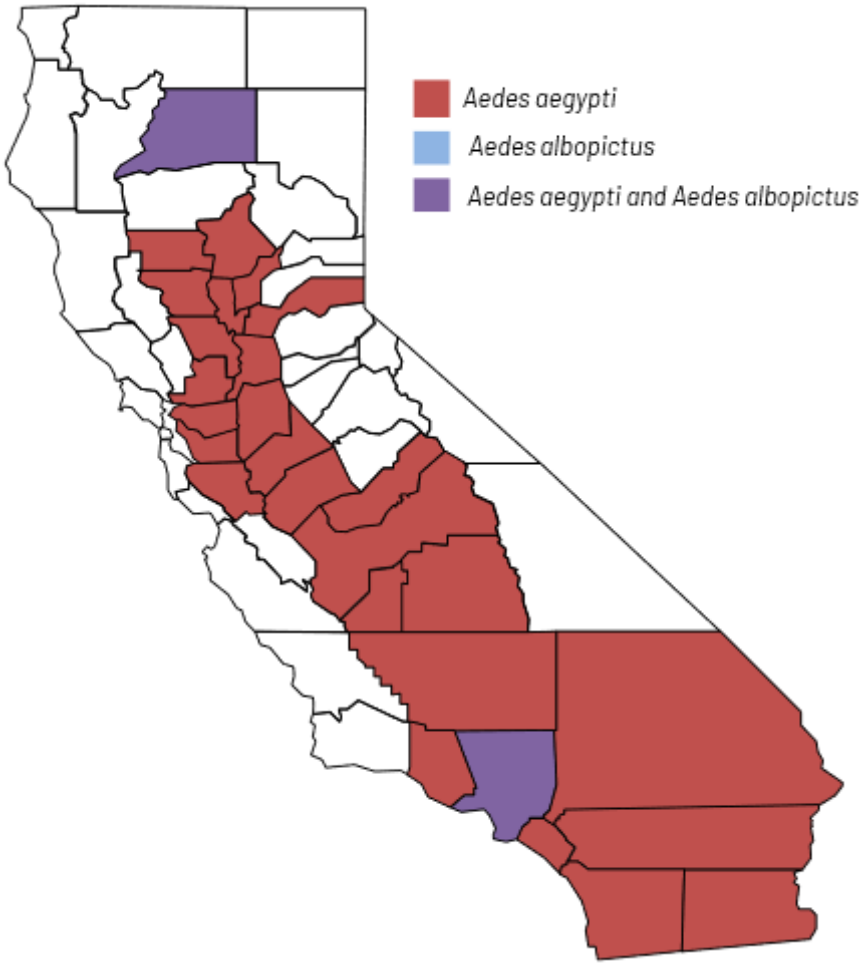
Dengue virus has become a global health crisis in recent years, surging from 505,430 cases worldwide in 2000 to 6.5 million in 2023 and 14.6 million in 2024 (PAHO, 2025),

likely due to the combined effects of international travel, climate change, and the rapid expansion of dengue vectors into new areas (Abbasi, 2025; WHO, 2023). Cases of dengue reported in California (**Figure 5.5.2**) are predominately associated with international travel, but limited local transmission of dengue virus was reported in Los Angeles County in 2023 (2 cases), in three counties in southern California in 2024 (18 cases total for Los Angeles, San Diego, and San Bernardino counties), and in Los Angeles County in 2025 (6 cases) (Feaster et al., 2024; CDPH, 2024, 2025a, 2025d).

Aedes aegypti is the primary worldwide vector of dengue, chikungunya, and Zika viruses, and *Aedes albopictus* is also capable of transmitting these viruses. These mosquito species are not native to California, but repeated introductions attributed to global and domestic shipping and transport have resulted in established populations in California (Metzger et al., 2017; Porse et al., 2015). Invasive *Aedes* mosquitoes are currently established in 26 counties across the state (**Figure 5.5.5**), making it possible for returned travelers to introduce historically travel-associated viruses into local mosquito populations.

Local transmission of dengue in California is very rare and constrained by low temperatures compared to endemic areas in the tropics. Currently, temperatures in parts of southern California with invasive *Aedes* mosquitoes support local transmission for just a couple months of the year (VectorSurv Maps, 2025). With additional warming, currently cooler parts of the state may become more suitable for local transmission (Gorris et al., 2024) and the proportion of the year that is suitable for local transmission may increase (Mordecai et al., 2017). The number of travel-associated cases is also predicted to increase as climate change intensifies the transmission of these viruses in currently endemic areas (Childs et al., 2025).

Figure 5.5.5. Distribution of invasive *Aedes* mosquitoes in California.



Source: CDPH (2026a).

Tick-borne diseases

In addition to mosquito vectors, climate change can impact ticks, the pathogens they carry and their animal reservoirs. Unlike mosquitoes, the tick life cycle does not have an aquatic stage, but does have four distinct life stages: egg, larva, nymph, and adult. Depending on the infectious agent, ticks usually acquire pathogens in one life stage by feeding an animal reservoir and then passing those pathogens on to other animals or people in subsequent life stages (CDC, 2024). In general, ticks have a much longer life cycle than mosquitoes, taking two to three years to complete their life cycle from egg to

adult. Because ticks can typically live for multiple years, climate-driven changes in temperature and seasonal patterns influence the transmission of tick-borne diseases in unique ways compared to other vector-borne diseases.

Lyme disease is the most reported tick-borne disease in California (**Figure 5.5.3**), although it remains relatively rare on the west coast compared to other parts of the United States (CDC, 2025c). Lyme disease is caused by the bacteria *Borrelia burgdorferi*, which is transmitted by the western blacklegged tick (*Ixodes pacificus)* in California. Western blacklegged ticks occupy dense woodland, mixed forest, and coastal scrub habitats and acquire the pathogen in their larval or nymphal stage when feeding on an infected small mammal such as a deer mouse or a woodrat and can pass it to people in their nymphal or adult stage. Between 2015 and 2024, the average number of confirmed Lyme disease cases reported in California was 82 cases per year. Approximately 1 in 3 cases of Lyme disease in California occurred in people who were infected while traveling outside of the state (CDPH, 2024). Ticks carrying Lyme disease in California are more commonly found in the northern and central coastal regions and in the northern foothills of the Sierra Nevada (CDPH, 2025b).

Tribal Connection 5.5.1

The Wiyot Tribe, living around *Wigi* or Humboldt Bay since time immemorial, writes, "*Wiyot community members have noticed an increase of disease-carrying ticks within the region. Changes in temperature have allowed ticks to become more active in the spring and fall seasons. Humboldt County, as well as Santa Cruz and Sonoma, have higher than average rates of Lyme disease when compared to other regions of California (CDPH, 2021)*" (Wiyot Tribe, 2026).

Why is this indicator important?

Because vectors and reservoirs are sensitive to environmental conditions, changes in temperature and precipitation can influence the seasonality, distribution, and prevalence of vector-borne diseases (USGCRP, 2016). However, the impacts of climate change on vector-borne diseases in California will be diverse, varying by pathogen, vector, reservoir, and geography.

As vector-borne disease activity increases globally, increasing numbers of travelers may become infected while visiting areas where certain diseases are prevalent, return to California, and serve as a source of infection to local vectors. This possibility is particularly apparent for invasive *Aedes*-borne viruses, such as dengue, whereas returned travelers with Lyme disease may require care for their illnesses but are not likely to pass their infections on to local ticks. Increasing numbers of travel-associated and locally acquired cases will impact on the healthcare system and as transmission shifts to new areas, so will the needs, resources and capacity for vector control in different jurisdictions.

Vector-borne diseases cause significant illnesses in California and can be fatal. While most infections cause no apparent illness, severe and fatal cases are reported each year. Many individuals hospitalized for WNV experience long-term physical, cognitive, and functional complications, with 30–40% of patients discharged to long-term care or rehabilitation facilities, and more than half still experiencing symptoms a year after their initial illness (CDC, 2025b). Similarly, bleeding and/or shock resulting from severe dengue is considered a medical emergency and requires immediate medical attention (CDC, 2025a), while delay in Lyme disease diagnosis may lead to complications or rarely, post treatment Lyme disease syndrome (PTLDS) (Angell et al., 2025).

What factors influence this indicator?

The effects of climate change on vector-borne diseases can be complex and multifaceted, occurring in conjunction with other factors, such as land use change and human behavior. The diverse ecology of vector-borne diseases makes it challenging to predict exactly how climate change affects these diseases and the resulting alterations in their magnitude and geographic distribution. Below are examples of how climate change can influence the spread of vector-borne diseases (de Souza and Weaver, 2024; Ogden & Lindsay, 2016). For information about climate change impacts on other zoonotic diseases in California, see the *Zoönoses* emerging chapter.

Shifts in geographic range

Warmer temperatures and changing precipitation patterns may allow vectors and reservoirs to survive in geographic areas that were previously unsuitable. While some

areas may become more suitable with rising temperatures and changing precipitation patterns, others may become less suitable, surpassing thresholds that no longer support the physiological needs of vectors or reservoirs. Rising temperatures will shift the suitability for transmission of mosquito-borne pathogens according to the thermal stress tolerance of different vector species and the rate at which pathogens replicate inside vectors (Mordecai et al., 2019). Increases in Lyme disease cases in eastern North America have been attributed to climate change primarily at the northern edge of the geographic distribution of *Ixodes scapularis* (Gilbert et al., 2021). In California, the range of *Ixodes pacificus* is predicted to expand to one-third of the state, particularly in the northwest, south central, and southern coastal regions where winter precipitation is predicted to increase (Hahn et al., 2021, Eisen et al., 2018).

Shifts in seasonality

Because of the highly seasonal nature of prevailing precipitation patterns in California, changes in precipitation due to climate change will impact the seasonality of vector-borne disease transmission. The amount of winter and spring precipitation and snowpack determine the springtime abundance of rural vectors of WNV (Reisen et al., 2008). Even in the presence of strong seasonality in precipitation patterns, water management, particularly irrigated agriculture, can stabilize mosquito populations and virus transmission in agricultural areas (Kovach and Kilpatrick, 2024). Such patterns may contribute to differential impacts of climate change on *Culex* species occupying rural, agricultural areas (e.g., *Culex tarsalis*) compared to those found in urban habitats (e.g., *Culex pipiens* complex).

The abundance of *Ixodes pacificus* is limited by abiotic conditions during the summer dry season (Swei et al., 2011), which impact microclimates where certain tick life stages survive (Kilpatrick et al., 2017). Humidity from increased rainfall may limit the need for ticks to rehydrate in leaf litter and allow for more host seeking on emergent vegetation (Ogden and Lindsay, 2016).

The seasonality of host-seeking activity among *Ixodes pacificus* ticks in California is predicted to vary by region and climate scenario. Wetter future conditions may change host-seeking behavior in some regions (MacDonald et al., 2020). In northern California,

where lower temperatures and higher baseline humidity generally support tick activity, changing patterns of temperature and precipitation may alter the overlap between different stages of ticks (e.g., larvae and nymphs) in ways that affect pathogen transmission risk (Sambado et al., 2025b).

Warmer temperatures may also shift the seasonality of pathogen transmission in mosquito, tick and reservoir populations. Warmer winter temperatures may lengthen seasonal vector activity, particularly delaying the overwintering behavior of mosquitoes (Reisen et al., 2006; Diniz et al., 2017; Fyie et al., 2023), although periods of extreme heat negatively impact vector survival. Mosquito survival begins to decline at temperatures above 95°F (35°C) (Reisen, 1995), and in the Coachella Valley in southeastern California, *Culex* abundance is already known to decline during the hottest summer months (Reisen et al., 1992; Reeves et al., 1994; Ward et al., 2023). Increased frequency or duration of extreme heat events may make summer months in certain parts of the state less suitable for vector populations and shift seasonal peaks from a single summer peak to two peaks in the late spring and early fall.

Impacts of precipitation extremes

California oscillates between the precipitation extremes of drought and flood (Swain et al., 2018). Extreme precipitation events, such as droughts and floods, will have complex, even counterintuitive impacts on the transmission risk of mosquito-borne diseases. Since standing water is necessary for mosquito breeding, WNV cases sometimes, but not always, increase following rainfall and flooding events (Coalson et al., 2021). Decreases may occur after heavy rain events flush immature mosquitoes from their aquatic habitats (Benedum et al., 2018; Koenraadt & Harrington, 2008). While aquatic habitats available to mosquitoes contract under drought conditions, especially at seasonal timescales (Russell et al., 2025), higher infection rates in smaller mosquito populations have been observed in California's Central Valley following drought (Sambado et al., 2025a, MacDonald et al., 2025). Such elevated infection rates are thought to arise from increased contact between mosquito vectors and bird reservoirs (Paull et al., 2017). Drought may have contributed to the relatively high number of cases of WNV in 2014 and 2015 (CDPH, 2015; Sambado et al., 2025a).

Exposure-related human behavior

Warmer temperatures can lead people to spend more time outdoors, including more time outside in the spring and fall as seasons lengthen. This behavior increases the risk of getting bitten by infected vectors. Urban heat islands can amplify this effect in cities where mosquito-borne diseases can be prevalent. In natural areas, more time spent hiking and camping increase exposure risk to tick-borne diseases.

Travel outside of California to destinations with elevated risk for vector-borne disease transmission impacts case reporting within the state. The majority of cases of dengue, chikungunya, and Zika reported in the state are due to California residents who became infected while visiting countries where these viruses are endemic. Similarly, a significant proportion of tick-borne disease cases, including Lyme disease, result from out-of-state exposures, primarily in high-incidence states in the northeastern and midwestern United States. As a result, the impacts of climate change on vector-borne diseases beyond California's borders influence the burden of disease among California residents.

Additional factors

Additional anthropogenic factors that influence vector-borne disease transmission include changes in ecosystems and land use, socioeconomic status, the status of public health infrastructure, and response capacity (Carney et al., 2011; Rochlin et al., 2016; USGCRP, 2018). These diseases and their vectors and reservoirs have been linked with local-level factors such as income, housing conditions, and population density
(Donnelly et al., 2020; Harrigan et al., 2010; Hernandez et al., 2019; Hill et al., 2023; Watts et al., 2021). People in low-income communities may find it difficult to adopt protective measures to reduce exposure, such as using air conditioning, keeping areas in and around homes free of vector and reservoir habitat, and using insect repellent. Fewer educational resources may be accessible or available in lower-income communities, resulting in lower awareness of symptoms and risks of vector-borne diseases, and the importance of getting tested. Access to healthcare can also be a significant barrier to diagnosis and treatment for vector-borne diseases.

Technical considerations

Data characteristics

The California Department of Public Health Vector-Borne Disease Section coordinates statewide surveillance of all vector-borne diseases presented in this chapter, in collaboration with numerous local, state, and federal agencies, and members of the medical community. Testing for some human infections for vector-borne pathogens is performed at the California Department of Public Health's Viral and Rickettsial Disease Laboratory, the Centers for Disease Control and Prevention (CDC) as well as at local county public health laboratories and commercial laboratories. Surveillance also includes monitoring pathogen presence in mosquitoes, ticks, and their animal reservoirs.

Vector control agencies serving approximately 90% of the California population conduct surveillance and control for mosquito vectors. These agencies trap mosquitoes, sort and count them by species, and group female mosquitoes from the genus *Culex* into pools of ≤50 for virus testing, which is conducted at UC Davis or locally. A pool of mosquitoes is considered positive if at least one mosquito is infected. Minimum infection rate (MIR) – calculated as the number of positive mosquito pools divided by the total number of mosquitoes tested and multiplied by 1000 – provides a standardized measure of virus prevalence in *Culex* mosquitoes (CDPH, 2026b).

The ability to use surveillance data to support public health and vector control decisions in real-time is a key part of California's efforts to mitigate the growing effects of climate change on vector-borne disease incidence. California is a national leader in the development of such decision-support systems that are being used to inform local and state policies. Public-facing data on WNV and other vector-borne pathogens are provided via maps, reports, and other visualizations through the CDPH Vector-Borne Disease Section website and the California West Nile Virus website. Statewide data on environmental surveillance of vectors and the pathogens they carry are managed, analyzed, and shared through the CalSurv data system, which is supported by funds from the state of California and housed at UC Davis through a partnership with CDPH and the Mosquito and Vector Control Association of California. The CalSurv system

provides a wide range of tools for data entry, analysis, and visualization that are used by agencies throughout California daily. Maps showing CalSurv's data are available at https://maps.vectorsurv.org.

Strengths and limitations of the data

This indicator uses surveillance data on vector activity, pathogen presence, and reported human infections to track how climate has impacted the occurrence of vector-borne pathogens over time.

Due to underreporting, human disease surveillance for vector-borne diseases is not a very sensitive measure of disease transmission. However, reporting human disease cases to local vector control agencies facilitates rapid response to emergent situations and is an essential complement to routine environmental surveillance activities. Routine environmental surveillance activities, including the trapping and testing of vectors and/or non-human hosts provides valuable and timely information about infection risk. In areas with robust mosquito testing, mosquito infection rates are especially useful indicators of West Nile virus transmission risk, and local vector control agencies can use mosquito infection rates to target mosquito control efforts. However, sampling effort and spatial coverage vary widely across the state, so the intensity of surveillance should be considered when comparing mosquito infection rates among counties and regions. Although 90% of California's population lives in areas with vector control agencies, not all agencies have the capacity to conduct robust mosquito surveillance and testing.

OEHHA acknowledges the expert contributions of the following to this report:

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Introduction

Climate change poses a threat to California's tribes through its impacts on the ecosystems in which they live and are connected. The health of a tribe is tied to the health of the land and environment. California tribes are the original biologists, historians, climatologists, and scientists of the land. Tribal knowledge, developed through generations of observation, stewardship, and reciprocal relationships with the land, is a key component in understanding the impacts of climate change on human lives and their environment.

This is the second time that the *Indicators of Climate Change in California* report has included tribal reports. In the previous edition (4th edition), over 40 California tribes contributed to documenting the tribal impacts of climate change by producing eight tribe-specific reports and co-hosting and participating in three listening sessions. Four of those reports were updated for this edition, one was reprinted without updates, and three new reports were added. Three tribe-specific reports from the 4th edition were not updated or re-published and have been included in the appendix to this tribal volume in their original form. In addition to reports, five tribes have shared their experiences of climate change through OEHHA's video series, *California Tribes and Climate Change: Voices from the Frontlines*. Collectively, these narratives reflect a diverse range of landscapes, perspectives, cultures, beliefs, and climate change experiences. All reports, listening session summaries, and videos are available on OEHHA's website.

In this report, the term "California tribes" refers to all tribal nations in the state, including those that are not federally recognized or currently landless. Each tribe has

the right to govern the collection, ownership, and application of its own data. This report upholds Indigenous data sovereignty by presenting knowledge and data only with the explicit permission of the respective tribes.

This volume contains tribes' descriptions of changes to the ancestral lands they have taken care of since time immemorial, the boundaries of which are beyond government-imposed reservations or rancherias. While much of traditional tribal territory is now divided and regarded by colonizers as distinct districts, to tribes, the land is physically and conceptually inseparable in terms of ecology as well as culture, spirituality, and history. Territory maps are often not agreed on, while language maps depict more fluid borders that are respected by tribes and illustrate where tribes historically traveled.

When tribes speak of nature, they include themselves. Nature and its great variety of plants and animals are on an equal level with people. Caring for the non-human environment is as important as caring for one's relatives. The Earth provides food, medicines, and ceremonial materials that are part of tribes' daily life. They are embedded within the tribes' cultural, social, spiritual, economic and political systems. Knowledge of the unique interactions between species and their habitat provides the foundation for tribal actions to manage the landscape. This is ever more important under the evolving conditions due to climate change.

Reports from the following eight tribes in this volume and three tribes from the previous edition bear witness to the impacts of climate change on tribes:

Reports in the current (5th) edition:

Big Pine Paiute Tribe of the Owens Valley
Big Valley Band of Pomo Indians of the Big Valley Rancheria
Bishop Paiute Tribe
The Karuk Tribe
Mono Lake Kootzaduka'a Tribe[1]
Nevada City Rancheria Nisenan Tribe
Pala Band of Mission Indians
The Wiyot Tribe

Reports from the 4th edition which are included in the volume Appendix for reference:

Amah Mutsun Tribal Band, 2022
North Fork Rancheria of Mono Indians of California, 2022
Santa Ynez Band of Chumash Indians, 2022

[1] The Mono Lake Kootzaduka'a have included a summary of their climate change impacts in this publication. For more information, please contact the Tribe using the contact information provided at the end of their summary.

6.1 Impacts of Climate Change on the Big Pine Paiute Tribe of the Owens Valley

Depleted groundwater, drought, degraded air quality, and decreased traditional foods are threatening the physical, cultural, and spiritual health of the Tribe, its habitats and ecosystems, and its built environment.

This document is written by L'eaux Stewart, the former Chairperson of the Big Pine Paiute Tribe, and is based on her observations of climate change in the Owens Valley.

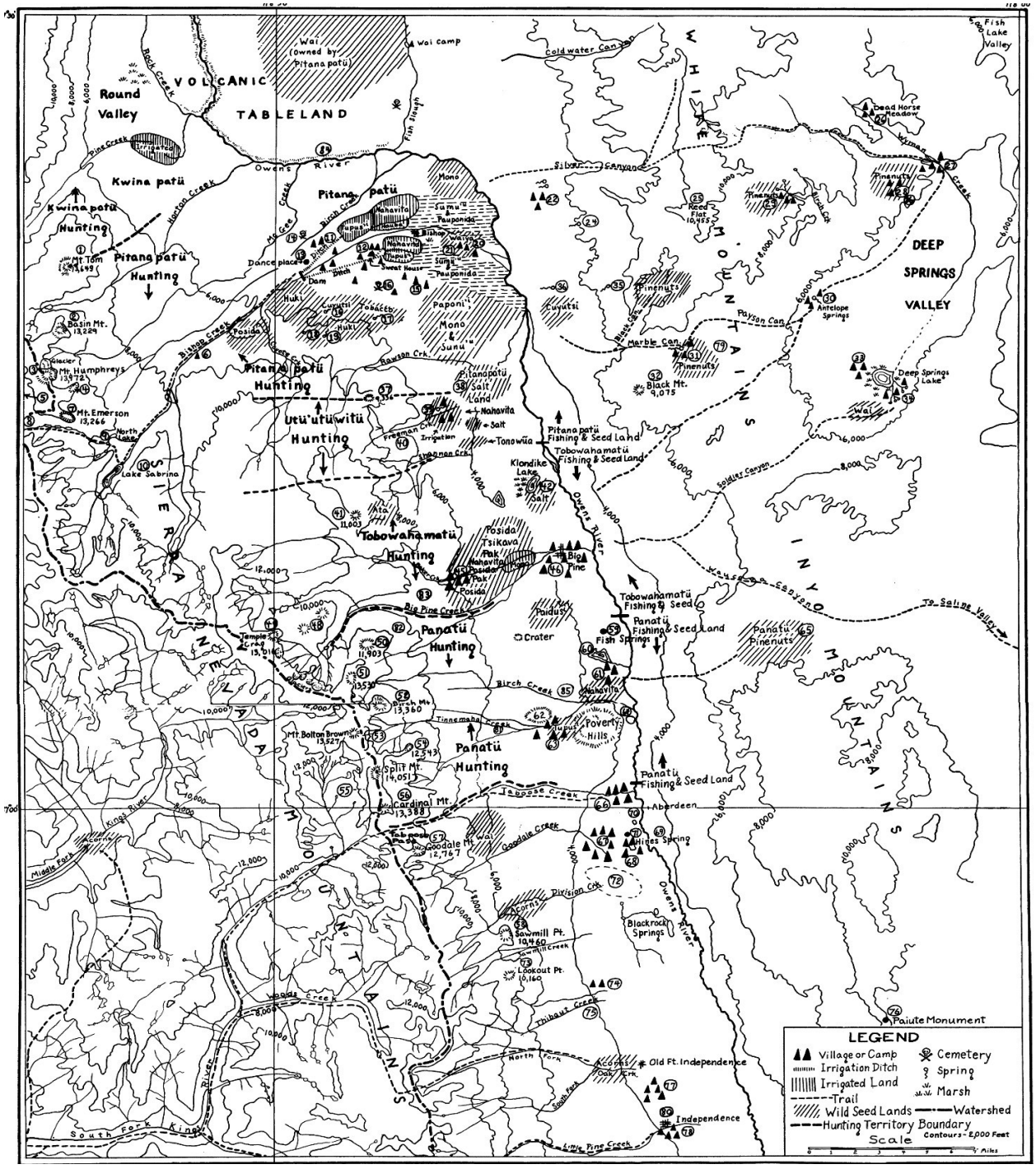
Background

The Big Pine Paiute Peoples are comprised of three different groups from the Big Pine region: Tovowahazi, the people of Tovowahamatü (the land now currently containing the Big Pine Paiute Reservation); Panapitahahnwitü, the people of Panapita (the land on the west side of Big Pine currently known as The Indian Camp); and Tunigahahnwitü, the people of Tunigawitü (the land to the south of Big Pine known as Fish Springs). The overlapping areas inhabited by these groups and other Paiute neighbors are shown in **Figure 6.1.1**. The Big Pine Paiute People referred to themselves as Nümü, "The People", as did other tribes in the area, so for this document, we will refer to them as the Big Pine Nümü to differentiate them from other Paiute People in the community.

The boundaries of the traditional lands used by the Big Pine Nümü begin at Keogh's Hot Springs (seven miles north of Big Pine) and extend south to Fish Springs (two miles south of Big Pine). The two mountain ranges, the Whites and the Sierras, formed the east and west boundaries, respectively. The entire area was considered territory of the Big Pine Nümü and was regarded as important to them for purposes of food and material collection, spiritual and ceremonial practices, and living space.

Certain families and groups had unique sites that were important to them, and those locations are passed on through lineal dependency via oral storytelling.

Figure 6.1.1. Hand Drawn Map Showing Paiute Areas and Boundaries.



Source: Steward (1933)

Figure 6.1.2. Map Showing the Owens Valley and Big Pine (Below The Word "Owens").



Source: Danskin (1998)

The traditional lands of the Big Pine Nümü have since been developed for wildland grazing, grass grazing, residential properties, commercial properties, and pumping by the Los Angeles Department of Water and Power (LADWP). The majority landowner is LADWP. **Figure 6.1.2**, above, shows the current lands of the Big Pine Nümü and the surrounding area.

When the land that is now known as the Big Pine Reservation was originally set aside for Native Americans in the 1930s, it was originally designated as a Rancheria, which designated the land to be used as small homesteads for the people who were admitted to live upon it. In the 1970s the Rancheria was converted into a reservation, which permitted more home building upon the land and agricultural practices became reduced.

Figure 6.1.3. The Eastern Sierras Route to the Palisades, Part of the Big Pine Traditional Territory.



Source: Photo by Becky Wood (2019)

In the Big Pine (Tunigawitü or Fish Springs Band) *Creation Story of the World*, Coyote and Wolf created the Owens Valley region and by proxy the surrounding lands that other tribes live on; it is originally described as a great flood that covered the world, higher than the mountain tops and by having Mud Hen retrieve soil from the bottom of the flood, Coyote was able to rebuild mountains and cover up the water. In the *Creation of the Big Pine Peoples*, actual landmarks within the Big Pine Region are mentioned: a sub-alpine lake above Big Pine in the Eastern Sierras was the location of The Most Beautiful Woman's Mother's house; a fresh spring about a mile north of Big Pine at the base of the Eastern Sierras was The Most Beautiful Woman's home; and there are big boulders on the north end of Big Pine where Coyote hunted game for The Most Beautiful Woman.

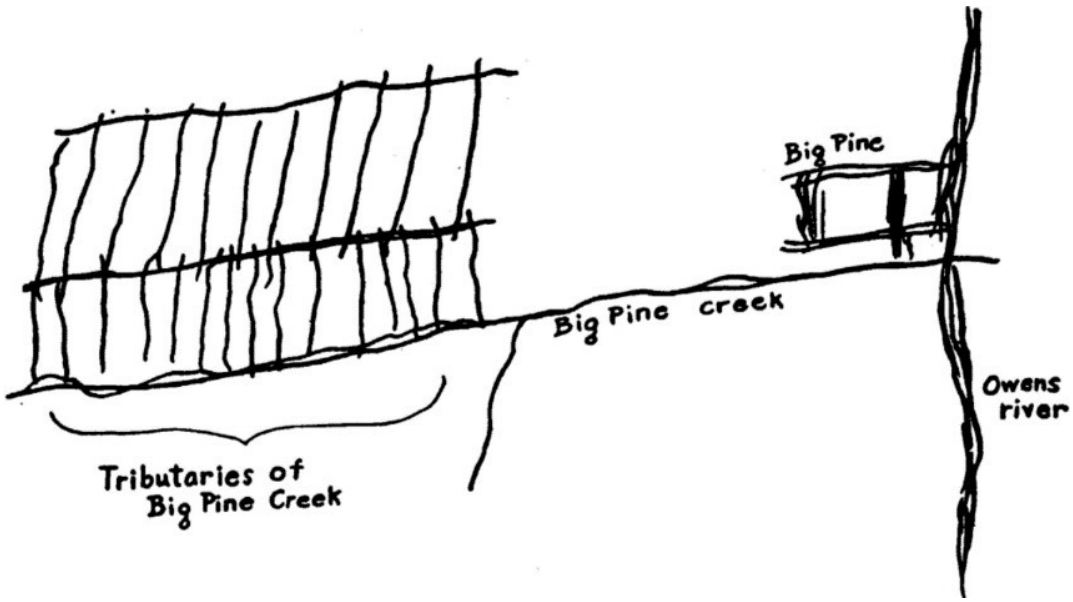
Figure 6.1.4. Volcanic Field at Fish Springs.



Source: Photo by L'eaux Stewart

Hunting was performed with bows and arrows, snares, rabbit drives, sheep drives, deer drives, atlatls and points, and clubs. (Drives are a hunting activity.) Rabbits, chuckwallas, birds, deer, elk, big horn sheep, and pack rats were hunted for meat. Fishing was performed with special baskets and woven traps to catch fish that lived in creeks and streams. Pole fishing, spears, and nets were also used to catch fish. In addition, fish were collected from the streams and rivers of the area by diverting water out of the body of water into shallow ditches so that the fish might be stranded on the ground to be picked up. As shown in **Figure 6.1.5**, the Big Pine Paiute Nümü would create a drain off the side of the small creek or stream with fish; the drain would lead down rows scraped out of the ground by sticks. The water would flow down the rows and the fish would be left behind. These ditches would also irrigate the surrounding areas, bringing water to wild seeds and plants that would nourish the people. There were also stories about golden trout in lakes at the top of the mountains that were fished; settlers believed these stories to be myths until the forties when aerial photography showed alpine lakes that later were found to have the golden trout.

Figure 6.1.5. Drawing of Paiute Irrigation.



Source: Steward (1933)

The food of the Big Pine Nümü was bland for the most part, as only limited salts and sugars were available, but they were high in protein and nutrients. Rabbits were the most constant source of protein; both Jackrabbits and Cottontails were eaten. Rabbit meat would be added to acorn mush to create a protein and vitamin-rich meal that was very filling. Due to diseases, any rabbit that had been hunted would be checked fastidiously for signs of lumps on the body and discarded if found with any irregularities. Deer were hunted and often divided up amongst two or three family groups. Bighorn sheep were a prized catch and hunted in drives in the mountains. Smaller game such as ground squirrels, porcupines, and wildcats were caught in snares. Birds were often hunted; quail, doves, and waterfowl were shot with arrows or snared. Swans and birds of prey were not eaten. There were taboos on eating bear meat as a skinned bear's body resembles a human's body.

Chia seeds were also a regular staple in the diet; they were often ground and kept in small buckskin pouches, where the ground chia could be snacked on while walking. Other seeds from plants in the valley were eaten frequently and provided both fiber and folic acids.

The Big Pine Nümü ate cicadas as they emerged from the ground and beetle larvae; these insects would have their heads pinched off and would be toasted in a basket and salted. Acorns and pine nuts were vital to year-round survival. Both were harvested in the fall in large quantities by entire communities. The acorns were buried next to the riverbed so that the water could leach the tannins out of the nuts, and pine nuts were cooked in baskets. The buried acorns were removed from the ground up to a year later to be shelled and ground into a fine flour. Both the pine nuts and acorns were made into mushes which were seasoned with chunks of meat and fat, or bitter salt. Sweetened acorn mush was created by adding a large amount of harvested sugar to a bowl of acorn mush, which was then placed outside in the snow, where it would freeze. The mix was then scraped to create a pseudo-ice cream style treat.

Cattail and tule shoots were eaten, especially when they were young and tender. Clovers, cresses, and small greens were harvested and eaten fresh. Berries that grew in the hills were harvested and eaten fresh.

There was a “coyote potato,” an unknown fungus (likely the *Calvatia booniana*, “Western Giant Puffball”*)* which grew in the sand around the roots of plants, particularly sagebrush. It could be dug up and cooked.

Teas were made from many of the leaves and barks of the plants; ephedra was the most common tea consumed, though pine needles and sagebrush bark were brewed and seeped as well. Wild rosehips were a quite common ingredient in teas due to the vitamin C they provided and the abundance in which they could be gathered.

In modern times, when money was scarce, a family member would go out to hunt rabbits or deer (sometimes out of season), or to harvest wild plants. Grinding stones, metates, baskets, and pottery bowls were used in food preparation and storage.

Gatherings

Figure 6.1.6. Photograph of a Paiute Gathering, Circa 1906 to 1913.



Source: Photo by Andrew Alexander Forbes

Fandango, the fall gathering, was a practice shared by many of the tribes in the Owens

Valley as a gathering of all peoples. It was hosted by a different group each year and provided an opportunity for everyone to see each other. Traditional activities included dancing, gambling, and a communal rabbit drive. Big Pine is the only community in the Owens Valley who has continued this gathering annually. The modern version of the Fandango involves a parade on the Reservation roads to the “Fandango Grounds” and tribal members participate in the parade with floats, horses, cars, and by foot. There have also been games such as bed races, early morning walks, and volleyball tournaments. There are also competitions for traditional and non-traditional food cooking. It is held in October each year, usually during the first weekend.

Places

Figure 6.1.7. Paiute Men Performing War Dance.



Source: Photo by Andrew Alexander Forbes (circa 1906 to 1913)

The burial sites of the Big Pine Nümü located throughout the territory have often been desecrated and their locations are no longer shared with outsiders. Burial was usually done in locations that were not common to visit and were not near water so that they would not be disrupted.

Agriculture

While the Big Pine Paiute Nümü did not have developed agricultural processes such as row crops, they developed the practices of plant grooming, which create ideal materials and seed collections for later usage. The creeks and streams were expanded to improve irrigation of plants and to strand fish to make them easier to catch. Basket makers would often tend to willows and maintain spacing so that in two to three seasons the willows growing would be ideal for basket making. Those who produced bows and arrows did the same with saplings, grooming them to grow the best materials for later harvest. Oak trees and pine trees had their habitats tended to so that harvests the following year were bountiful.

Changes in climate

Changes in weather

The spring and early summer seasons have become more temperate; during the 1990s, it was common for the month of May to be extraordinarily hot, with temperatures reaching over 110 degrees Fahrenheit (°F) (43 degrees Celsius, °C). Memorial Day Weekend has been an especially good marker for this as now it is common to bring a jacket along while watching the parade in the neighboring town of Bishop due to the slight chill in shade. It still reaches the 90s (°F) (between 32 and 37°C) during the day, but we do not experience the heatwaves that were once so common in May. In the past, it wasn't unusual to have at least a dozen cases involving tourists being treated for heat exhaustion or heat stroke in the spring. Heatwaves still exist in Big Pine but now occur later in the summer.

Drought conditions have become commonplace over the past twenty years; the region is a Great Basin High Desert climate, so there is not an abundance of water during the year, but over the past ten years it has become more noticeable that the amount of

rainfall and snowfall has significantly decreased.

High winds have always been a part of the weather in the Owens Valley, but the frequency at which these winds occur is increasing; this has led to soil erosion around the community, the uprooting of rabbitbrush and sage brush, and complications in native plants establishing root systems when the seeds try to grow. Paired with the drought conditions, this has led to areas that once had established root systems becoming barren spaces.

On April 27, 2021, various residents of Big Pine spotted what appeared to be a tornado north of Big Pine. Had I, the author, not been driving by at the time I might have believed it was a dust devil that people spotted and pulled over to take a photo of it as it started to break apart. The criteria for classification of a funnel being called a tornado is that the funnel is both in contact with the ground and the cloud base, which was confirmed in this case by multiple witnesses and the photo below (**Figure 6.1.8**).

Figure 6.1.8. "Dust Devil" as Seen from Route 168, Heading East Towards the White Mountains and Westgaard (East of Big Pine).



Source: Photo by L'eaux Stewart

As the location where the tornado touched down lacks any mechanism for recording wind speeds and has little vegetation, one would have to assume the event could only be classified as an EFU (where EF stands for Enhanced Fujita and U stands for Unknown) on the Enhanced Fujita Scale: "No survey-able damage. Intensity cannot be

determined due to a lack of information. This rating applies to tornadoes that traverse areas with no damage indicators, cause damage in an area that cannot be accessed by a survey, or cause damage that cannot be differentiated from that of another tornado." Outside of the photo, there is no formal documentation of the event as has happened with other alleged tornadoes that have touched down sporadically over the year, though some of those were recorded in the local county newspaper.

Another type of wind event that has been extensively documented in the Owens Valley, but particularly by Big Pine's segment of the Eastern Sierra Nevada Mountain Range, is the "lee wave", an atmospheric stationary wave. As the wind flows towards a mountain range, it will ride over the top and then drop down the other side, creating a movement that rises and drops again in the same motion of a wave on the ocean. Mountain waves are common in the Eastern Sierra, and many pilots have noted that flying through the valley can be perilous as a result, having led to numerous fatalities locally over the years. The energy from lee waves affects clouds and often the ability for storm clouds to reach the valley from the west, where they are often caught on the mountain tops and create rain shadows within the valley. One of the most noticeable types of lee waves is the hydraulic jump induced wave, notable for the clouds it creates, but also for the sharp rotor that is also created: a rotor is a turbulent vortex with an axis of rotation parallel to the mountain range and is generated around the first trough of the wave as it reaches the valley floor. These rotors have been known to create incredible wind forces that knock things over or throw objects at a distance from where they'd originally been located.

One Tribal member recalled a story of their grandfather having endured a particularly violent windstorm as a child; this event would have occurred around the late 1800s. The child was five or six at the time and his grandparents, whom he was staying with, told him to hide inside the large steamer chest they owned. Shortly thereafter, a large wind violently tore the traditional living home ("novi") apart and the trunk was moved about a quarter of a mile away from the living site with the child still inside. Aside from minor injuries, the worst of the devastation from the wind event was relegated to the living site itself. This occurred at the Panapita living site, which is located on the hillside west of Big Pine. Whether the wind event was a tornado or a lee wave is unknown.

Figure 6.1.9. Alpine Lake Within the Eastern Sierras, at the Palisades (West of Big Pine and Part of the Big Pine Watershed).



Source: Photo by Becky Wood (2019)

Winters often lack snow on the valley floor, though it will snow in the mountains. “White Christmas” was fairly common until the early 2000s. Now winters are typically milder in temperatures and drier. Any rain begins in January and then there is typically no rain again until the start of Spring. The milder temperatures have resulted in certain insects such as mosquitos and wasps coming out of hibernation earlier in the year. These insects would normally die off during the cold winter but now they persist.

Wildfires

Since the original draft of this report was written in 2021, the Big Pine area of the Owens Valley has undergone further ecological shifts due to the ongoing and intensifying impacts of climate change. Tribal members have observed an increase in wildfire activity, as well as stronger and more persistent winds across the valley floor—

wind events reaching speeds and duration not previously experienced in living memory. Prolonged drought conditions continue to affect the region, and seasonal cycles have become increasingly unpredictable, with shifts in temperature and precipitation patterns that impact the natural balance. These changes have had significant effects on local plant communities, wildlife behavior, air quality, and soil health—further complicating traditional stewardship practices and deepening concern for the long-term health of the land.

On February 15, 2022—the day after Valentine's Day—a wildfire ignited on the east side of Bishop, California, approximately 15 miles north of the Big Pine Reservation. Within two to three hours, the fire had traveled the entire distance, reaching within a quarter mile of Big Pine's eastern boundary. Evacuation orders were issued for residents on the east side of the Reservation due to the imminent threat. While the cause of the fire was ultimately determined to be man-made, its rapid spread was fueled by unusually strong winds and a dry landscape still reeling from the severe 2020 drought, during which no measurable rain fell in the spring, summer, or fall. This event marked a turning point in how local residents understood the accelerating climate risks facing the valley.

Community members were forced to evacuate as far as an hour's drive from their homes to seek safety. Evacuation orders also extended to the non-reservation side of Big Pine, impacting residents across the entire community. Containing the fire required a coordinated response with significant personnel from neighboring towns and CAL FIRE. Despite the speed and severity of the fire, no structures were lost, no lives were taken, and the flames never reached the town of Big Pine or the Big Pine Paiute Tribe's Reservation. The near-miss served as a sobering reminder of how quickly fire behavior is changing—and how vulnerable even long-standing communities have become in this shifting climate.

The extreme dryness of the landscape created ideal conditions for the fire to spread rapidly. One of the most pressing concerns in the aftermath was what vegetation would return to the burned areas. While the chemical composition of ash can initially create favorable conditions for native plants to take root, the recovery process for deep-rooted native species is slow and vulnerable. In the meantime, shallow-rooted invasive species

such as cheatgrass, tumbleweeds, and Russian thistle often establish themselves more quickly. These plants not only out-compete native vegetation but also contribute to future fire risk due to their flammability and lack of root structure. Their presence weakens the soil structure, increases erosion, and prevents limited water resources from benefiting the native ecosystem. The 2022 fire occurred along the Owens River between Bishop and Big Pine, where firefighters had the advantage of ready access to water. However, this raised concerns about how differently the event might have unfolded had the fire ignited in a more arid stretch of the valley. Without a nearby riparian corridor, the need to haul water by helicopter or tanker could have resulted in slower response times and a far greater burn area.

The fire also raised broader questions about the responsibilities of landholders surrounding residential communities in maintaining defensible space and managing the landscape to reduce wildfire risk. In areas like the Owens Valley, where much of the land adjacent to towns is held by outside entities, this becomes a complex issue. The land through which the fire traveled in 2022 is predominantly owned and managed by LADWP. In the aftermath, concerns were raised about whether adequate fire breaks had been implemented and maintained in accordance with urban-wildland interface laws. Specifically, some questioned whether a designated buffer zone should have been established around the town of Big Pine to prevent future fires from encroaching so close to the community. As climate change continues to increase fire frequency and intensity, these questions of land stewardship, accountability, and proactive mitigation have become increasingly urgent.

While questions of land management responsibility remain unresolved, they highlight the importance of considering long-standing tribal knowledge in fire mitigation strategies. In 2024, a now-deceased tribal member shared a story about his great-aunt, the renowned Big Pine basket maker Emma Harry, and her daughter: in the 1970s, Emma and her daughter practiced small-scale cultural burning to maintain patches of willow used in their traditional basketry. The burning of willow patches cultivated by basket makers allows for better access to high quality materials. One day, as they tended a controlled fire near one of these willow stands, they were approached by representatives from the California Department of Fish and Game (now Fish and

Wildlife). Despite their efforts to explain that cultural burning had long been used by local Native peoples to encourage healthy plant growth and manage the land, they were warned to cease the practice or face legal consequences if it occurred again. The tribal member was unsure whether they ever stopped burning altogether, but his account speaks to the deeper understanding Indigenous people have held for generations: that fire, when managed properly, is not destructive, but a powerful ecological tool. This knowledge, once dismissed or penalized, is now being reconsidered by state and federal agencies seeking more sustainable approaches to land stewardship in the era of climate crisis.

As the author of this report and a Tribal member, I want to note that while tribal leadership is increasingly being asked by state, local, and federal agencies how they can support and incorporate traditional fire practices, the reality is far more complex. From an Indigenous perspective, the conditions we now face—the result of decades of fire suppression, ecological disruption, and land mismanagement—have pushed the landscape into a state that traditional practices were never meant to navigate alone. Cultural burning was never intended to act as crisis response or large-scale wildfire suppression. It was a preventative practice, rooted in the rhythm of the seasons, the relationship to the environment we were actively living in, and the long-term care of a landscape we'd been inhabiting from the start of our people's history. Now, many areas are so overgrown or overtaken by invasive species that cultural burning is no longer viable without first undergoing major ecological reset—often through the very wildfires we seek to prevent. Paradoxically, it sometimes takes a catastrophic event to clear the ground enough for traditional methods to become possible again, though by that point the damage is already done. This is not a failure of Indigenous knowledge, but a reflection of just how far the land has been pushed beyond its natural systems of balance.

Flooding

In addition to wildfire and drought, the region has also faced climate extremes in the form of heavy snowmelt and runoff. In 2023, a season of significant snowfall in the Sierra Nevada was followed by a rapid and intense melt, forcing the community to

prepare for possible flooding. This was not a new concern—Big Pine and the surrounding areas have experienced flash flooding before, particularly when the land becomes too saturated to absorb additional water. Historically, water flowing off the mountains during the spring melt was absorbed by the valley's meadows, wetlands, and creeks, but with shifts in precipitation timing, land development, and soil health, the ability of the land to buffer these events has weakened. Much of the land where one of our tribal groups traditionally lived lies directly in a floodplain, placing areas of cultural and ancestral importance at continued risk. These patterns further underscore how the challenges we now face are not isolated or seasonal—they are cumulative, intersecting, and deeply tied to both climate and the long-term legacy of altered land management.

Historically, flooding has been part of the oral and lived history of our people. Traditional stories often reference water's power, and in more recent memory, major flood events in the 1920s or 1930s and again in the 1980s serve as stark reminders of the valley's vulnerability. In early 2023, unusually heavy Sierra snowpack led to warnings that the coming runoff could rival those earlier floods in scope and damage. Fortunately, that year's flood never fully materialized thanks to the coordinated efforts of local agencies, who spent the entire summer carefully diverting excess runoff. Their work helped prevent catastrophic flooding from reaching Big Pine. However, the risk was not limited to snowmelt alone. In March of 2023, a series of powerful rainstorms hit the region, overwhelming infrastructure and forcing the temporary closure of highways through Big Pine as water pooled inches deep across the roadway. While the valley avoided large-scale disaster, these overlapping climate events illustrate the increasing volatility of water systems in the Owens Valley—and the scale of response now needed to protect both human life and cultural landscapes.

Impacts on physical systems

Petroglyphs and pictoglyphs in the area have been affected by climate change due to erosion of the rock faces due to the increased frequencies of dust storms, and moisture from rain and dew accumulating under the surface of rock panels which causes them to fall and damage other panels below them. The pigments in the pictoglyphs are becoming lost due to the wind erosion.

Areas north of the town of Big Pine and to the east accumulate water during the wet seasons, forming temporary lakes; the water leaches alkaline soil to the surface which causes a thin crust to form when the water eventually evaporates. The alkaline dust then gets caught in wind and blows south into the town, affecting everyone's breathing. Due to less precipitation each year, the alkaline dust caught in the air becomes greater overtime. Currently the Tribe tracks air particulate matter through their Air Quality program to document the increase in particles trapped in the air that is causing breathing issues. The Tribe has seen an increase in dust and is working with outside officials to mitigate the problem.

Wetland areas have nearly disappeared due to the declining water table and the lack of sustained rainy seasons. The Big Pine People's ancestral territories included many freshwater springs that have now disappeared or remain mostly dormant; these areas were the sites of traditional stories and often were markers of certain family boundaries. The loss of these areas is due to a drop in the water table, likely a combination of LADWP pumping activities and the lack of rainfall to replenish the aquifers.

Snowpack has been reduced for years and has impacted the amount of water runoff into the valley, which leads to further issues such as reduction of native plants in the spring and summer, causing animals to have to move to different areas to find resources.

Access to traditional pine nut harvesting areas has been greatly impacted by soil erosion; root networks in the soil have disappeared in many areas due to a lack of water and as a result, many roads and paths have been washed out due to rainstorms that cannot be absorbed into the soil and create mini mud/rockslides. This requires hiking into areas, which can be perilous as the disturbed roads and trails might not be stable and the hiker risks the possibility that the rocks they're walking on might slide out from under them.

Impacts on vegetation

The abundance of plant species has reduced by a significant amount in the Big Pine area: plants typically associated with basket making such as willow and devil's claw are often so difficult to source that they must be found outside of the traditional land boundaries (often by Bishop or Mono Lake). Food such as Taboose (*Cyperus*

esculentus), a plant that grows a small nut-like tuber, was once so prevalent that a person could walk through miles of plants within arms distance; Taboose is now only found in spaces in the backcountry around Big Pine and can no longer serve as a supplementary food to an adult's diet without depleting the plant population severely.

Acorns were another primary source of protein for the Big Pine peoples. Now to harvest acorns, one would have to travel south to Fort Independence, which does not produce acorns regularly enough to support an adult through the winter season. Previously, acorns could be gathered in such large quantities that it was common to bury a large cache in a riverbank over the year so that the running water could leach the tannins out of the nut meat. The taste of the local acorns has purportedly changed so that the tannins are stronger and require more time being leached.

Pine nut harvests are commonly less successful. This is not due to an overharvest or loss of land, but due to climate change. Pine nuts grow on a seven-year cycle, and it is common to rotate traditional pine nut harvesting sites every year. Families select their own harvesting site and often keep the information private; it is not an easy task, and most people aren't knowledgeable about pine nuts. There is little evidence that the lack of pine nuts from year to year has to do with interference by anything but the climate change that our area experiences. Pine nuts are no longer the primary source of winter foods due to convenience of modern foods, but they are still a very welcomed food in the Paiute and non-Native community of the Owens Valley. We have also noticed that the size of the pine nuts has gotten smaller.

Tule and cattail are no longer harvested in abundance for food or housing material due to the development of the lands that they grew on. Wetlands have dried up and houses or other development have replaced the tule beds. There is also high concern about the quality and safety of eating them due to chemicals that are sprayed on them for mosquito control and in the water that they grow around.

Wildfires in the area have become increasingly dangerous due to the drier plants in the wildland areas around Big Pine; certain plants have a difficult time regrowing after the area has been burned such as blackbrush, while others invade the area, such as foxtails and cheatgrass.

The coyote potato has been difficult to find, and it is unknown if this is due to the destruction of the land by development that would have typically served as its habitat or due to loss of water in the area overall.

Wild tobacco grows in recently burned areas, so there has been an increase in wild tobacco growth around the town of Big Pine in areas where wildfires burned; however, there is a lack of native plant growth in those same areas afterwards. Instead, those places have become covered by cheatgrass and tumbleweeds, which do nothing to save the soil during windstorms, or create a root network to help establish soil stability. This also means that looking for traditional plants that might grow after the tobacco has repaired the soil is becoming difficult.

Impacts on wildlife

There has been a noticeable decrease in the number of Jackrabbits and Cottontail Rabbits in the valley due to a combination of predators moving down into the areas where we would hunt for rabbits and due to a lack of vegetation for the rabbits to eat. Our area was known for the rabbit drives (a hunting activity) that occurred in the fall, where it was common to kill between 70 and 100 rabbits in a day. That is no longer a sustainable activity, and Tribal members no longer rely on rabbits as a main source of food.

The insects once harvested for food are now no longer easily found; the landscapes where insects such as cicadas once lived have changed so drastically due to lack of water and vegetation in the past thirty years that the insects have either migrated or died out.

Larger predatory animals such as mountain lions and bears, as well as smaller predatory animals such as coyotes and bobcats have begun to appear more frequently on the reservation lands; there have been numerous incidents of pets and livestock being killed or maimed, trashcans being disturbed, or prowling on Tribal member assignments (plots of land held by the Tribe but assigned to Tribal members) in the past fifteen years. Some of the animals have been captured and relocated by California Fish and Wildlife, while other animals have been killed by cars or shot by townsfolk within Big Pine for the danger they pose. This is likely because their typical hunting areas have

been deeply affected by their prey migrating to different areas closer to town to access water and vegetation.

Birds of prey are slowly returning to the area due to conservation efforts, however many lack the areas they would typically use for nesting and hunting. The foods upon which these avian predators rely, such as rabbits and mice, are impacted by a lack of vegetation. The trees in which the birds of prey would typically live are dying due to lack of water. Owls have been able to adapt by living in abandoned or isolated human-built structures such as silos. They are now seen often in residential areas; owls are considered an omen of bad luck, so many Tribal members are uncomfortable with their frequent presence.

Native fish species are on the endangered species list due to introduction of other fish species, destruction of habitat, and lack of water, the impacts of which are exacerbated by climate change. Fish can be very delicate to care for, as even small fluctuations in temperature and sunlight can negatively affect their health. Re-establishing the native fish populations has been a struggle due to the change in the landscape and the lowering of the water table throughout the valley. If more is not done to protect them, there is a likelihood that species such as the Tui Chub and Owens Valley Pupfish will go extinct in the next decade. The Big Pine peoples have focused all their attention on preserving the native fish and no longer fish for them.

Bighorn Sheep (**Figure 6.1.10**, below) have been impacted by drought and are no longer in the area, though they are slowly returning with the assistance of the California Fish and Wildlife Bighorn Sheep Reintroduction Program. They were once a staple of the Owens Valley Paiute life but can no longer be hunted even for cultural purposes; to hunt Bighorn Sheep in the White Mountains, one must acquire one of the six hunt tags through a lottery offered by the state. The Big Pine Peoples have been incredibly supportive of areawide conservation efforts to restore the original herd sizes to the valley.

Figure 6.1.10. Bighorn Sheep.



Source: CDFW (2021)

Impacts on human health and well-being

While the spring is becoming milder, summers are hotter. As our people no longer travel to the mountains to live during the hotter summer months, they are routinely exposed to higher temperatures in the summer. Summer is typically dry and windy, with exposure to smog from tourist vehicles and smoke from California wildfires. During the 2020 fire season, residents of the Owens Valley were forced to remain indoors for many months straight. It should be noted that during this time there was little wind, which allowed the smoke to settle over the town of Big Pine; many people commented about how unusual it was. Not all households own air conditioners or swamp coolers, so many people are left in houses that are too hot to safely occupy.

Droughts have become commonplace in the area. The dry soil leads to dust, which often affects the breathing of all community members; there are a number of elders with lung issues and a growing number of cases of children with asthma and other breathing issues. The soil is alkaline and causes clouds of dust that are very irritating to the eyes, throat and lungs.

Hunting is not as readily accessible due to game having left the immediate area. Smaller game such as dove and quail are easy to find around the south and eastern border of the reservation, but rabbits and deer must be sought out. The death and/or

lack of plants has also led to a huge change in diet for the people and has spanned over multiple generations.

Summary

Overall, climate change and the lack of water within the Big Pine area have become of great concern. Climate change has led to soil erosion, loss of wetlands and springs, loss of plants, animal migration, changes in traditional trail systems, and changes in diets and cultural practices; these impacts are tied to water, heat, wind, and fire hazards. Without a return of water to the area, the Tribe is looking at scenarios where the land will not recover and thus will lose out on many of the practices that make up our culture. As a result, the Big Pine Paiute Tribe has become involved in water rights, and activism surrounding the politics and usage of water in our community. It has led to the Tribe working hard to manage water and educate our Tribal members on how to best use the water we are able to obtain.

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Suggested citation:

Big Pine Tribe (2026). Impacts of Climate Change on the Big Pine Paiute Tribe of the Owens Valley. In: OEHHA 2026 Indicators of Climate Change in California.

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6.2 Impacts of Climate Change on the Big Valley Band of Pomo Indians

Warming air temperatures, variable precipitation, drought, wildfire, warming lake temperatures, harmful algal blooms, reduction of fish, bird and animals, as well as other stressors are impacting Tribal livelihood, culture, and traditions.

Background

Figure 6.2.1. Clear Lake Basin from What Is Now Called Soda Bay.



Source: Photo by Laurie Monserrat

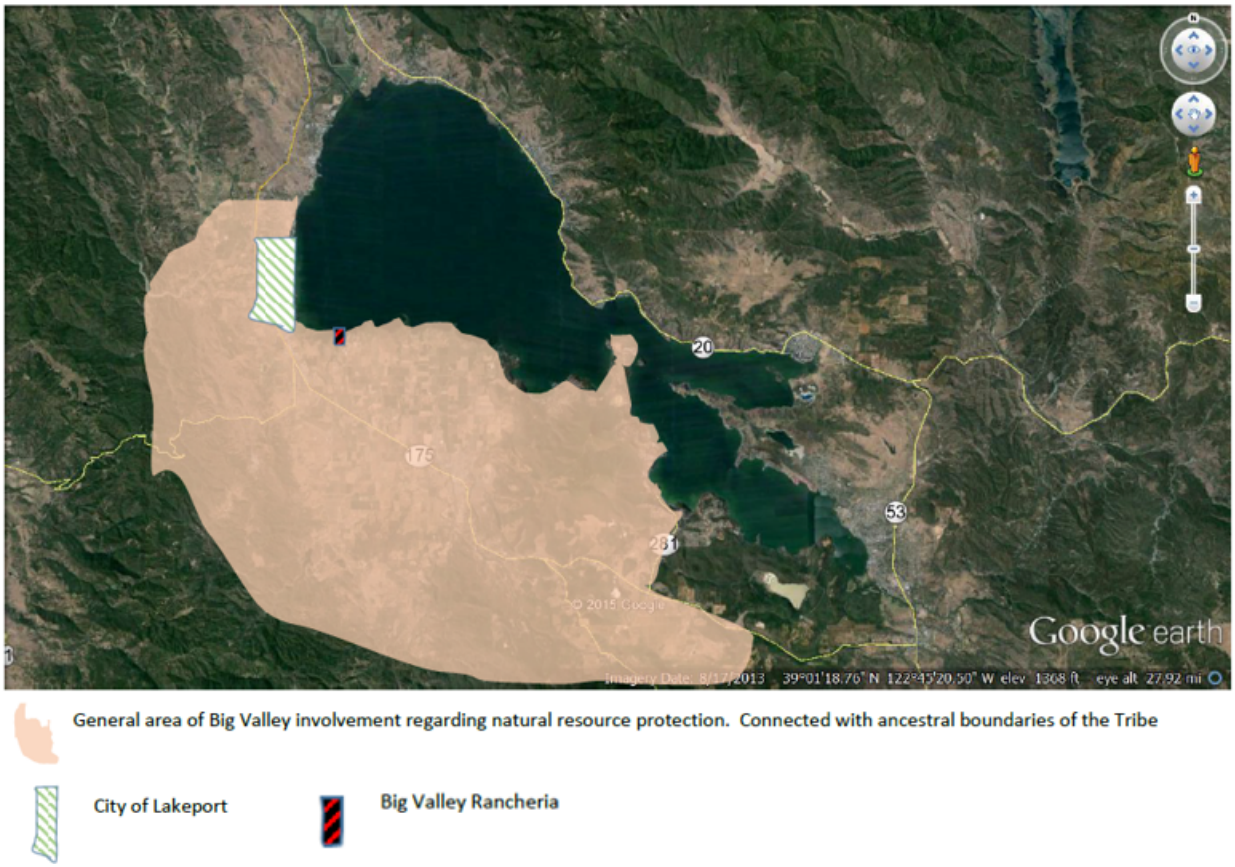
The Big Valley Band of Pomo Indians of the Big Valley Rancheria of California is a self-governing, federally recognized Tribe of Pomo Indians residing on the shores of Clear Lake in Lake County, California (**Figure 6.2.1** and **Figure 6.2.2**). Their ancestors, the Xa-Ben-Na-Po Band of Pomo Indians, inhabited the Clear Lake area for over 11,800 years (BVR, 2022). In 1851, a treaty was agreed upon with the office of the U.S. President which established a reservation of approximately 72 square miles with extensive lake front property, including much of the Clear Lake basin including Mt.

Konocti. However, the U.S. Senate refused to ratify this treaty and 17 others on July 8, 1852. The U.S. Senate placed the treaties under an injunction of secrecy which was not removed for over 50 years (Flushman and Barbier, 1986). Instead, Congress passed the Land Claims Act of 1851 requiring claims to California lands be presented within two years (Patrick, 2008). Tribes were intentionally never told of this new requirement. Like all tribes, the Big Valley Band of Pomo leaders failed to meet the statutory deadline, and their Tribe and others became landless. After the U.S. Government took Indian homelands, they gave loans to settlers to buy Indian land (Montez, 2022).

Big Valley, along with other bands of Pomo, were granted small rancherias years later. In 1914, the U.S. Department of the Interior purchased land for the Big Valley Rancheria. In 1936, under the Indian Reorganization Act of 1935, the Tribe became federally recognized, formed its government, and ratified its constitution. Then in 1963 the Tribe was illegally terminated under the California Rancheria Act of 1959. The Tribe was subsequently re-established by court order as a federally recognized tribal entity in 1983. During that 20-year period approximately half of the original Rancheria land, including Mt. Konocti, had been seized and sold to non-Indians. In 1986 the Big Valley Tribe began the process of reconstituting their rights of self-determination by re-forming their government through the guidance of their 1936 Constitution. The Tribe is also in the process of buying back their homelands. They recently created housing for more than 70 Tribal members through the purchase of a 15-unit apartment property in Lakeport, the construction of five tiny homes for unhoused Tribal members, and through securing eight homes for Elders.

Current Big Valley Tribal membership is approximately 1,300 people. Though the Rancheria sits on 350 acres today, traditional Tribal lands extend much farther. Additionally, Tribal members live all around the lake, and throughout California. **Figure 6.2.2**, below, shows the Rancheria territory, the City of Lakeport, and the much larger general area in which Big Valley is involved in natural resource protection. This map helps illustrate that the lands the Tribe uses and cares for extend beyond Rancheria borders. Big Valley Pomo rely heavily on Clear Lake and the resources surrounding it for subsistence and livelihood, as well as for important cultural and spiritual practices.

Figure 6.2.2. Big Valley Natural Resource Protection Areas.

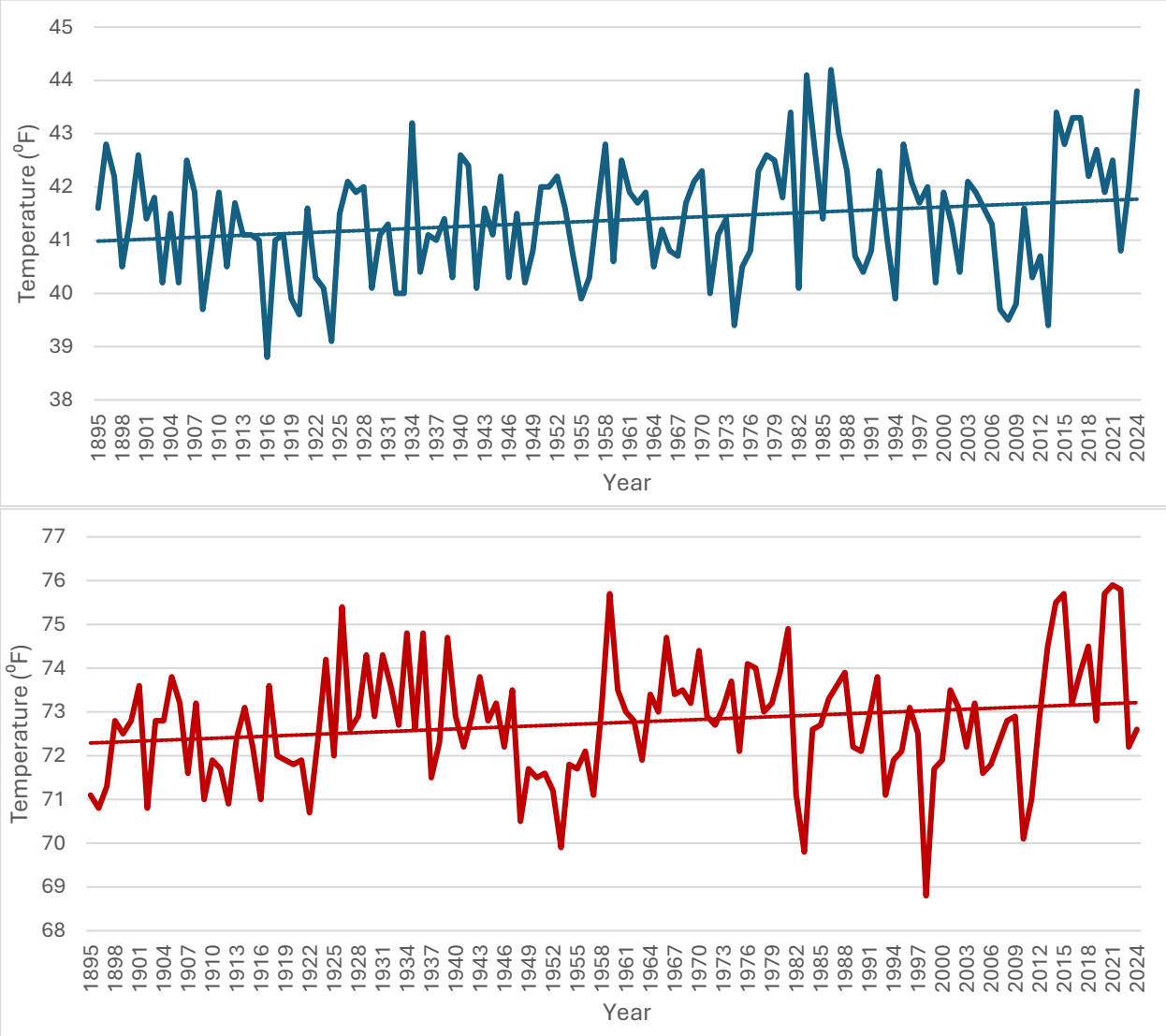


Map showing location of Big Valley Rancheria (red-striped area), the City of Lakeport (green-striped area), and the general area in which the Tribe engages in natural resource protection (tan area). The tan area is also closely tied to the Tribe's ancestral boundaries. Source: BV EPA (2014)

The waters of Clear Lake itself are of cultural importance to the Big Valley Tribe. The Tribe conducts their Tule Boat Festival and other important cultural and spiritual events on Clear Lake. The Tule Boat Festival is a three-day festival showcasing traditional Pomo boat-making skills. The boats, constructed primarily using materials gathered from shoreline tule plants, are raced by Tribal members. The festival draws tribes from around the North Coast region and beyond and provides an opportunity for sharing traditional foods (BVBPI and MRPI, 2021).

Air temperatures

Figure 6.2.3. Nighttime (Top) and Daytime (Bottom) Temperatures at Big Valley Rancheria, 1895 to 2024.



The annual average minimum or nighttime temperatures (top) and annual average maximum or daytime temperatures (bottom) are shown as solid lines. Linear trends over the entire period are shown as dotted lines. Source: PRISM Climate Group (2025)

Over the past 129 years, annual average minimum temperatures (nighttime) and annual average maximum temperatures (daytime) have increased at the Big Valley Rancheria. **Figure 6.2.3**, above, shows that nighttime temperatures are increasing at an average

rate of 0.06 degrees Fahrenheit (ºF) or 0.03 degrees Celsius(ºC) per decade, and that daytime temperatures are increasing at an average rate of 0.07ºF (0.04ºC) per decade.

In July 2024, Big Valley Rancheria experienced 15 days of temperatures above 100ºF (37.8ºC). During this heat wave, the Tribe experienced the hottest week, two-week, and month-long period on record (Abatzoglou et al., 2025).

Warming daytime and nighttime air temperatures are linked to numerous impacts on human health and livelihood, as well as ecosystem health and function. Warmer air temperatures change precipitation and runoff patterns, which impact the availability of freshwater. Warming air temperatures lead to changes in species distribution and abundance and the timing of life-cycle events, all of which alter the ecosystem as a whole. Rising temperatures also strain energy demand and infrastructure, increasing the number and length of the Public Safety Power Shutoffs (PSPS) the Tribe has seen. To protect Elders during these PSPS events the Tribe has purchased generators. Increasing air temperatures promote ozone formation leading to adverse health effects such as lung irritation, inflammation, worsening of asthma, and increasing mortality (US EPA, 2021).

Warmer air temperatures along with a lack of rainfall over time stresses vegetation, creating susceptibility to pests, disease, and death. The increase in dead vegetation then increases wildfire risk for the Tribe. The effects on vegetation also reduce the availability of materials and resources important to the Tribe for various cultural and spiritual uses, such as Tules.

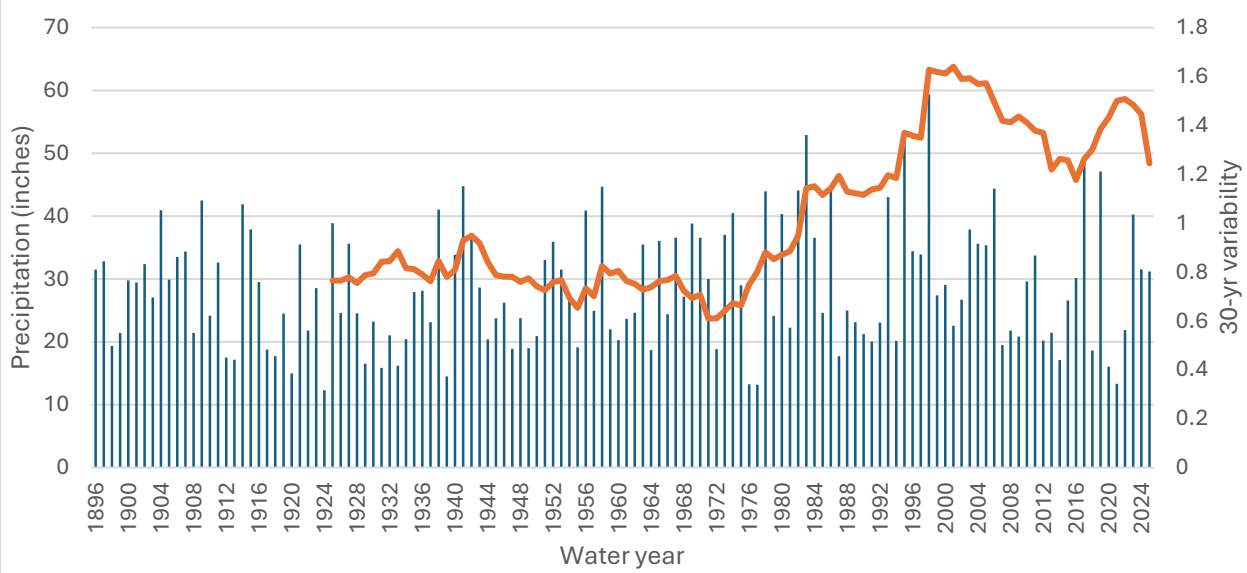
Warming temperatures and changing precipitation patterns are associated with increased harmful algal blooms (HABs) in Clear Lake. Additionally, warmer winter temperatures have allowed the invasive water primrose to flourish year-round, leading to further tule loss along the shoreline due to competition (BV EPA, 2014).

Precipitation

As shown in **Figure 6.2.4**, below, there is considerable year-to-year variability in the annual precipitation at the Big Valley Rancheria, particularly over the last 30 years. Average annual precipitation dropped to its lowest around 2013 and 2014 during a

period when Lake County experienced extreme drought (Lake County, 2021). The Rancheria has experienced years of extremely high and extremely low rainfall, as well as increasingly unpredictable precipitation patterns throughout the year. High rainfall events result in a sharp increase in surface water flow into Clear Lake, leading to sedimentation and erosion, particularly in shoreline areas where vegetation has been lost. Sediment deposition into the lake impacts water quality (USDA, 1995). Sediments carry contaminants such as trace metals and organic and inorganic compounds which are toxic to plants and animals (BV EPA, 2017a). Sediments are often nutrient-rich, and these excess nutrients promote the development of HABs.

Figure 6.2.4. Water Year Precipitation and Variability at Big Valley Rancheria from 1896 to 2025.



Blue bars represent precipitation totals for each water year (October 1st of the previous year through September 30th of the year). The orange line shows variability: a ratio of 30-year variance divided by the total record variance. Values higher than 1 represent more fluctuation in rainfall totals, while values less than 1 represent more consistency. Source: PRISM Climate Group (2025)

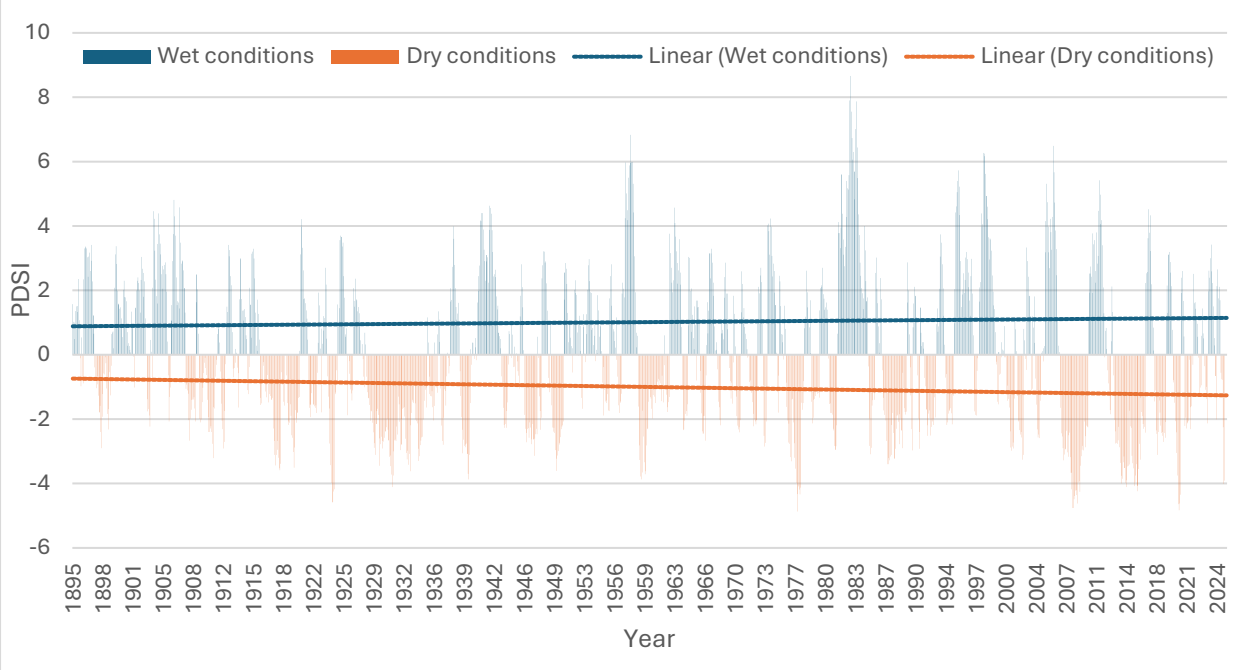
Heavy rains affect infrastructure at Big Valley. The Rancheria needs a better drainage system to prevent flooding which also damages homes. Many Tribal members live in mobile homes, which are particularly susceptible to flooding. Several members have

had to build their own weirs to access their homes during high rainfall. The Tribe has identified increased mold growth in Tribal members' homes after heavy rain events as an impact of climate change (BVBPI and MRPI, 2021). The marina at the Rancheria has been replanted with vegetation previously lost along the shoreline to combat erosion, but during periods of heavy rain, large sections of shorelines wash away.

Big Valley's Integrated Solid Waste Management Plan addresses climate change impacts such as flooding and resulting landslides the Tribe is seeing as a result of extreme rain events. The Tribe has experienced landslides that blocked roads and damaged Tribal buildings and lands following heavy rainfall in recent past and the Tribe is working to protect its facilities from future impacts (BV ISWMP, 2023).

Drought

Figure 6.2.5. Monthly PDSI for Big Valley Rancheria, 1895 to 2025.



Source: Abatzoglou et al. (2025)

Figure 6.2.5 shows the monthly Palmer Drought Severity Index (PDSI) for Big Valley Rancheria from 1895 to 2025. PDSI is a commonly used measure of drought that

integrates temperature, precipitation and soil moisture data to provide a measure of relative dryness (drought) on a scale from -10 (dry) to 10 (wet). A PDSI of negative four (-4) or less indicates extreme drought, while a PDSI of four (4) or more represents very wet conditions. Drought conditions at Big Valley have gotten more severe over this time period.

Drought has impacted Clear Lake resources, lake water quality, and consequently, the people and other species that rely on the lake. Additionally, drought has caused stress to vegetation throughout the Lake County area, notably to native pine and oak trees, making them more susceptible to pests such as the pine bark beetle and Mediterranean oak borer, respectively. Dead trees and other vegetation increase fuel for wildfires.

Water scarcity also impacts local agriculture, stressing crops such as pears, walnuts, and grapes. Increased reliance on groundwater to support agriculture in areas near the Rancheria reduces the volume of surface water entering streams where Clear Lake Hitch, an endemic and culturally significant fish, spawn (see **Impacts on Creeks** section). Investigations by California Water Boards and Big Valley have found that 90% of groundwater in the Big Valley basin is used for agriculture (SWRCB, 2023). The PDSI metric does not account for the role that increased groundwater pumping from subsurface creek flow plays during droughts and extreme heat events, causing much more severe impacts than might be expected based on PDSI alone. Many streams and creeks surrounding Clear Lake have dried up during periods of drought (BVBPI and MRPI, 2025).

During periods of drought, decreased stream flows into Clear Lake reduce dilution, resulting in higher concentrations of pollutants, and increases in microbes and pathogens in the lake, which in turn affects public health. Additionally, drinking water sources are impaired and with 17 water purveyors pulling water from the lake, the increased cost is passed to the consumer. Partnering with Tracking California, which compiles and analyzes data about public health and the environment, Big Valley tested self-supplied drinking water systems on Clear Lake for cyanotoxins, nitrates, coliform bacteria and herbicides, all contaminants of concern for self-supplied drinking water systems (BV EPA, 2017b). During the most recent testing between June and October

2021, 20 of the 36 homes tested had detectable cyanotoxins and 13 were above the US Environmental Protection Agency (US EPA) health advisory level of 0.3 micrograms per liter (µg/L). The highest resulting concentration was 3.85 µg/L. In November 2021, 41 homes were tested and cyanotoxins were found in 22 samples; of those 10 were above the US EPA health advisory level (Cal-WATCH, 2022). Since 2021, the Tribe has been implementing a program to measure groundwater elevation in local wells. Increased withdrawals during drought have been correlated with reduced tributary flows into Clear Lake and poorer lacustrine water quality. The Tribe seeks better understanding of the variations in groundwater storage to ensure long-term sustainability of surface and subsurface water.

Declining lake water levels in Clear Lake due to drought have exposed cultural resources, such as arrowheads. This has exacerbated the problem of non-natives actively searching for these resources to sell. These items are Tribal property and taking them is disrespectful and disturbs the Tribe as a whole. Artifacts found need to be honored and left in place or returned to the tribes (BVBPI and MRPI, 2021).

Impacts on creeks

As drought and extreme heat increase demand from other water users, such as agriculture, the Tribe has observed decreasing creek water levels earlier in the year and a corresponding reduction in suitable fish spawning and rearing habitat. The Chi or Clear Lake Hitch is a species of high cultural and dietary importance that is being particularly impacted. Hitch are also discussed in the **Culturally Important Species** section, below. Hitch depend on adequate freshwater flows and habitat in creeks through the summer to connect tributary spawning grounds and the Lake, and to maintain proper depth, water temperature, dissolved oxygen (DO) levels, and other conditions necessary to the survival of their young. When flows drop, Hitch can be stranded in shallow pools where they face certain death without intervention.

Many of the freshwater bodies most critical to the survival of the Hitch face multiple stressors that contribute to habitat decline, although temperatures and drought are most notable. In 2025, of the 23 creek sites that are monitored by the Tribe, 19 had dissolved oxygen below the attainment threshold, 20 had pH outside of the acceptable range, and

22 exceeded temperature standards (BV EPA, 2025). Clear Lake, McGaugh Slough, Rodman Slough, Manning Creek, Kelsey Creek, and Forbes Creek were also designated as impaired waterways in 2024 for not meeting other cold freshwater habitat requirements (US EPA, 2025a). Several of these waterbodies were first listed as impaired in 2022. Clear Lake was first listed in 2018.

In 2022, Big Valley and other entities began monitoring Hitch-bearing creek levels, noting where and when creeks become disconnected and rescuing stranded Hitch and other native fish species when possible (**Figure 6.2.6**, below).

Figure 6.2.6. Rescuing Hitch.



The pool in this photo was once part of the flowing creek. As creeks dry, they leave behind pools where Hitch become stranded and die unless they are rescued. Source: BV EPA (2025)

Due to drought conditions in 2022, low flows, disconnected pools and even dry creek beds were observed as early as January. Following precipitation events in 2023, low flows, creek disconnection and drying began a few months later than in 2022, and 26,090 stranded Hitch, mostly fry, were rescued. In 2024, drying conditions began slightly later than in 2023, and 24,541 Hitch, all fry, were rescued. However, in 2025 Big Valley again observed low flows as early as January, with disconnected pools and dry beds occurring in March and May, respectively. They rescued 28,125 stranded Hitch, predominantly juveniles, from unsuitable creek habitat in the Big Valley area alone in 2025 (BV EPA, 2025). Collectively, these data illustrate that drying is occurring during critical Hitch spawning and rearing windows and, without intervention, will strand and kill large numbers of Hitch.

In 2023, Governor Newson issued an executive order (N-5-23) which highlighted the ongoing impacts of severe drought on the Clear Lake and Klamath River watersheds (State of California, 2023). He directed the State Water Board and California Department of Fish and Wildlife (CDFW) to study the minimum flow requirement in all Hitch-bearing streams and consider necessary regulations (SWRCB, 2025). This resulted in an emergency information order of all water users in the watershed.

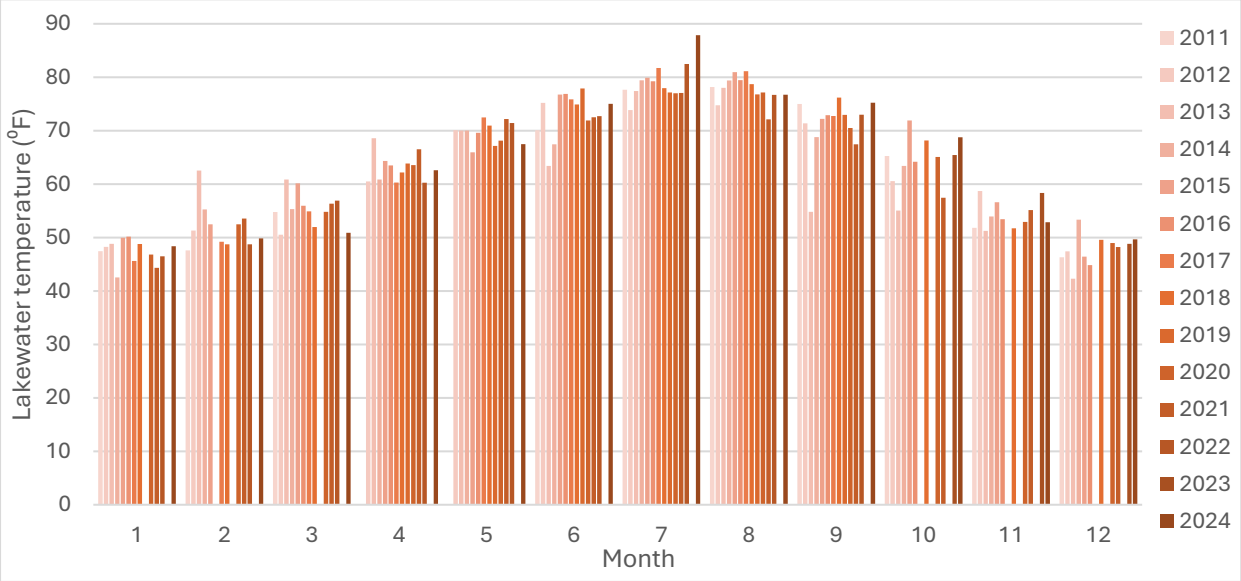
The Water Boards shared preliminary results of this investigation with the Tribe in 2023. They estimate that there may be two to three times more unpermitted agricultural wells (850–1800 wells) than permitted agricultural wells (600 wells) in the Big Valley water basin, and their pumping rates are mostly unknown (SWRCB, 2023). Of the 225 water rights holders along Hitch-bearing creeks, 50% did not report diversion and use statements in 2022. The 50% of diversion and use statements that were reported were of poor quality. Of the 100 water rights holders that were subject to measurement requirements, 90% were out of compliance. Additionally, 200 reservoirs that did not have water rights were found near creeks. Getting a better understanding of water use in Big Valley basin is essential for the Tribe and state agencies to better address the problem of insufficient flows for fish.

Lake water conditions

Lake water temperature

Figure 6.2.7, below, presents lake surface water temperature measured monthly between 2011 and 2024 at sampling site BVCL6, an area of Clear Lake of particular importance to the Tribe. This site has seen monthly average water temperatures that are highly variable across years, marked by exceptionally warm temperatures in certain years. Notably warm temperatures were observed from February to April in 2013, in December 2014, in October 2015, and through the second half of 2024. The highest temperatures on record were observed during the July 2024 heatwave.

Figure 6.2.7. Monthly Clear Lake Surface Water Temperature from 2011 to 2024.



Source: National Water Quality Monitoring Council (2025)

Even seemingly small increases in water temperature can significantly affect key physical and biological processes in lakes. Lake impacts have also affected the Tribe. Fish and other aquatic species often do best within a certain range of water temperatures. As water temperatures rise, native populations of fish and other species which are important to the Tribe might not thrive, while introduced species that

previously would not survive in the lake are absent their natural predators. Balance is key for a healthy lake.

Big Valley's understanding, based on their communication with the Central Valley Regional Water Board, is that the maximum temperature for surface water in the Clear Lake watershed should be 69.8˚F (21˚C). **Figure 6.2.7** above shows that Clear Lake surface water temperatures were regularly above 69.8˚F from May to September of 2011 to 2024.

Figure 6.2.8. Map Showing Key Big Valley Freshwater Concerns.



Source: BV EPA (2014)

Changing lake temperatures affects the habitat and distribution of fish. **Figure 6.2.8**, below, shows creeks feeding into Clear Lake in the Big Valley area (BVBPI and MRPI,

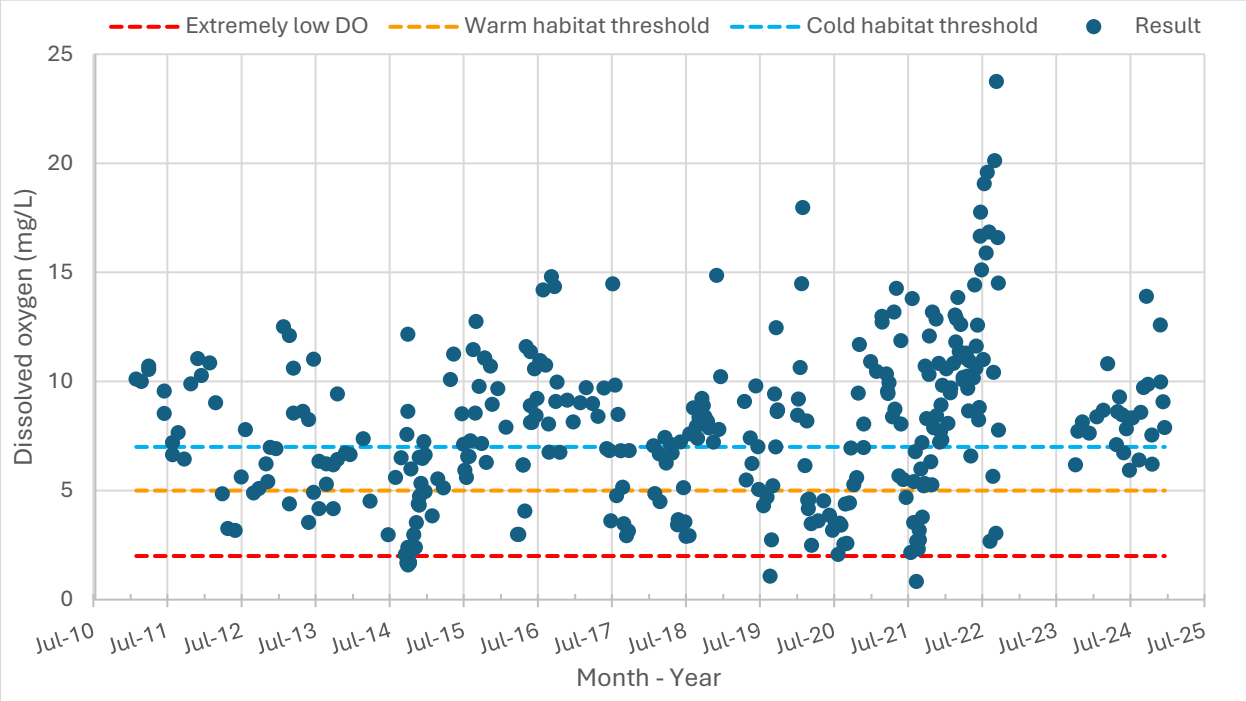
2021). Clear Lake Hitch, a threatened species of "immeasurable ecological and cultural value" (CDFW, 2014) migrate from Clear Lake into tributary streams such as Kelsey Creek and Adobe Creek (indicated with yellow stars on the map) for spawning (Feyrer et al., 2019a). In 2014 Hitch were only observed spawning in these two streams.

Dissolved oxygen in Clear Lake

Dissolved oxygen (DO) is the most important health indicator of a water body and its capacity to support a balanced aquatic ecosystem of plants and animals. Oxygen from the atmosphere and photosynthesis dissolves into the upper level of all bodies of water. The amount of DO in a water body decreases with depth, rising water temperatures, and the oxidation of organic matter and pollutants. Erosion and sedimentation caused by high precipitation events carry organic, oxygen-consuming material into Clear Lake leading to a reduction in DO. Low levels of precipitation reduce surface flow into Clear Lake and can both increase water temperature and reduce DO.

Big Valley Rancheria uses Central Valley Regional Water Quality Control Board objectives for DO that outline three beneficial uses: (1) warm freshwater habitat – uses of water that support warm water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish or wildlife, including invertebrates; (2) cold freshwater habitat – uses of water that support cold water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish or wildlife, including invertebrates; and (3) warm spawning, reproduction and/or early development – uses of water that support high quality aquatic habitats for reproduction and early development of fish (BV EPA, 2017a). These water quality objectives dictate that DO concentrations in Clear Lake should not fall below 5.0 milligrams per liter (mg/L) for warm habitat and 7.0 mg/L for both cold habitat and warm spawning habitat. **Figure 6.2.9**, below, shows DO levels at site BVCL6 over the past 14 years. During that time DO dropped to extremely low levels (below 2.0 mg/L) six (6) times, below 5.0 mg/L 73 times, and below 7.0 mg/L 140 times.

Figure 6.2.9. Dissolved Oxygen Concentrations at a Clear Lake Monitoring Site from 2010 to 2025.



Source: National Water Quality Monitoring Council (2025)

Data collected by multiple agencies over the last several years on Clear Lake show extended periods of time where DO was suppressed throughout the lake, leading to fish kills that have been investigated by CDFW who have confirmed that low DO was the cause (BV EPA, 2017a). The Upper Arm of Clear Lake, where the Tribe and monitoring station BVCL6 is located has shown lower DO and increasing frequencies of hypoxic conditions since 2000 (UCD, 2010).

Low DO in Clear Lake can both be caused by and contribute to blooms, or rapid growth, of cyanobacteria. Big Valley Environmental Protection Department (BV EPA) monitoring data showed a lake-wide cyanobacteria (*Synechocystis* spp.*)* bloom in September 2025 that coincided with a drop in DO observed by CDFW biologists, and a fish kill numbering in the millions observed by Clear Lake tribes and communities (BV EPA, 2025). These data provide strong evidence that cyanobacteria die-offs are driving low DO. In turn, oxygen-depleted conditions have been shown to trigger the release of

phosphorous from sediments at the bottom of Clear Lake. This phosphorous becomes bio-available and fuels the rapid growth of cyanobacteria.

To help mitigate the cycle of cyanobacterial blooms, low DO, and fish kills in Clear Lake, multiple projects are being developed to interrupt the life cycle of cyanobacteria in different ways. These initiatives are funded by the Blue Ribbon Committee for the Rehabilitation of Clear Lake (BRC, 2026). One such project is the Hypolimnetic Oxygenation Pilot Project that the UC Davis Tahoe Environmental Research Center recently began in the Oaks Arm. Simultaneously, a web-based clearinghouse is being launched to host and share data and documents having to do with Clear Lake (BVR, 2026).

Culturally important species

Climate change has impacted species of cultural significance to the Big Valley Band of Pomo Indians. The Tribe is seeing fewer, quail, otters, turtles and other animals that are important to the Tribe. These species have diminished due to the cascading impacts of climate change on their habitat (BV EPA, 2022a). Additionally, the Tribe has observed fewer flicker and red-wing blackbird species. These are important birds because the Tribe uses their feathers in regalia and other important cultural activities. With the loss of these birds, the passing on of skills, vocabulary, and ceremony to younger generations is impacted. This constitutes a larger loss than just having to change which feathers the Tribe uses for regalia; it constitutes a loss of culture and an important part of Tribal identity and long-standing traditions (BVBPI and MRPI, 2021). Twenty-eight percent of the native aquatic fish species in Clear Lake have become extinct in the last century (UCDNAR, 2022).

Asian clams

The Asian clam (*Corbicula fluminea*) was historically invasive to this area but over time became a staple food source for the Tribe and others living around Clear Lake. Tribal members have observed changes in the size and availability of Asian clams in Clear Lake. Asian clams are short-lived filter feeders, consuming large quantities of

phytoplankton (Sousa et al., 2008). As such they are susceptible to contaminants such as mercury and cyanotoxins, which pose serious health risks to people who consume Asian clams.

Clear Lake Hitch

Figure 6.2.10. Clear Lake Hitch.



Source: Photos by Richard Macedo, CA Department of Fish and Game

One native species of concern is the Clear Lake Hitch (*Lavinia exilicauda chi*). Hitch are large minnows, 14–16 inches long found only in Clear Lake and its tributaries. Hitch typically live six to seven years. Unlike salmon that die after spawning, Hitch normally return to Clear Lake at the end of their spawning season. They have been impacted by reduced stream flows from drought and decreased precipitation, loss and degradation of spawning habitat, water pumping, barriers to fish migration (such as dams), pollution, and competition from invasive fish (Center for Biological Diversity, 2013; Feyrer, 2022).

Clear Lake Hitch were formally listed as a threatened species under California's state Endangered Species Act (ESA) in 2014 due to significant decline in numbers of Hitch, and the fish's disappearance from most former spawning streams. In January 2025, the U.S. Fish and Wildlife Service (USFWS) proposed to list Hitch as threatened under the Federal ESA as well (USFS, 2025). However, USFWS missed the January 2026 deadline for issuing a decision. In response, the Center of Biological Diversity sued USFWS in April 2026, arguing that by failing to issue Federal protection, the agency is

increasing the chances that Hitch will go extinct (Center for Biological Diversity, 2026).

Elders of the Big Valley Tribe have seen Hitch numbers decline in their lifetime. In the 1960s and 1970s, Hitch were so numerous that they made the water appear to boil in area creeks and streams (BVBPI and MRPI, 2021). Hitch now spawn regularly in only two streams, Adobe Creek and Kelsey Creek. One Big Valley Elder reported that while Hitch used to be plentiful in Kelsey Creek, which runs behind his home, he has not seen Hitch in the creek since 2010. He also noticed that the spawning season has shortened. Traditionally Hitch would spawn for about six weeks and now the spawning season seems to be about three weeks.

"The chi are vital to our people, our heritage and our future. We cannot afford to lose them. That is why we strongly support federal endangered species protections and every available tool to safeguard their survival. We must act now to ensure that future generations can continue to have a relationship with this important species."

~ Tribal Chairman Flaman McCloud Jr., of the Big Valley Band of Pomo Indians

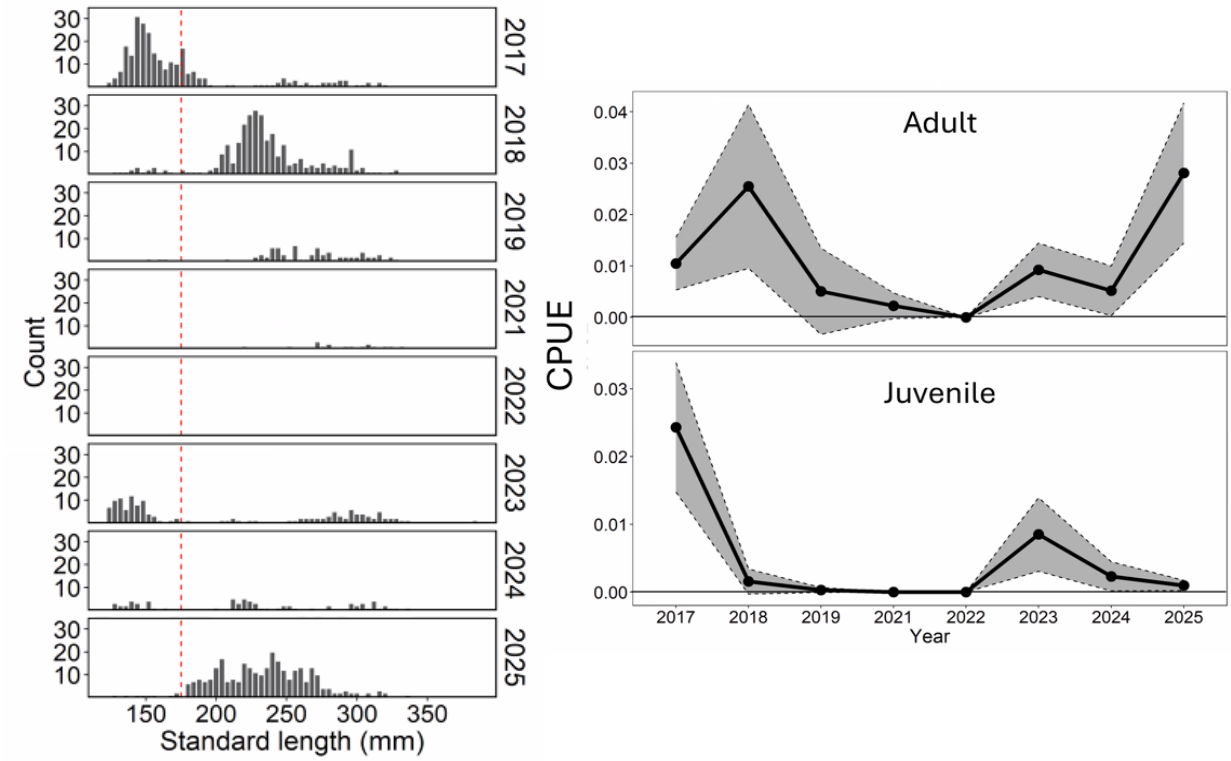
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The Clear Lake Hitch are a culturally and biologically important fish. Another Elder explained that the Hitch were dried and kept for use throughout the winter and was a valuable trade item with Coastal Pomo tribes for resources such as seaweed, clam shells and abalone. Hitch were also a major food source for ceremonies (BVR, 2013). The loss of this fish impacts the community, the history, and the culture of the Pomo people. Restoring their habitat and numbers will also improve the health of Clear Lake overall as they are also an important food source for numerous birds, fish and other wildlife.

Lake and stream surveys of Hitch

Monitoring of the Hitch in Clear Lake (**Figure 6.2.11**, below) shows a troubling pattern. There are fewer juvenile Hitch; and the overall numbers are drastically lower than the historic levels on which Big Valley relied for hundreds if not thousands of years.

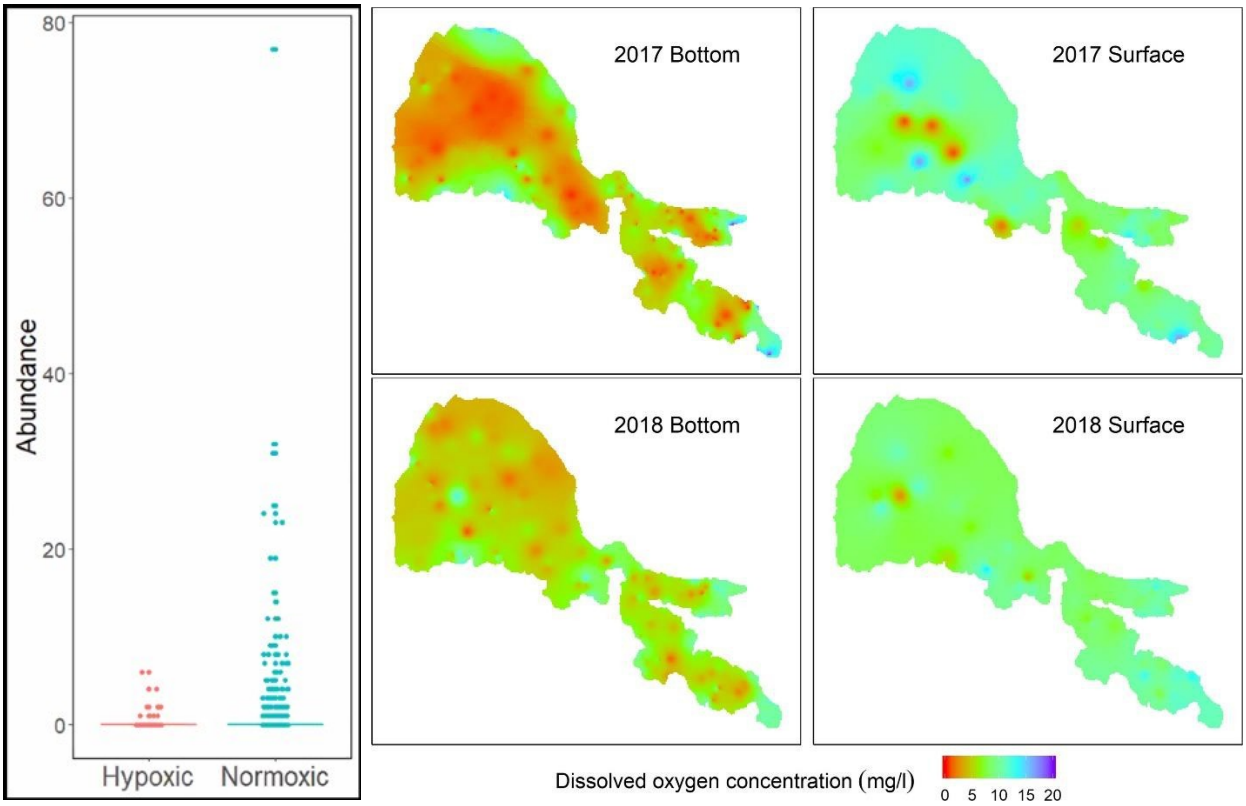
Figure 6.2.11. Results of Clear Lake Hitch Gill Net Monitoring.



The graphs on the left show number of fish (y-axis) of different sizes (x-axis) caught each year. The graphs on the right show catch per unit effort (CPUE) or abundance of adults and juveniles. Source: Feyrer et al. (2025)

Along with showing changes in population structure, surveys also show that Hitch avoid areas with low levels of DO. Surveys done by the USGS from 2017 to 2025 identified abundance-habitat relationships for juvenile and adult Hitch. They observed that DO concentration was the most important habitat predictor for hitch abundance (Feyrer et al., 2019b; Feyrer et al., 2025). The graphics on the right side of **Figure 6.2.12**, below, show DO concentrations in different areas of Clear Lake in 2017 and 2018. The abundance graph on the left shows the relationship between the number of Hitch detected and dissolved oxygen conditions in Clear Lake. Hypoxic areas are those with a DO concentration of less than 2 milligrams per liter (DO <2 mg/L); normoxic areas have a DO concentration of 2 or more milligrams per liter (DO ≥2 mg/L).

Figure 6.2.12. Association Between Hitch Abundance and DO Concentrations in Clear Lake.

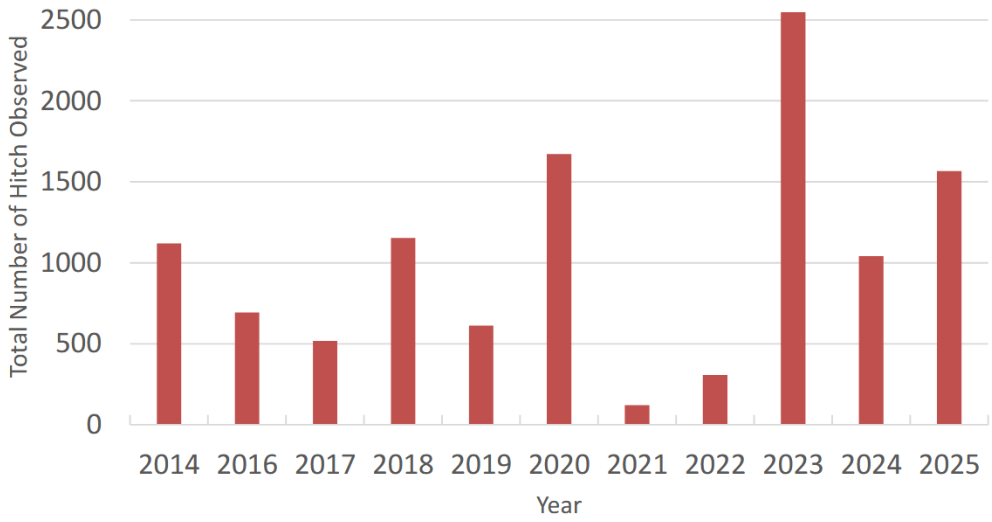


Source: Feyrer et al. (2019b)

Clear Lake Hitch also face challenges in their spawning tributaries. They have been forced to adapt to a very brief period of suitable stream conditions for their annual spawning run, as water diversions and a changing climate have caused streams to prematurely dry. Hitch typically spawn in the spring during periods when creek and groundwater levels are now lower because of drought, agricultural irrigation, and the use of pumped water for frost protection. Low water levels impact overall Hitch numbers. Increased drought and rapid climate change due to warming temperatures will likely accelerate this trend, causing further spawning failures. The spawning runs from 2013 to 2015 had an annual average of fewer than 1,000 spawning fish in the entire Clear Lake basin. Since 2013 the average number of spawning fish in the last two tributaries, Kelsey Creek and Adobe Creek, has been under 1,700 fish annually (Center

for Biological Diversity, 2021). Spawning, the process of releasing the eggs and milt, is only part of the success or failure of the Hitch to thrive. The fry must also hatch and survive long enough to travel back to Clear Lake and then live long enough to reproduce for the fish numbers to begin to rebound (Feyrer, 2022).

Figure 6.2.13. Results of CDFW Visual Creek Surveys, 2014 to 2025.



Red bars are the total number of Hitch observed across seven tributary creeks. Source: Ewing (2025)

Visual surveys (**Figure 6.2.13**, above) of Hitch in tributary creeks from 2014–2025 reflect the severity of the impact of the 2020–2022 drought on their population, with a record low of 120 Hitch observed in just one creek, Kelsey, in 2021 (Ewing, 2021). After record winter rainfall in 2023, 2,548 Hitch were observed across five tributaries, demonstrating their ability to take advantage of adequate creek flow (Ewing, 2023). Based on the 2023 spawning season, surveyors expected a higher return of adults in 2025, however they counted only 1,567 Hitch (Ewing, 2025). Flow and habitat conditions, along with other factors, may have contributed to lower returns. In 2025, Big Valley Environmental Protection Department staff began observing low flows and disconnected pools in two of the spawning tributaries, Thompson and Manning Creeks,

several months earlier than in 2023. The hydrologic research underway in the subbasin will help elucidate influential factors.

There are many ongoing efforts to study and protect the Clear Lake Hitch. Big Valley and nearby Robinson Rancheria and Habematolel Pomo of Upper Lake have been working together for the protection of the Hitch since 2005. In 2022, CDFW formed the Clear Lake Hitch Task Force, which includes Big Valley Band of Pomo Indians, Robinson Rancheria, Habematolel Pomo of Upper Lake, Scotts Valley Band of Pomo Indians, Middletown Rancheria, state agencies, county agencies, and USGS. The Task Force is funded by CDFW and other sources. Since 2023, Big Valley has received grants from both CDFW and the Resources Legacy Fund to conduct fish observations and rescues and install groundwater monitoring wells on the Tribe's land to better understand the factors impacting their habitat and survival, including groundwater pumping.

Clear Lake area tribes are hopeful that their collaborations with non-Tribal agencies will bring about more effective regulations to support the Hitch. Enforcement of penalties for violations of Fish and Game codes, illegal water diversions, and illegal cannabis cultivation has improved. They are optimistic about the Clear Lake Watershed Co-Management Memorandum of Understanding, which is being developed to provide a framework for increased collaboration and goal setting to restore habitat and Hitch populations.

Fish for consumption

Fish consumption by Big Valley Tribal members is often higher than among recreational anglers. A person who eats fish occasionally from sport fishing or commercial fish sources will also consume fish from multiple sources, thereby limiting exposure to contaminants found in a specific location. Tribal members eat large quantities of fish from Clear Lake during ceremonies or as a regular food source. Additionally, the Tribe consumes fish caught in different areas of the lake than recreational anglers. Tribal Elders have observed a large reduction in the abundance of other native fish species which Tribal members eat, such as blackfish, sculpin, and sunfish.

Tules

Tules, an important plant for the Tribe, are used to build boats, for weaving, in traditional ceremonies, as a food source, and for various household uses, and are also at risk from a changing climate and area development. Roughly 85% of the shoreline tules have been lost already (BVBPI and MRPI, 2021). Tules have been impacted by drought and warming temperatures, making them more likely to be impacted by pests, disease, and invasive species. One such invasive species is water primrose, which has taken over where many Tules used to grow along Clear Lake's shoreline.

"The Tule is part of our Traditional Tribal history, it was used for ceremony inside the Roundhouse as a ground cover and mat for the people to sit upon, The Big Head Dancers wore skirts made of Tule for our regalia, clothing for our women were made of Tule, Tule Mats were used as sleeping mats in our Hut made of a willow frame and a covering with Tules, men made a Tule Shirt worn in colder weather, we ate the Tule Roots for food, The health of the Tribe and the health of the Tules are interrelated. It is important to bring notice to and make others aware of the problems we are seeing in the quality of our lake waters and how it is affecting our cultural practices, our subsistence fishing, birds and loss of plant life (Tules) on the shores of our Rancheria."

~Ron Montez, Tribal Elder and Tribal Historic Preservation Officer

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Tules help buffer against wind and water, allowing the establishment of other types of plants and reducing erosion. Tules have roots at or under the waterline and play an important filtration role in Clear Lake's ecosystem. These Tule wetlands filter out much of the nutrient load and other chemicals found in storm water runoff before they enter the lake. Tules also provide habitat, food, and nesting materials for terrestrial and aquatic species.

Other culturally important plant species

The use of plants such as Tule, sedge, dogbane, and willow benefits not only the user, but the ecosystem as a whole. Stands of plants are tended and groomed to make them

more useful for basketry and other uses; grooming also helps strengthen riverbanks and reduces soil erosion. The plant bases go from short and knotty, to straight, long and strong. This grooming also promotes access for riparian animals who can more easily access the water in well-tended areas (Pearce, 2022).

Manzanita, a culturally important plant, produces berries that are eaten raw, used to sweeten other foods, or ground for flour; its bark and flowers are used to make a medicinal tea (Pearce, 2021). Manzanita is now seen as a fire risk by some and has been cleared by non-tribal members for fire mitigation and to clear land for vineyards. Removal of manzanita constitutes a loss of traditional food and medicine, as well as a loss of habitat and food for other species.

Angelica root is another culturally important medicinal plant that has been impacted by drought and erosion from flooding. The Tribe has tried to harvest Angelica from areas where it may no longer thrive and propagate it in areas where it grows better or is more accessible to the Tribe. Basketry materials such as willow, redbud, and dogbane have also been impacted by the changing climate. Traditional gathering areas have been reduced due to vegetation changes, wildfire, and the privatization of lands (BVBPI and MRPI, 2021). As the Tribe has seen a reduction in culturally important plants, they have seen a rise in invasives such as star thistle, Scotch, French and Spanish broom (BVBPI and MRPI, 2021).

Harmful insect pests

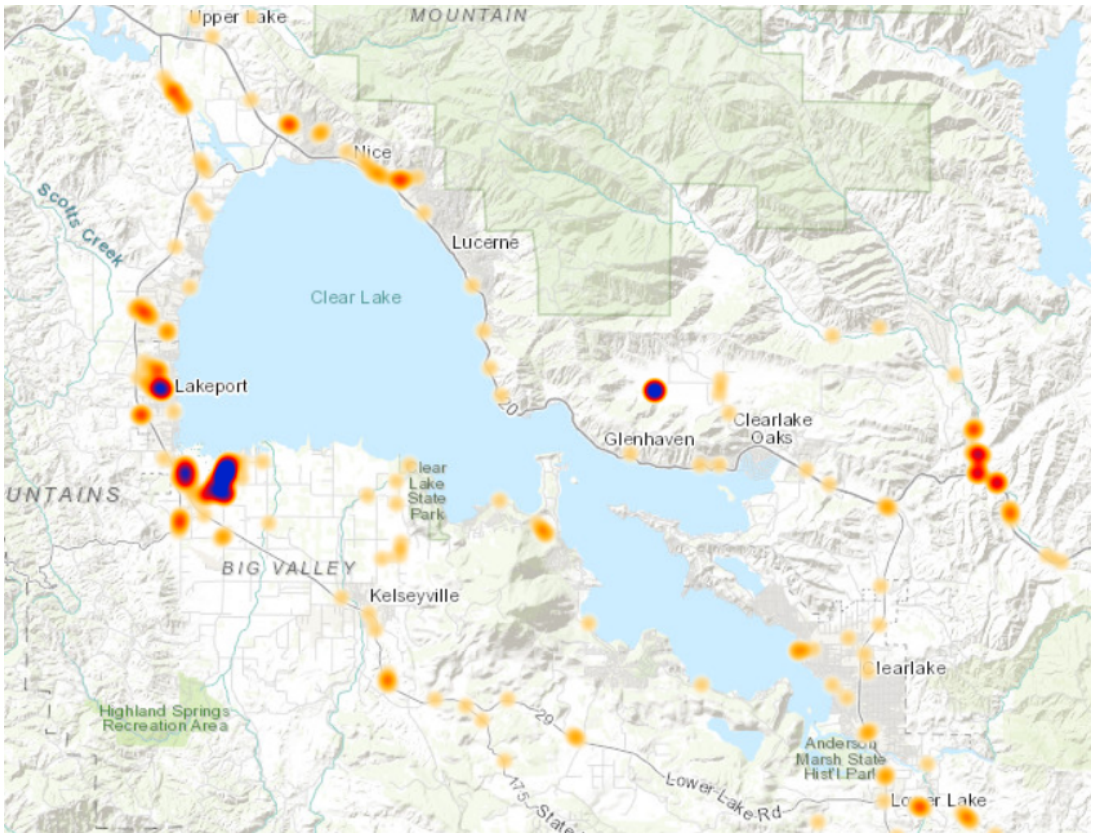
Drought, wildfire, and other stressors on trees create more favorable conditions for secondary insect pests. Pine bark beetles are secondary pests that continue to contribute to largescale mortality of already-stressed pine stands in Lake and other California counties. While most of the mortality has occurred in ponderosa pines infected by Western pine beetle, *Ips* spp. pine bark beetles have also killed large areas of Pinyon pine trees which are a food source for the Tribe.

Big Valley has also seen a recent and dramatic increase in the presence of the Mediterranean oak borer (MOB), an insect which infests and kills oak trees. MOB is a small ambrosia beetle originally from Europe that creates tunnels in oak wood to cultivate the fungi that it feeds on, and that can harm or eventually kill the host tree.

MOB tends to infect trees which are already weakened from other stressors such as drought, fire, or other diseases and pests. It affects 12 species of oak in California, mostly valley and blue oak. It was first detected in Big Valley in 2024, although it is suspected to have been in Northern California since 2012 or earlier.

Clear Lake Environmental Research (CLERC) has been tracking reports of MOB around Clear Lake since June 2023. **Figure 6.2.14**, below, shows a map of Clear Lake with the number of reports of MOB on oak trees from June 2023 to November 2025 represented as spots of color that range from pale orange (as few as one report in that area) to dark purple (as many as 113 reports in that area).

Figure 6.2.14. Number of MOB Reports Around Clear Lake.

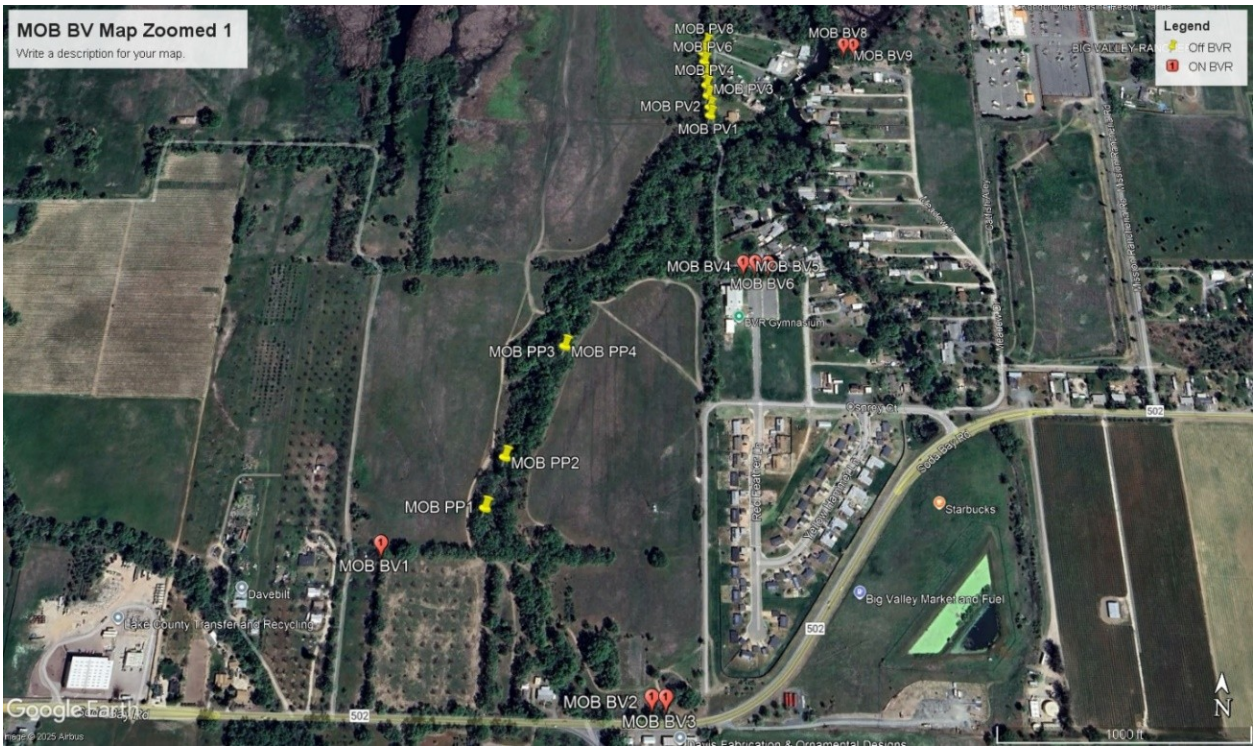


Source: CLERC (2025)

Valley oaks are the main oak species in the Big Valley area, and the Tribe is concerned about the potential impact of MOB. In the past year, the Tribe has mapped at least 15

infected trees on the Rancheria and additional infections nearby (**Figure 6.2.15**, below). Valley oaks are not only central to the Big Valley Band of Pomo Indians' culture as the primary source of acorns, but also to the ecosystem, providing food and habitat for other species.

Figure 6.2.15. MOB-infected Oaks On and Near Big Valley Rancheria.



Source: BV EPA (2025)

Government policies that have prevented traditional cultural burning have also led to an increase in large-scale wildfires and invasive species and pests. For example, invasive star thistle and other non-native plants have taken hold, increasing the use of herbicides which also poison native species, further exacerbating the issue. This increases the pesticide/herbicide exposure from dust and runoff from nearby agricultural operations that impact the health of Tribal members.

Harmful algal blooms

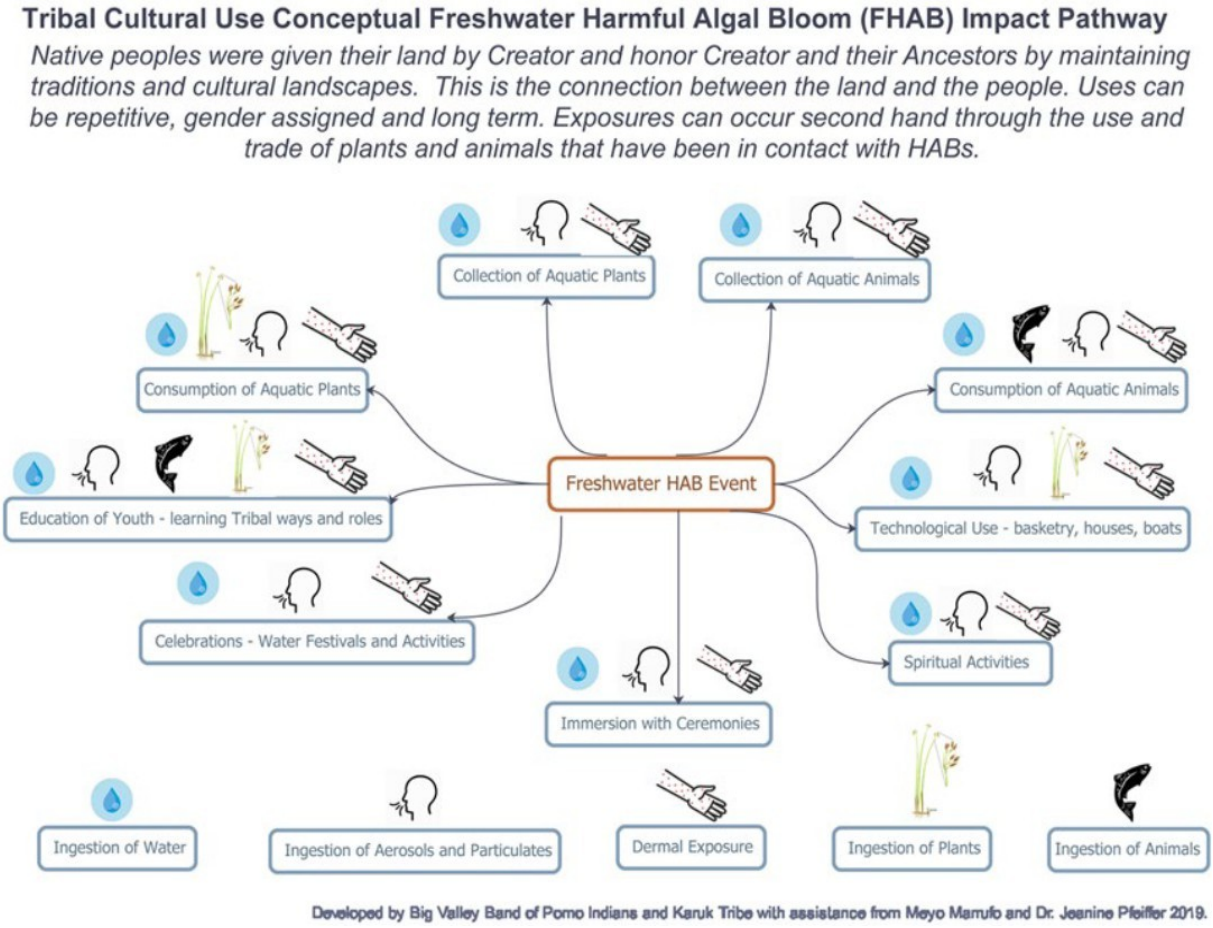
Harmful algal blooms (HABs) are colonies of algae and/or cyanobacteria that grow out of control, threatening fisheries, aquatic ecosystems, public health and economies. HABs produce toxins that contaminate waterbodies used for recreation or drinking water sources, and the shellfish, fish and wildlife living within them. Even without producing toxins, HABs damage aquatic environments by suffocating fish, blocking sunlight, or depleting oxygen in the water (COST, 2016; WHO, 1999).

Climate change affects the factors that drive HAB formation (US EPA, 2026). Warmer water temperatures, drought conditions, increased carbon dioxide and alternating periods of storms and drought are all known to promote HAB formation (Lehman et al., 2017; Power et al., 2015). Anthropogenic inputs of nutrients like phosphorus and nitrogen also promote HAB formation. A recent study of conditions from 1950 to 2019 suggests that more rapid warming of the Lake in the spring, driven by higher seasonal air temperatures, may be contributing to cyanobacteria dominance (Smith et al., 2023).

Tribal members and locals around Clear Lake report that HABs have become much more prevalent over the last few decades. HABs are regularly observed in Clear Lake; these blooms damage the environment and produce levels of cyanotoxins that are harmful to humans. The main cyanotoxin produced in Clear Lake is microcystin, which has been known to kill pets and other animals, and cause skin, gastrointestinal and liver impacts in humans. Tribal members are exposed to microcystin through interactions with the water such as swimming, cultural ceremonies, the consumption of aquatic organisms, and drinking water. **Figure 6.2.16**, below, illustrates the potential routes of exposure to HABs based on tribal uses and practices involving Clear Lake.

The California Cyanobacteria Harmful Algal Bloom (CCHAB) Network has adopted tiered cyanotoxin trigger levels for posting recreational waters (CWQMC, 2025). For microcystin these advisory levels are 0.8 µg/L (Caution - keep away from visible algae), 6 µg/L (Warning – no swimming) and 20 µg/L (Danger – do not contact the water or eat aquatic organisms). All advisory levels warn people to keep their pets and small children away from the water and shoreline and to avoid shellfish and wash fish filets before cooking them.

Figure 6.2.16. Potential HAB Exposure Routes Through Cultural Use.



Source: Big Valley Band of Pomo Indians (2019)

HABs on Clear Lake produce very high levels of microcystin and the Lake is often posted with recreational advisories from April through October. The Big Valley Band of Pomo Indians and the Elem Indian Colony have been actively involved in sampling and monitoring their waters. **Table 6.2.1**, below, shows monitoring results for 2014–2025.

Table 6.2.1. Concentrations of Microcystin in Clear Lake Water Samples from 2014 to 2025.

Arm of Clear Lake	Highest Level of Microcystins (µg/L)											
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Upper Arm	878***	Trace	0.3	4*	13**	0.3	1,146***	5,910***	70.3***	13.8**	28.1***	N/A
Oaks Arm	16,920***	278***	0.7	46***	4,800***	0.9*	79***	1,449***	790***	562***	2,261***	1,377***
Lower Arm	769***	10,162***	0.3	5,554***	230***	150***	902***	160,378***	489.3***	16,821***	16,025***	13**

*Above CCHAB Caution Trigger Level of 0.8 µg/L.

**Above CCHAB Warning Trigger Level of 6 µg/L.

***Above CCHAB Danger Trigger Level of 20 µg/L.

****Caution issued for Upper Arm in 2025 due to visual signs of HAB following CCHAB decision tree. BV EPA identified potentially toxic cyanobacteria through microscopy but did not send water sample to lab for microcystin analysis.

Source: BV EPA (2026b)

When advisories are posted at Clear Lake, Tribal Members can't safely participate in Tribal activities that require them to be in the lake. Important Tribal activities that are prevented by trigger level advisories include spiritual activities, water immersion for ceremonies, using plants for ceremonies and basketry, and the collection and consumption of fish and other aquatic organisms. Tribal members are also prevented from swimming or playing in the water, which is important for heat relief. In 2021, cyanotoxin was monitored from April through December. During that time there was never a period in which the whole lake was safe for contact (BV EPA, 2022b).

Cyanobacteria blooms can also cause harm to habitats such as Clear Lake through means other than cyanotoxin production. For example, the fish kill of 2025 (see the **Dissolved oxygen in Clear Lake** section) was attributed to a bloom and die-off of *Synechocystis* spp., cyanobacteria which were dominant from August through September. This bloom did not end up producing high levels of microcystin. Rather, it took up the ecological niche otherwise held by *Microcystis* spp., potentially preventing other HABs from growing. In this case it was the reduction of lake DO associated with the decomposition of cyanobacteria which killed millions of fish in Clear Lake.

Climate change may increase the frequency of HABs in drinking water sources. Big Valley Band of Pomo Indians has partnered with Tracking California to carry out the California Water: Assessment of Toxins for Community Health Project, or Cal-WATCH since 2019. The project found microcystins in the tap water of 71% of homes tested with lake water intakes, and microcystins at or above the US EPA drinking water health advisory concentration of 0.3 µg/L in 53% of homes with lake water intakes (Solomon et al., 2022; Tracking California, 2026). These results led the local health officer to issue an emergency "Do Not Drink" advisory for private lake water drinking systems in early fall 2021. Information and recommendations were shared with residents utilizing lake water to help reduce their exposure risk, and alternative drinking water sources were provided for those impacted.

HABs create sludge that clogs drinking water intakes in Clear Lake (**Figure 6.2.17,** below). This leads to higher operating and electrical costs due to filters needing to be flushed more frequently. It also increases the cost due to the need for sludge disposal.

When microcystin is present in raw water, water treatment plants must make sure this toxin is kept out of the finished drinking water. In Clear Lake, more carbon filters have been required to remove the cyanobacteria and toxins, which also increases costs.

Figure 6.2.17. Shoreline Sludge from HABs on Clear Lake.



Source: Justin Sullivan, Getty Images

The occurrence of HABs causes great economic losses in the Clear Lake region. Clear Lake is a destination for large-mouth bass fishing and other water activities, such as water skiing, jet skiing, and swimming. An early 1990's study estimated that HABs resulted in $7–10 million in lost tourist revenue annually in Lake County (Goldstein and Tolsdorf, 1994). Economic losses today are likely much greater.

To mitigate HABs and fish kills on Clear Lake, Big Valley Environmental Protection Department, with the assistance of a Bay Area Council California Resilience Challenge grant, has acquired and installed two Tribally managed water quality data loggers. This monitoring program for HABs and fish kills creates a real-time, open-access Clear Lake water quality data monitoring portal, to analyze and address aquatic species die-offs

impacting Tribal beneficial uses (BV EPA, 2026a).

Cyanotoxins in fish

Cyanotoxins, such as microcystin, can end up in aquatic species that are traditional foods for Tribal members (and others) and pose threats to human health. The Action Level for fish consumption recommended by CalEPA's Office of Environmental Health Hazard Assessment (OEHHA) based on total microcystin concentrations in fish and shellfish is 10 nanograms per gram (ng/g) and is calculated for a 70 kilogram person assuming a sport fish and shellfish consumption rate of one 8-ounce meal per week (Butler et al., 2012). However, many Tribal members eat fish and shellfish at a higher weekly consumption rate. Based on a subsistence consumption rate of five fish meals per week and a similar risk level, the recommended maximum total microcystin concentration in fish for tribal members is 2 ng/g (BV EPA, 2026b).

Fish and shellfish from ten species were collected from 2010 to 2018 and analyzed for microcystin using funds from a CalEPA Environmental Justice grant. Analysis of 91 fish tissue and 32 fish liver samples found detectable amounts of microcystin in all but one sample. Of these, all but one result were above the recommended threshold of 2 ng/g for tribal or subsistence consumption. Summaries of the average microcystin toxin levels per fish species in this study are shown in the second and third columns of **Table 6.2.2**, below (BV EPA, 2025).

Big Valley conducted a second round of microcystin analysis on 79 specimens comprised of nine fish species and one shellfish caught between 2017 and 2023. Only fish or shellfish tissue was tested; livers were not. They included some species that were not previously tested, such as goldfish and Sacramento sucker, and did not re-test largemouth bass, Tule perch, or mussel. Microcystin concentrations were considerably lower in the second round of analysis than the first, with only four results that were above the recommended level for tribal subsistence consumption. The highest detection was in a Sacramento blackfish caught in the Upper Arm, with a tissue microcystin concentration of 7.19 ng/g. Summaries of the average microcystin toxin levels per fish species in the second study are shown in the fourth column of **Table 6.2.2**, below (BV EPA, 2025).

Table 6.2.2. Concentrations of Microcystins (MC) in Clear Lake Fish.

Species	Tissue (2010-2018) MC ng/g average (count)	Liver (2010-2018) MC ng/g average (count)	Tissue (2017-2023) MC ng/g average (count)
Black crappie	4 (8)	*19 (5)	0.54 (6)
Blue gill	ND (2)	7 (2)	1.01 (2)
Carp	*14 (2)	*34 (2)	0.55 (8)
Catfish	2 (6)	*10 (6)	1.44 (8)
Goldfish	--	--	1.84 (14)
Hitch	*10 (8)	*16 (7)	3.7 (30)
Largemouth bass	2 (7)	6 (2)	--
Redear sunfish	--	--	ND (2)
Sacramento blackfish	7 (1)	*83 (1)	4.46 (5)
Sacramento sucker	--	--	3.17 (3)
Tule perch	6 (10)	*35 (8)	
Crayfish	4 (23)	--	6.8 (1)
Mussel	*10 (26)	--	--

Average MC concentrations for each species are given in nanograms per gram (ng/g). The number of fish of each species tested is in parentheses.

*Concentration is at or above OEHHA's state-wide Action Level for microcystin in fish consumed by humans (10 ng/g).

Source: BV EPA (2025)

Mining impacts

Alongside the climate change impacts causing HABs at Clear Lake, is the closed Sulphur Bank Mine, a flooded open pit mercury mine 23 acres long and 90 feet deep located 750 feet from Clear Lake. The site is filled with a combination of contaminated mine waste and natural geothermal water that seeps mercury into the lake. While the mine closed in 1957 it was not declared a Superfund site until 1991 (US EPA, 2025b). OEHHA has established fish advisories for Clear Lake based on high levels of mercury in fish (OEHHA, 2018).

In 2015, Big Valley's Environmental Protection Department measured total mercury

concentrations in several species of fish in different locations around the lake. Mercury concentrations in certain fish were found to exceed fish tissue goals established by the CA State Water Resources Control Board (SWRCB, 2015). More recent fish tissue results can be found in **Figure 6.2.A-3** (page 73).

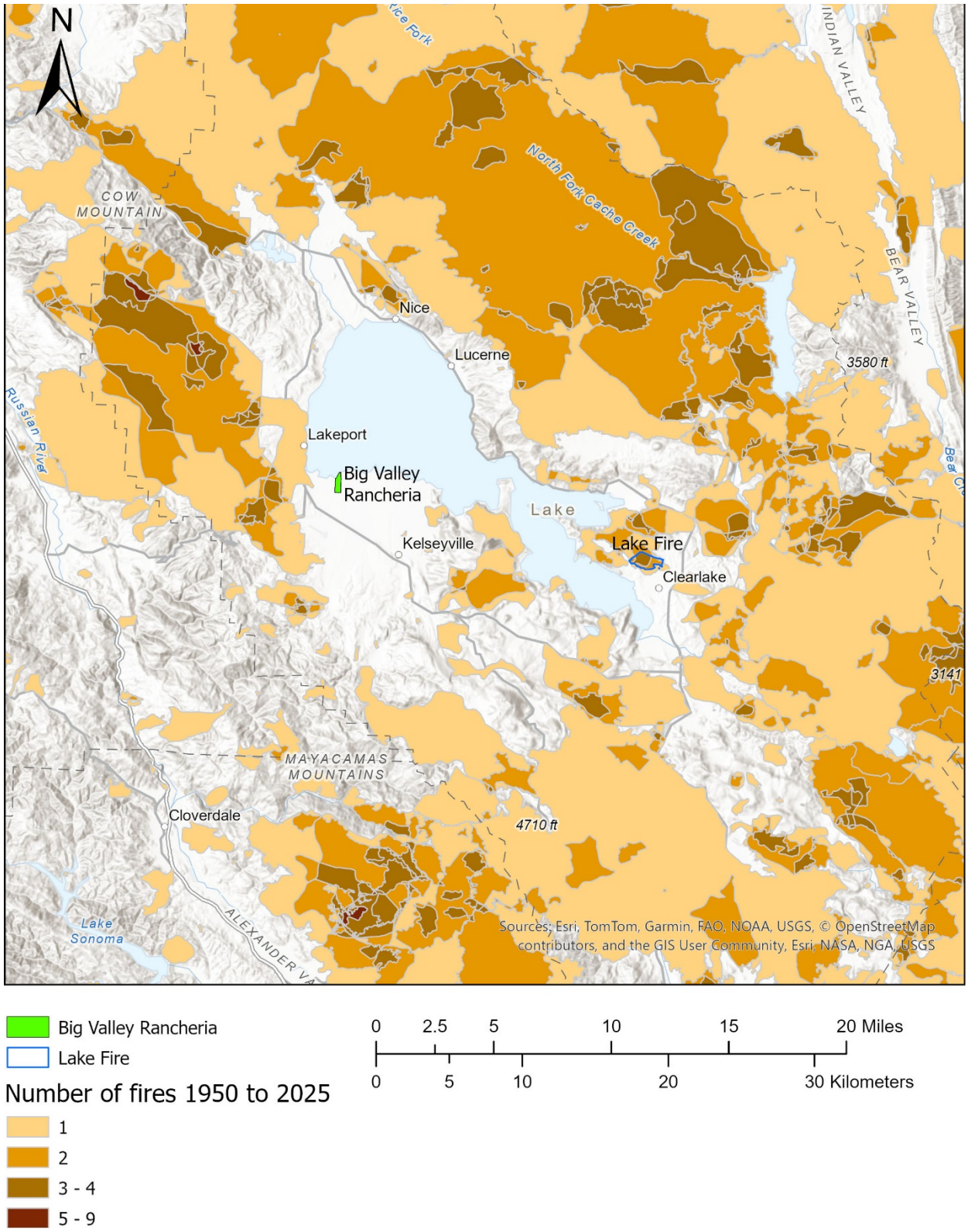
In September 2024, the US EPA began the main cleanup project, which will be broken into two phases: consolidation and capping. Initially, the plan involves moving smaller piles of mining waste onto large piles to shrink the area that needs to be removed before installing a heavy cap to act as a barrier over the site. The cap will then be covered with clean soil so that plants begin to grow and rehabilitate the area (US EPA, 2025b). The program manager for the cleanup verbally reported to the Tribe that it will take roughly 100 years for mercury levels in fish from Clear Lake to return to safe levels for human consumption.

Wildfires

Big Valley Rancheria (BVR) and surrounding ancestral lands are severely impacted by both wildfires and smoke. **Figure 6.2.18**, below, shows the number of times that parcels of land around Big Valley have burned between 1950 and 2024. A third of Lake County is considered very high wildfire risk area, which is more than four times the state average (CCHVIz, 2025). The county has lost more than 1,800 homes to wildfire since 2015. The number of fires occurring each year within a 50-mile radius of BVR has increased over the last half century by a factor of four (**Figure 6.2.A-1**, page 72). The corresponding burned area has increased exponentially in just the last 10 years (**Figure 6.2.A-2**, page 72).

In 2025, the Lake fire forced 3,386 people to evacuate and burned 401 acres just north of the town of Clearlake, roughly 13 miles across the lake from BVR (CAL FIRE, 2025). In 2024, the Glenhaven fire, roughly 10 miles across the Lake from BVR, threatened over 2,500 structures and forced over 3,400 people to evacuate (Tracking California, 2025). In 2020 alone, more than half of the unhoused population in Lake County said that a wildfire made them homeless that year.

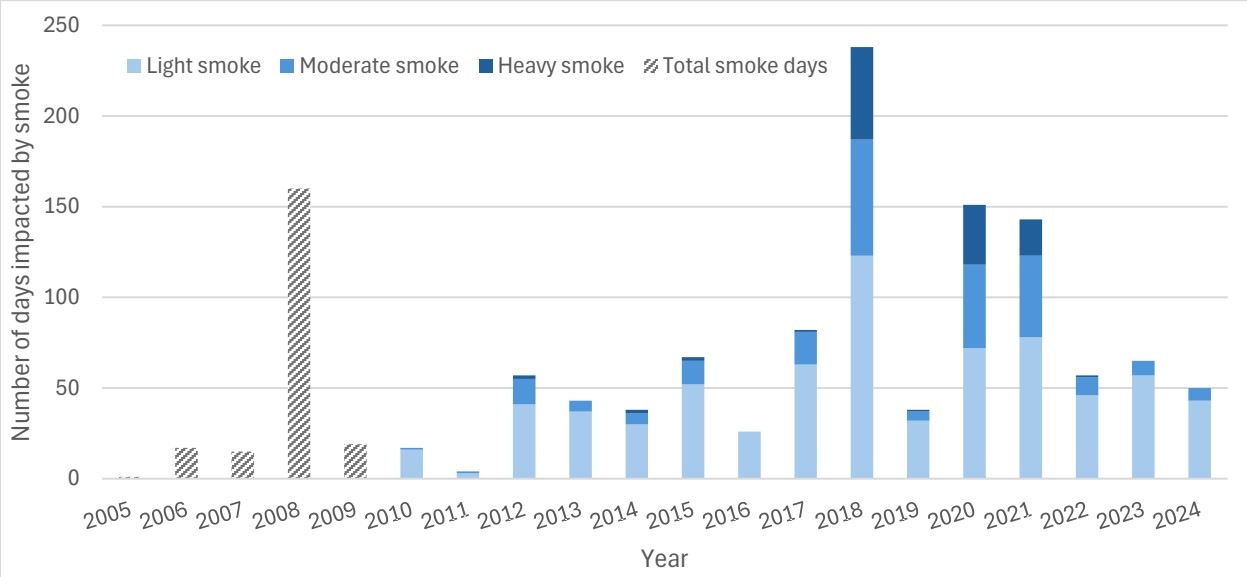
Figure 6.2.18. Fires Within 30 Miles of BVR from 1950 to 2025.



Source: Fire perimeter data from CAL FIRE (2026)

Along with threatening lives and structures, wildfires are increasingly impacting air quality for the Tribe. In 2018, the Ranch and River fires began during the Tribe's annual Tule Boat Festival and eventually merged into the 459,123-acre Mendocino Complex Fire, California's largest wildfire on record at the time. The Big Valley Environmental Director recounted, *"People were having trouble breathing on the rancheria. We have a lot of people with asthma and respiratory illnesses. We went to the local stores and tried to get some air purifiers, but everybody was sold out. A neighboring Tribe, the Middletown Rancheria of Pomo Indians, helped Big Valley acquire seventy air purifiers."*

Figure 6.2.19. Smoke-impacted Days Per Year for BVR, 2005 to 2024.



Source: CDPH (2025); NOAA (2025)

Figure 6.2.19, above, shows the number of days each year between 2005 and 2024 when the zip code containing BVR (95453) was impacted by wildfire smoke. Hatched bars from 2005 to 2009 represent any smoke-impacted days. From 2010 to 2024, stacked bars display the number of days impacted by light (pale blue), medium (medium blue), and heavy (dark blue) smoke.

BVR was impacted by smoke for 238 days in 2018, or for just over 65% of the year, making 2018 the most smoke-impacted year in a 20-year record available from the

National Oceanic and Atmospheric Administration (NOAA). During this time, there were 51 days of heavy smoke when there were likely to be exceptionally high levels of particulate matter of 2.5 micrometers or less in diameter (PM2.5) in the air. Exposure to PM2.5 poses the greatest health risk to health when inhaled (CARB, 2025). The Lower Arm of Clear Lake, just east of BVR, experienced smoke for 275 days in 2018, or roughly 75% of the year, with 64 days of heavy smoke. According to data from 2008-2018, BVR is an area with the highest likelihood of experiencing health impacts from smoke due to having high numbers of extreme smoke days and high socioeconomic vulnerability (UCLA, Tracking California and Howard University, 2026).

Wildfires are a natural function of California's ecosystems and are important for shaping ecosystem structure. Human influences and policies, however, have worked to prevent natural wildfires and cultural burning practices. Combined with drought, this has led to an increase in the intensity, duration, and frequency of large-scale wildfires which destroy habitat, human infrastructure and livelihood, and harm human health.

Historically the Pomo would have conducted cultural burns, low intensity burns on designated parcels which, under the right conditions, reduce the risk of wildfire by consuming dead wood and other fire fuels on forest floors (Miller et al., 2020).

While cultural burning is gaining respect and use, current levels of agency-prescribed burns and tribal cultural burns are too low to make a significant impact on millions of acres left untended for a century and a half. As a result, Tribal members today encounter a surge of catastrophic wildfires their great-grandparents never experienced. Wildfires pose unique and heightened challenges to tribes, given their relationships to the land. Further, non-Native government officials often lack an understanding of tribal customs and priorities.

Climate change has created shifting conditions for species and created new opportunities for invasive species in what were previously unfavorable climatic regions. Human activities are responsible for habitat and biodiversity loss, land use changes, anthropogenic climate change, forest management and the loss of cultural burning. As a result, droughts, fires, flooding, increases in HABs and other climate threats are impacting our Tribe.

Human Health

Figure 6.2.20. Mount Konocti in the Clouds.



Source: Photo by Laurie Monserrat

The health of the Big Valley Band of Pomo Indians cannot be separated from the health of their environment. Increasing temperatures, increasingly variable rainfall, wildfires and exposure to smoke, pesticides, mold, the loss of important plant and animal species, and exposure to mine waste from the nearby Sulphur Bank Mine Superfund site all impact the health of the Tribe. Exposure to cyanotoxins is a human health concern for the Big Valley Tribe. Tribal members have always used the lake for food, drinking water, ceremony and recreation (**Figure 6.2.21**, below). Thus, potential exposures to HABs that produce cyanotoxins include unique pathways that do not apply to non-tribal individuals (**Figure 6.2.16**, page 54). Cultural activities that require the use of the lake have had to be postponed or moved due to a lack of tule and other ceremonial material and poor lake water quality. Poor water quality limits Tribal members' access to the lake, an important cultural resource, as well as threatens access to safe and clean drinking water.

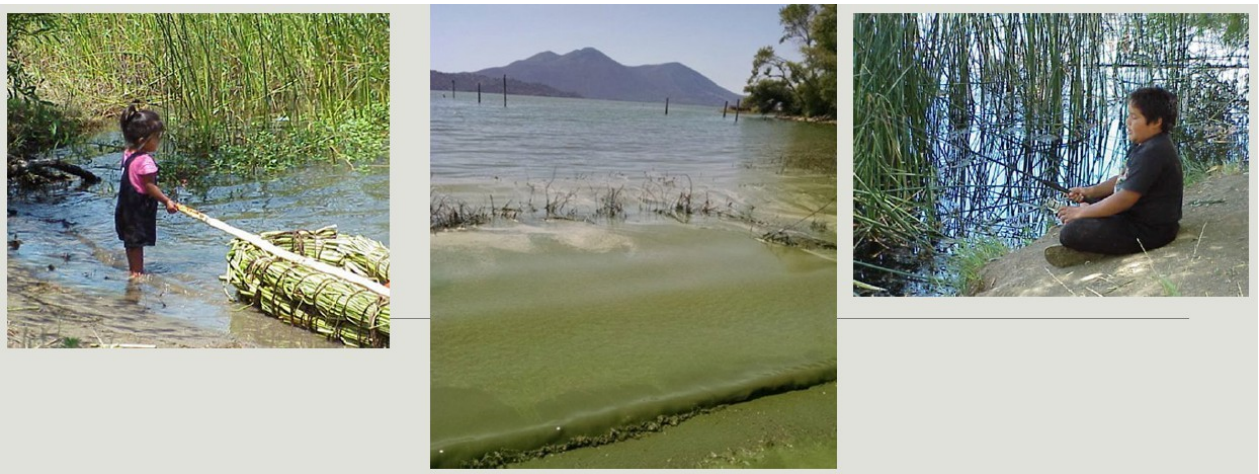
Climate change has exacerbated food insecurity and the nutrition of the Tribe. There are fewer native wildlife species on which the Tribe has relied on for food such as Indian potato, clover, acorn, pine nuts, edible mushrooms such as chicken of the woods (*Laetiporus sulphureus*), Clear Lake Hitch, clams, prickly sculpin, crayfish, and Tules.

The impact of extreme heat combined with poor air quality is of high concern for Big Valley Tribal members. Emergency room visits due to heat-related illness in Lake County and their incidence rate for heat-related illness has been among the highest in the state since 2007 (Tracking California, 2025a). Roughly 37% of homes in Lake County lack air conditioning, and 22% of residents live in mobile homes where indoor heat exposure deaths are more likely. One in four residents of Lake County are age 65 or older, and one in five residents have some sort of disability, which is almost double the statewide average (Tracking California, 2025b).

Lake County's incidence rate of emergency department visits due to asthma has been among the highest in the state for the last decade and has exceeded the state average for the last two decades (Tracking California, 2025b). The incidence rate of chronic obstructive pulmonary disease (COPD) is three to four times higher in Lake County than the state average and was the first or second highest rate in the state almost every year between 2013 and 2023. While these statistics are for all of Lake County, it is likely from anecdotal evidence that Tribal members would have similar if not greater vulnerability to heat- and air quality-related illnesses.

Big Valley used a Tracking California grant to install Purple Air air quality monitors in five Tribal households in 2024, allowing them to compare indoor and outdoor air concentrations of PM2.5, and the composite metric of Air Quality Index (AQI). Households report weekly activities such as cleaning, smoking, cooking, gathering, etc. The Tribe has observed that newer homes which are "tighter," or have less air exchange, have higher 5-month averages of PM2.5 and higher AQIs than older homes. This phenomenon was particularly noticeable during and after wildfires, when newer homes reached AQI's in the 800s (which is considered "Hazardous") and had poor air quality for weeks following outdoor wildfire smoke events. The Tribe continues to monitor air quality to protect Tribal health.

Figure 6.2.21. Scenes from Big Valley.



Left, child at Tule Boat Festival. Center, HABs impacts at Clear Lake. Right, a child fishing in the tules. Source: Big Valley EPA

Summary

The Big Valley Band of Pomo Indians has been living alongside Clear Lake and managing their ecosystem since time immemorial. Big Valley Tribal members, like other tribes have similar challenges as non-tribal members. Temperatures are warming, rain is less predictable, the environment is stressed. The Tribe is working to restore the balance in their environment. Pomo Tribal members have historically been careful about the balance of consumption and restoration of the environment. The Big Valley Tribe is working both internally and with outside agencies to help to restore a balance and provide a more sustainable and certain environment for future generations.

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Suggested citation:

Big Valley Band of Pomo Indians (2026). Impacts of Climate Change on the Big Valley Band of Pomo Indians. In: OEHHA 2026 Indicators of Climate Change in California.

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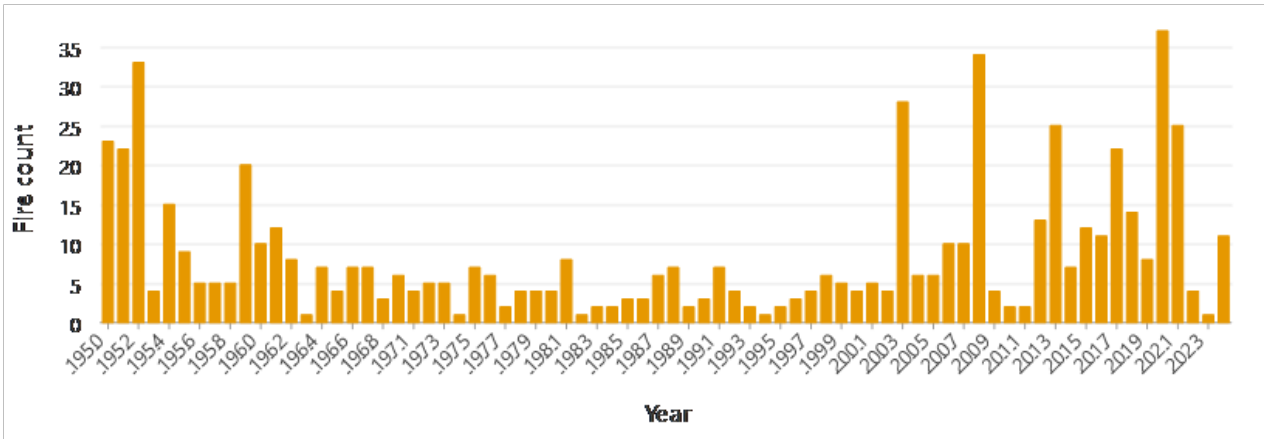
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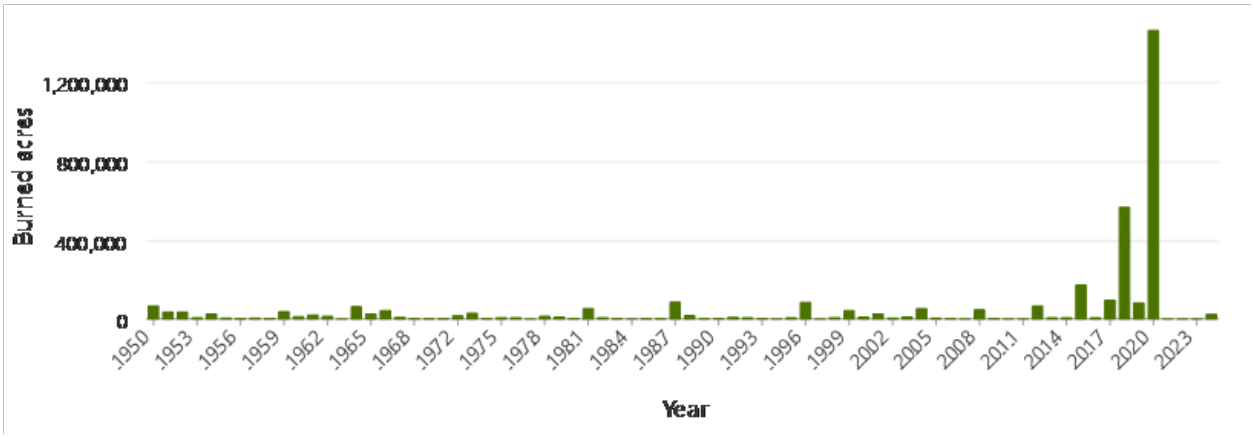
Appendix:

Figure 6.2.A-1. Number of Fires Within 50 Miles of Big Valley Rancheria from 1950 to 2024.



Source: CAL FIRE (2025)

Figure 6.2.A-2. Annual Acres Burned by Fires *Within 50 Miles of Big Valley Rancheria from 1950 to 2024.

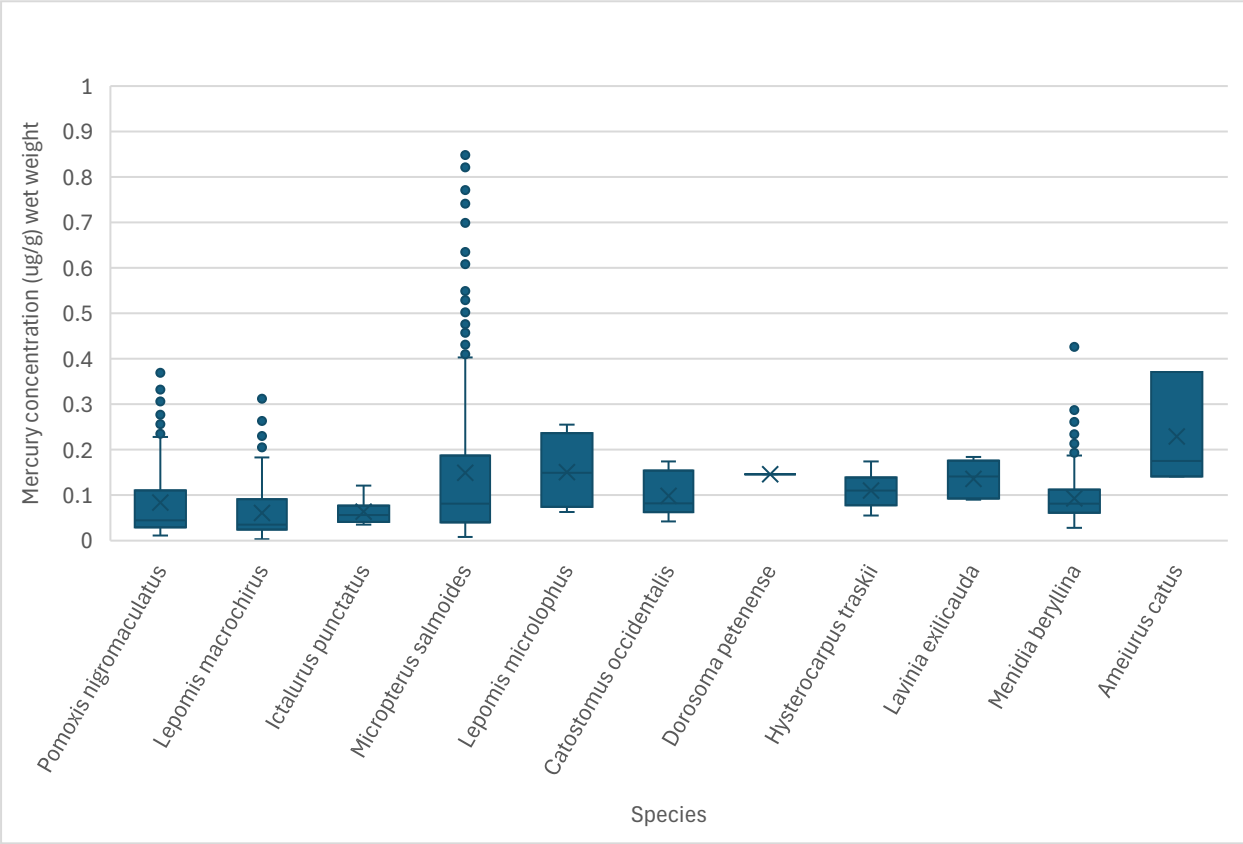


Acres burned were estimated using ArcGIS Pro, based on fire perimeter data from CAL FIRE.

*This includes *all* acres burned by fires which had any portion of their perimeter within 50 miles of the Big Valley Rancheria.

Source: CAL FIRE (2025)

Figure 6.2.A-3. Total Mercury Concentration in USGS Fish Tissue Samples from Clear Lake, 2019 to 2020.



Total mercury concentration is given in microgram per gram (ug/g, equivalent to mg/kg or ppm) wet weight fish tissue samples. The Tribal Subsistence Fishing Objective for mercury in fish tissue is 0.04 mg/kg (SWRCB, 2026). Common names, number of samples, and types of samples for each species are given in the table below.

Species	Common name	# Samples	Axial muscle	Whole body
Pomoxis nigromaculatus	Black crappie	128	32	96
Lepomis macrochirus	Bluegill	285	65	220
Ictalurus punctatus	Channel catfish	15	15	0
Micropterus salmoides	Largemouth bass	331	127	204
Lepomis microlophus	Redear sunfish	9	9	0
Catostomus occidentalis	Sacramento sucker	8	8	0
Dorosoma petenense	Threadfin shad	1	1	0
Hysterocarpus traskii	Tule perch	14	14	0
Lavinia exilicauda	Clear Lake Hitch	5	1	4
Menidia beryllina	Inland silverside	274	0	274
Ameiurus catus	White bullhead	3	3	0

Source: Plot and table created using data published by the USGS from Pierce et al. (2022)

6.3 Impacts of Climate Change on the Bishop Paiute Tribe

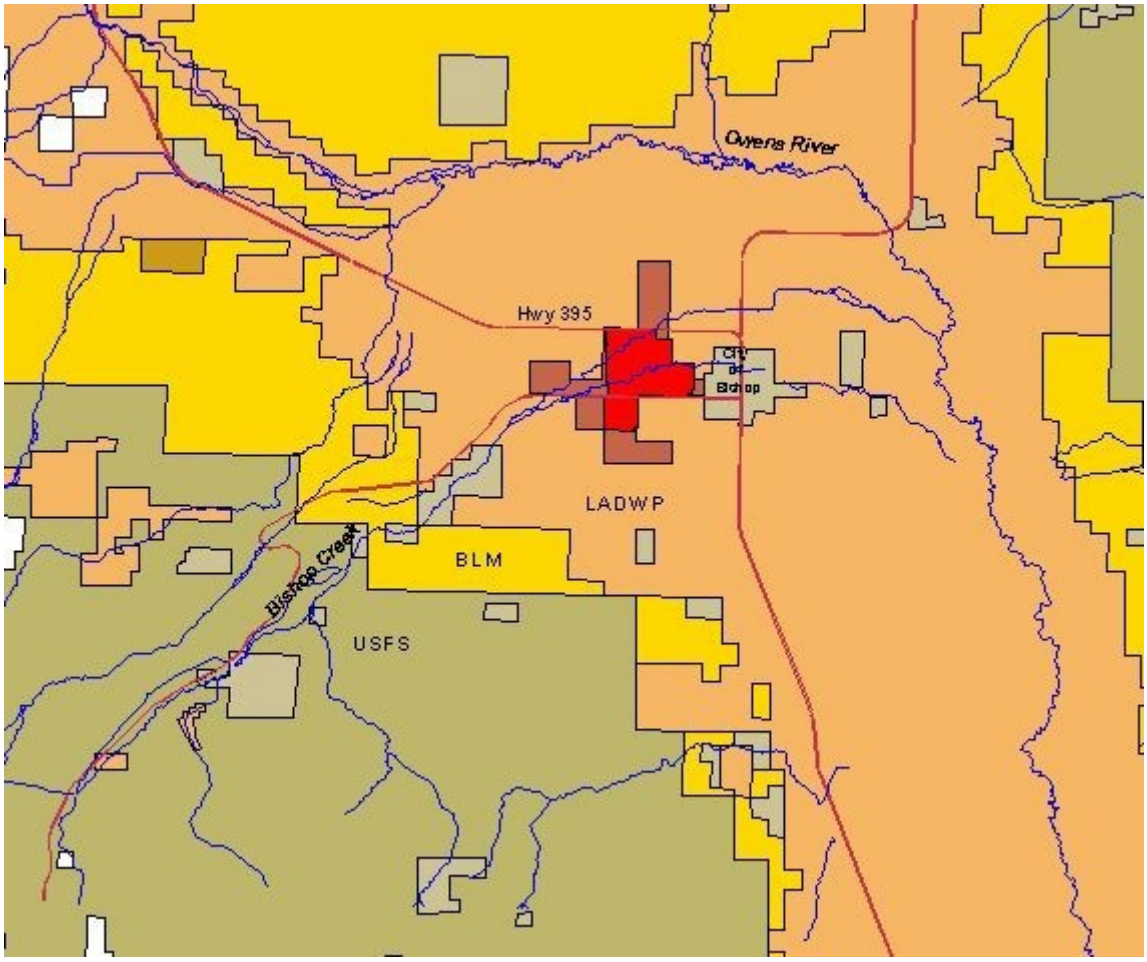
Rising temperatures, flooding, drought, and wildfire are impacting the physical, cultural, and spiritual health of the Bishop Paiute Tribe, its habitats, and ecosystems.

Background

The Bishop Paiute Tribe is a federally recognized Tribe living in Inyo County at the foot of the Eastern Sierra Nevada mountains in the Owens Valley, just west of the city of Bishop. They are the fifth largest Tribe in California with approximately 2,200 enrolled members and have one of the smallest land bases (875 acres). Payahuunadü, or land of flowing water, is one of the Paiute words for the Owens Valley and Eastern Sierra region of California.

The people of the Bishop Paiute Tribe are descendants of the “Nüü-Mü,” the original people of the Owens Valley who have lived in the area since time immemorial and whose ancestral lands encompassed over two million acres of the greater Owens Valley (BPT, 2018). In 1912, under pressure by the U.S. Government, the Bishop Paiute people entered into a treaty in which the U.S. Government reserved 67,120 acres of land in the Owens Valley named the Casa Diablo Indian Reservation for Indians of the area. However, the Paiute were never allowed to move to this Reservation. This treaty was broken in 1933 when President Franklin D. Roosevelt revoked the agreement (Executive Order 6206), and the lands were placed in watershed protection for the City of Los Angeles (OVIWC, 2021). In 1936, the City of Los Angeles and the federal government “traded” the 67,120-acre Casa Diablo lands for the 875 acres that now comprise the Bishop Paiute Reservation, which is shown in bright red in **Figure 6.3.1**, below (BPT, 2021a).

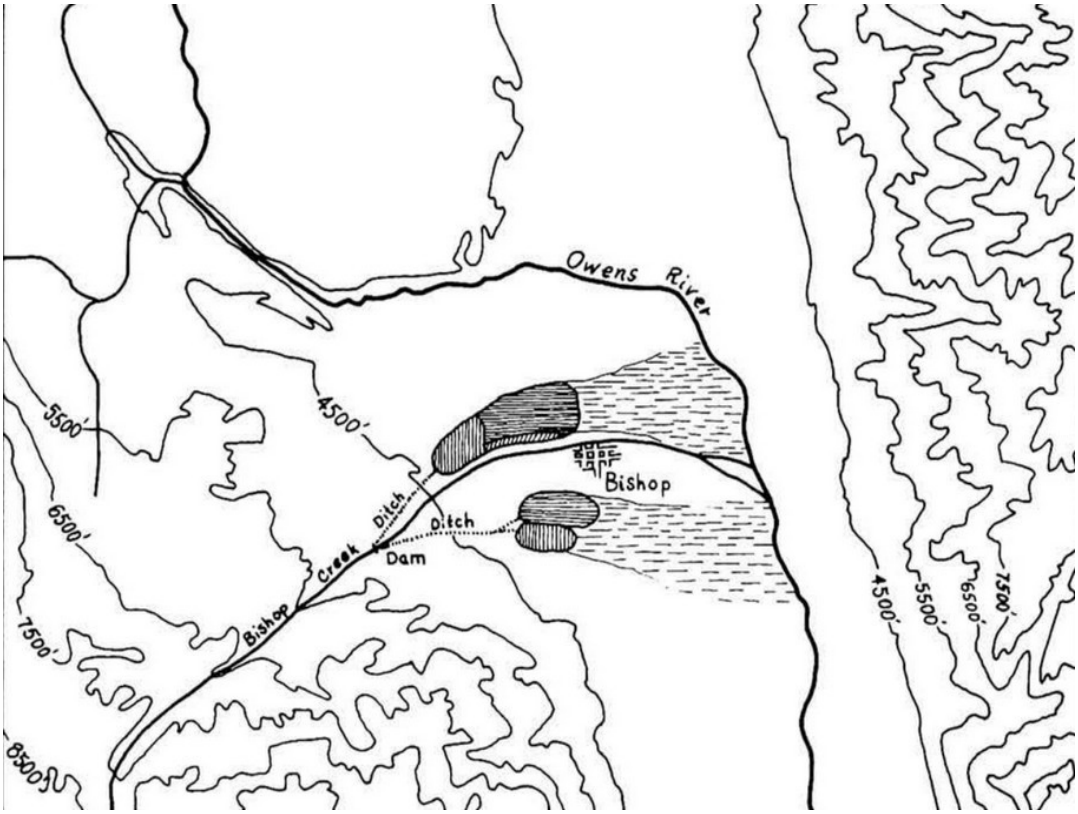
Figure 6.3.1. Bishop Paiute Reservation (Bright Red) Within the City of Bishop (Brown).



Source: BPTEMO (2021)

Historically, the Paiute dug irrigation ditches that routed runoff from melting Sierra Nevada snow into the Payahuunadü. Unlike modern irrigation practices, the Paiutes did not channel the water onto farms or specific plots of land. Bishop Paiute Tribal Elder and water protector Harry Williams explained: “We looked at everything as a garden. The natives made this place bloom like a rose. The water was used to irrigate ‘wild’ seed plants” (Wei, 2016). Water was so important to the Tribe that they had an elected position called the Tuvaiju who oversaw irrigation. The Tuvaiju would use an irrigating tool known as a “pavado” to direct water into the ditch network in the Payahuunadü.

Figure 6.3.2. Drawing of Traditional Paiute Irrigation System at Pitana Patii, Near Present-Day Bishop, Owens Valley, California.



Source: Lawton et al. (1976)

The Paiutes' valley was divided by Bishop Creek into northern and southern plots. As is shown in **Figure 6.3.2** above, the Tribe created a dam system designed so that only one of the areas would receive water each year; the plots were purposefully alternated to conserve soil fertility. The irrigation helped the growth of grass nuts and tubers that made up a significant part of the native diet. The ditches also funneled native fish into areas where they were easy to catch. The irrigation canals distributed the water across the Payahuunadü (Wei, 2016).

Although the northern and southern portions of the Payahuunadü are hydrologically connected, they are also distinct. The current Bishop Paiute Reservation, along with the town of Bishop, are in the northern region of the Payahuunadü and part of the Bishop Basin, a sub-basin draining into the Owens River (Danskin, 1998). The flow of water

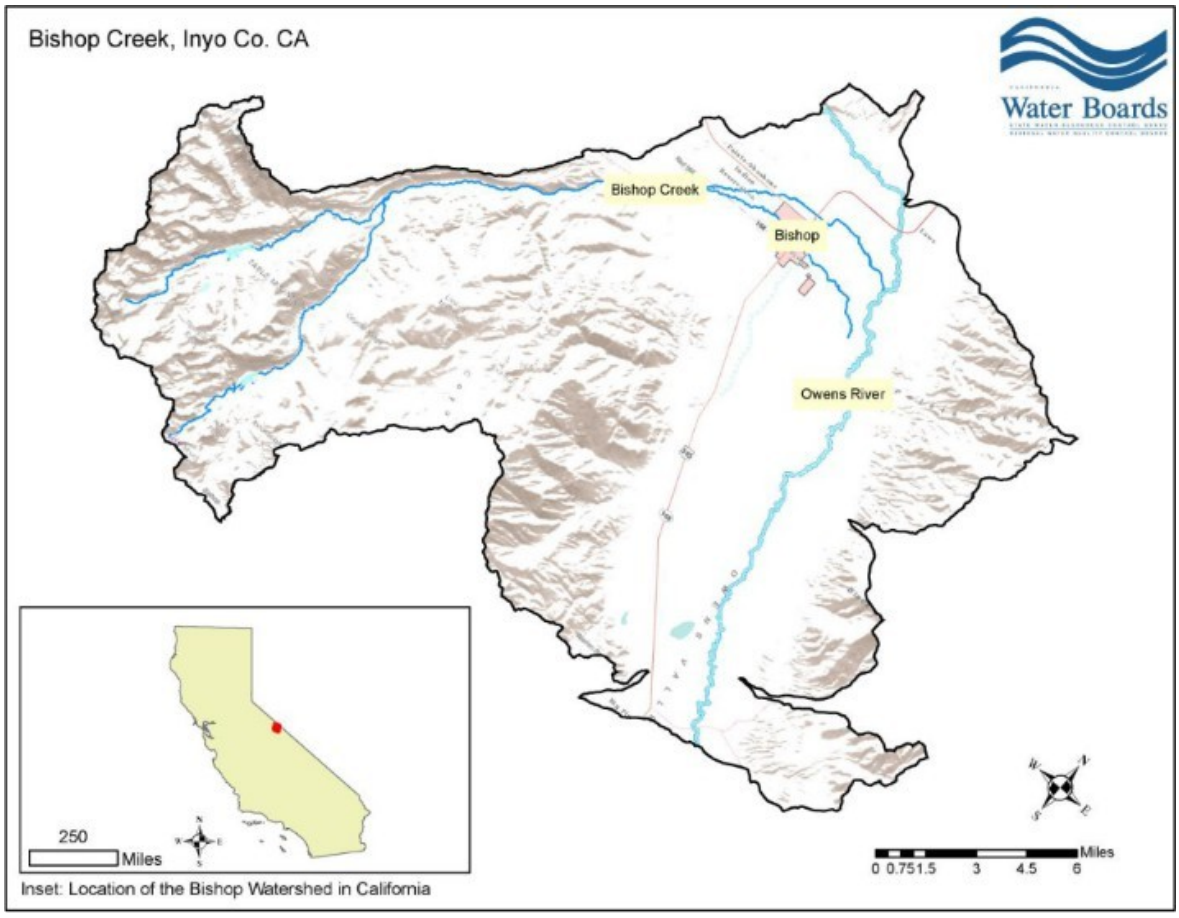
draining into this basin from surrounding mountains and hills is generally to the Owens River and south to Owens Lake. Natural vegetation communities, land use and habitat types in the Payahuunadü reflect the hydrological differences along the North-South gradient, with dense vegetation and agricultural lands concentrated in and around the Bishop Basin and an increasing dominance of salt-tolerant dessert plants in the Owens Lake Basin in the south (ICPD, 2015). Reflecting their location in the upper portion of this watershed, environmental management efforts of the Bishop Paiute Tribe are unique from priorities in the southern Payahuunadü. Some of their current focus areas include vegetative fuels reduction (including trees), rain and snowstorm preparation and disaster claims, flooding, irrigation system, gardening and food growing (BPTEMO, 2026).

The Los Angeles Department of Water and Power (LADWP) owns most of the land immediately surrounding Bishop and the Owens River, and their ongoing control over land and water resources is of grave consequence to the tribes who have been there since time immemorial. The historical draining and subsequent re-watering of Owens Lake by LADWP is a significant environmental concern in the Payahuunadü. While Owens Lake is not a current programmatic focus of the Bishop Paiute Tribe Environmental Management Office (BPTEMO), they continue to support and work together with the Lone Pine Paiute-Shoshone Tribe to their south whose water, lands and air quality are more directly impacted by LADWAP's water extraction from Owens Valley. The Bishop Paiute Tribe were historically impacted by windblown particulate matter (PM) with diameter of 10 micrometers and less (PM10) coming off the dry lakebed, this now occurs only occasionally during storm events. The water and air quality issues driven by LADWP water exports and impact on the entire Owens Lake ecosystem have therefore been moved from the body of this report to the **Appendix**. Bishop Tribal leaders and members are also engaged in ongoing water management efforts through their seats on the Owens Valley Indian Water Commission.

The current Bishop Reservation ecosystem is over the Bishop Cone, within the Bishop Basin, an area characterized by a shallow water table with depths ranging from 1 to 10 feet below ground level. Availability of groundwater substantially enhances vegetation coverage, including a variety of pasture grasses and several types of deciduous tree

species. As shown in **Figure 6.3.3**, below, both North and South Forks of Bishop Creek traverse the Reservation. Excluding relatively recent increases in bacterial levels in South Fork, stream water quality is excellent and supports a 5-mile-long riparian forest corridor providing a rich habitat for a variety of flora and fauna (BPT, 2018).

Figure 6.3.3. Bishop Creek and Surrounding Watershed, Inyo County, CA.



Source: LRWQCB (2020)

In 1988 the Bishop Paiute Tribe established the Conservation Open Space Area (COSA) in the southeast corner of the reservation. The COSA contains a wetland and serves as important habitat for native plants and animals. Furthermore, the COSA is currently being utilized to increase populations of threatened and endangered plants and animals, such as the Owens pupfish, Owens Valley Checkerbloom, and the Inyo County

Mariposa Lily.

Because the impacts of climate change do not start and stop at the Reservation borders, and because the culture of the Bishop Paiute Tribe is tied to all their traditional lands, this report covers both the changes seen on the Reservation lands as well as on traditional lands of the Bishop Paiute such as Volcanic Tablelands and Fish Slough. Petroglyphs within the Volcanic Tablelands are shown in **Figure 6.3.4**.

Figure 6.3.4. Petroglyphs at the Volcanic Tablelands.

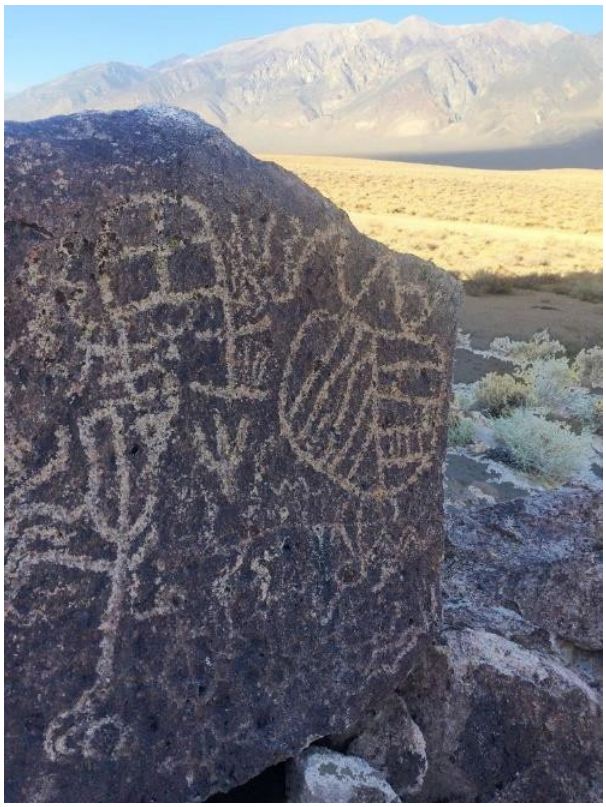


Photo credit: Sarah Rea (2018)

Cultural and spiritual health

As the climate changes, the cultural and spiritual health of the Bishop Paiute Tribe are impacted. You cannot separate the health of the earth from the health of the Bishop Paiute Tribe. The Tribe has seen a loss of gathering areas and ceremonial locations, a reduction in traditional medicines and foods, impacts on culturally important fish

species, and a loss of the Bishop Paiute's traditional waters through both drought and groundwater pumping for export by LADWP and other commercial producers. The Tribe has observed pumping causing local streams and springs to dry up, which has a cascading and compounding impact on the surrounding insects, fish, mammals, and vegetation (BPT, 2020).

The Bishop Paiute Tribe has created a web of interconnected efforts aimed at responding to the complexities of climate change. They are protecting their natural resources with a combination of mitigation efforts, such as installing rooftop solar panels, increasing food sovereignty, and invasive plant removal, as well as adaptation strategies such as protecting tribal waters, providing cooling for elders, and educating Tribal members (Kapp, 2019).

Climate change impacts

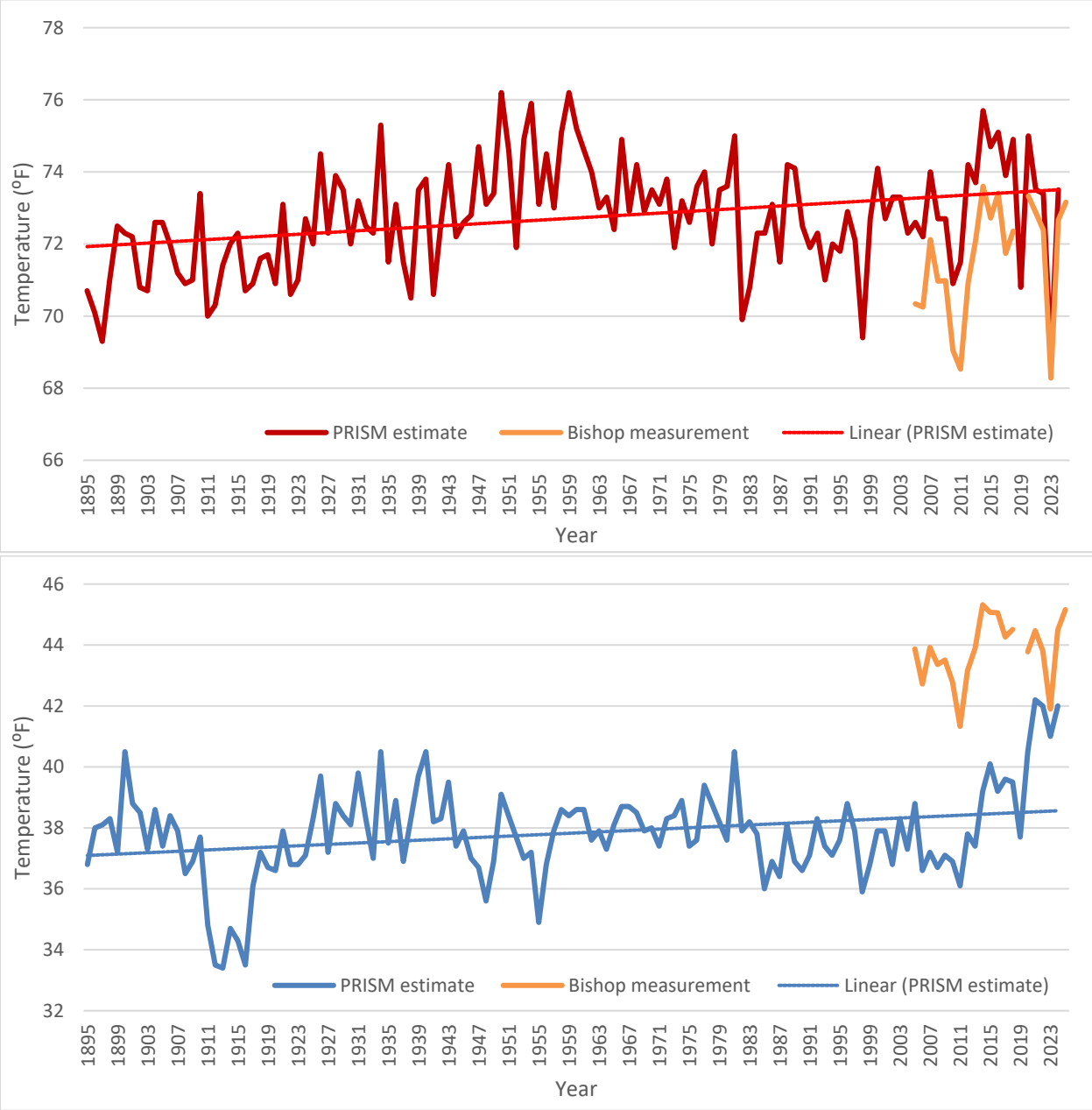
Climate change has impacted wildlife, native vegetation, and culturally important foods such as pine nuts, acorns, fish, and wild game in the Bishop Tribal lands in the Eastern Sierra.

Elevated temperatures

Daytime and nighttime temperatures have been increasing in Bishop since 1895. Elevated temperatures affect human physical health, mental health, cultural and spiritual health, socio-economic health, and the plants and animals that are part of the Bishop Paiute's ecosystem. Elders, children, outdoor workers, and those with existing medical conditions are particularly susceptible to these impacts.

Continuous outdoor air temperatures measured by the Bishop Paiute Tribe's weather station are available for the last 20 years, 2005 to 2025. These measurements are plotted on the same graph as temperature estimates for the Bishop Reservation from PRISM Climate Group (Parameter-elevation Regressions on Independent Slopes Model) in **Figure 6.3.5**. PRISM estimates that both the annual average daily maximum (daytime) temperatures and the annual average daily minimum (nighttime) temperatures have risen at Bishop at approximately the same rate of 0.1ºF (degrees Fahrenheit) per decade, or 0.06ºC (degrees Celsius) per decade over the past 130 years.

Figure 6.3.5. Average Daytime (Top) and Nighttime (Bottom) Temperatures on Bishop's Reservation from 1895 to 2025.



Top graph: average annual maximum or daytime temperature estimates from the PRISM model are shown in red. Actual temperatures observed at the Bishop station are shown in orange. Bottom graph: average annual minimum or nighttime temperature estimates from the PRISM model are shown in blue. Actual temperatures observed at the Bishop station are shown in orange. Source: PRISM Climate Group (2026)

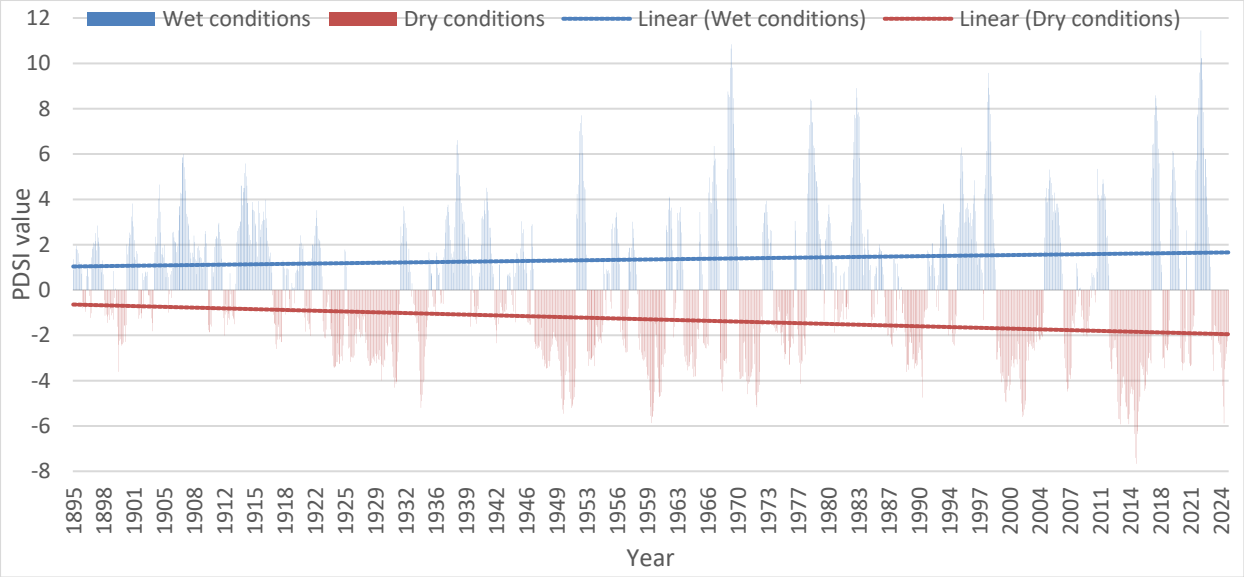
Warming temperatures are considered a high-risk exposure for the Bishop Paiute Tribe. The Bishop Paiute community may experience warmer daily minimum (i.e. night and early morning) temperatures than are recorded at the Valley floor due to a seasonal inversion layer: a layer of warmer air that sits above cold dense air under stable conditions for many hours. Data from the Tribal station demonstrate that annual average minimum (nighttime) temperatures have been increasing and have been 4.81ºF (2.67ºC) higher, on average, than PRISM estimates for the last 20 years (**Figure 6.3.5**).

Drought and flood

The severity of both drought and flood events is increasing in the Owens Valley. In just the last 12 years, Bishop experienced its two driest water years on record in 2014 and 2015, and its wettest water year on record in 2023. The 2023 water year brought a significant threat of flooding. Record-breaking snowpack in the Sierra Nevada led to increased snowmelt runoff during the spring and summer, necessitating a proactive and coordinated response from the Bishop Paiute Tribe and local agencies, including LADWP. This heightened runoff, combined with local precipitation, contributed to various instances of localized flooding on the Reservation. These events isolated Tribal members, including elders, in their homes for a brief period due to flooded driveways.

Figure 6.3.6, below, shows the monthly Palmer Drought Severity Index (PDSI) value for Bishop from January 1895 to September 2025. PDSI values combine temperature and precipitation data to provide a measure of relative dryness (drought) on a scale from -10 (dry) to 10 (wet). Values below negative four (-4) are considered extreme drought, and values above four (4) are considered very wet conditions. While both drought and flood conditions are intensifying over time, the overall trend for the region is towards increasing dryness.

Figure 6.3.6. PDSI at Bishop Reservation from 1895 to 2025.



Source: Abatzoglou et al. (2026)

Table 6.3.1, below, shows the same trend by comparing two time periods: the first 65 years of the record, and the most recent 65 years. There have been twice as many years of extreme drought and more than twice as many years of very wet conditions in the last 65 years as there were previously. These years of extreme conditions are shown in parentheses. While Bishop used to have more wet years than dry years, they now have more dry years than wet years. The arrows next to the numbers in the second row are to emphasize the direction of change over time.

Table 6.3.1. Number of Wet and Dry years at Bishop.

Water years	**Dry years (Extreme drought)**	**Wet years (Very wet conditions)**
1896 to 1960	28 (2)	37 (3)
1961 to 2025	35 ↑ (4 ↑)	30 ↓ (7 ↑)

Source: Abatzoglou et al. (2026)

The impacts of drought are intensified in the Owens Valley due to ground and surface water pumping by LADWP to supply water to Los Angeles (ICWD, 2021a). No matter how much snow or rain falls in the Eastern Sierra, differing by year due to the latitudinal position of the jet stream, the water needs of Los Angeles remain and will increase as populations increase, further burdening the Owens Valley. As detailed in the history of the Bishop Paiute, water holds a strong cultural significance for the Paiute people. A lack of water impacts the survival of plants and animals, which hold cultural importance to the Tribe.

Impacts to groundwater

The Bishop Paiute Tribe has a different groundwater situation from other tribes in the Owens Valley due to their position within the Bishop Cone, as explained in the Background section. While their Reservation lands are not as impacted directly by water shortages resulting from LADWP groundwater extraction as other tribes to the south, surrounding areas within the ancestral homelands of the Tribe are experiencing notable changes. For example, the Fish Slough area 10 miles north of Bishop, within the Volcanic Tablelands, is facing the compound impacts of climate change and excessive groundwater pumping.

Fish Slough, a critical habitat for endemic and endangered species, has endured decades of climate variability. However, recent studies indicate that the annual recharge and outflow relationship at Fish Slough is now "weak." Other factors, likely human-induced, such as groundwater pumping are playing a more significant role in the depletion of springs, such as the Northeast spring drying up (Albano et al., 2024).

The BPTEMO is concerned that the drying of Fish Slough, driven by both climate variability and human-induced factors, will have far-reaching consequences. If the drying trend continues, not only will this critical ecological area suffer, but so too will the communities that live downwind of the Tablelands. As Fish Slough becomes increasingly arid, dust storms are likely to intensify, carrying loose sediments, including fine particulates, toward the town of Bishop and the Bishop Paiute Reservation. Residents could face increasing risk of health impacts, such as respiratory illnesses, due to exposure to wind-driven PM10 which already arrives occasionally from Owens

Lake to the south and may now also come from the north.

The interplay of climate change and unsustainable water management is not only altering the ecological integrity of Fish Slough but also posing direct risks to public health in nearby communities. Addressing these challenges requires coordinated action to mitigate groundwater depletion, restore habitat resilience, and protect the well-being of both the environment and the people who depend on it.

Impacts on vegetation

Culturally important plants

Climate change impacts in the Bishop Tribe's ancestral lands in the Eastern Sierra have negatively affected native vegetation, including culturally important medicines and foods through mechanisms such as drought and phenological shifts. The Bishop Paiute Tribe has long been attuned to seasonal variations related to planting and stewardship of plants. A former employee for the Tribe reported, "*Several Elders have noted changes in harvest times for traditional foods. Community members have also mentioned changes in seasons such as out of the ordinary weather patterns, warmer fall weather and colder spring weather"* (Kapp, 2019).

In addition to the overall decline in the quality and abundance of native vegetation due to climate changes, the Bishop Paiute have seen a decrease in culturally important food species such as "wai" (Indian Ricegrass), tule, acorn and pine nut (BPT, 2020). In addition to the decreased availability of acorns, the Bishop Paiute Tribe and other Eastern Sierra tribes reported a change in the taste of the flour made with local acorns.

Drought in the Eastern Sierra, along with beetle infestations by the mountain pine beetle (*Dendroctonus ponderosae*), has caused an increase in tree mortality. As trees in Eastern Sierran forests become stressed by drought, their vigor and defense mechanisms weaken, making them more vulnerable to attack. Bishop staff monitor trees along the valley. They assess pinyon trees using signs that indicate if a tree is in poor health and will soon die by biological factors such as black fungus, mistletoe, and Pinyon Needle Scale. High temperatures exacerbate already stressed conditions for tree survival in areas like The Glass Mountain Range, approximately 50 miles north of

the Bishop Reservation (BPT, 2020). The buildup of dead trees combined with increased presence of invasive perennial weed and shrubs increase the fuel load and fire risk in these areas.

Conditions for invasive species

Sporadic heavy rains in the winter and spring increase the growth of vegetation which then dries and becomes fuel in the hot summers (BPT, 2020). The increase of perennial weeds, shrubs, and other flashy fuels have increased the fire danger over time. Invasive species in the Table Lands, including Russian thistle and cheat grass, were brought in by the grazing animals and now are transferred by people visiting sites.

Wetlands provide some of the richest habitat on the Bishop Reservation, supporting many species of plants and animals. There are approximately 25 acres of federally designated wetlands located in the eastern section of the Reservation (BPT, 2021b). One observable way the area has changed in the last 20 years is that much of the alkali meadow portion of the wetlands has been invaded by perennial pepperweed (*Lepidium latifolium*). This plant, not native to Owens Valley, has proved extraordinarily difficult to control. It propagates by seeds that are spread by animals and by water, and has very deep roots (BPT, 2021b).

At the COSA, land disturbance caused by trail construction created the opportunity for invasives, including all the species mentioned above in this section, to become established. During wet periods, water breaches a ditch that flows west to east North of the COSA and floods into the COSA, carrying perennial pepperweed with it. Pepperweed is also taking over certain sites at Fish Slough with no known eradication treatment. Chemicals and mechanical methods have only contained it in certain areas.

Impacts on wildlife

Climate change impacts threaten the Bishop Paiute's access to traditional foods such as fish, game, and wild and cultivated crops. These resources have provided sustenance as well as cultural, economic, and community health for generations.

Owens pupfish

Figure 6.3.7. Owens Valley Pupfish.



Photo credit: Joe Ferreira, CDFW

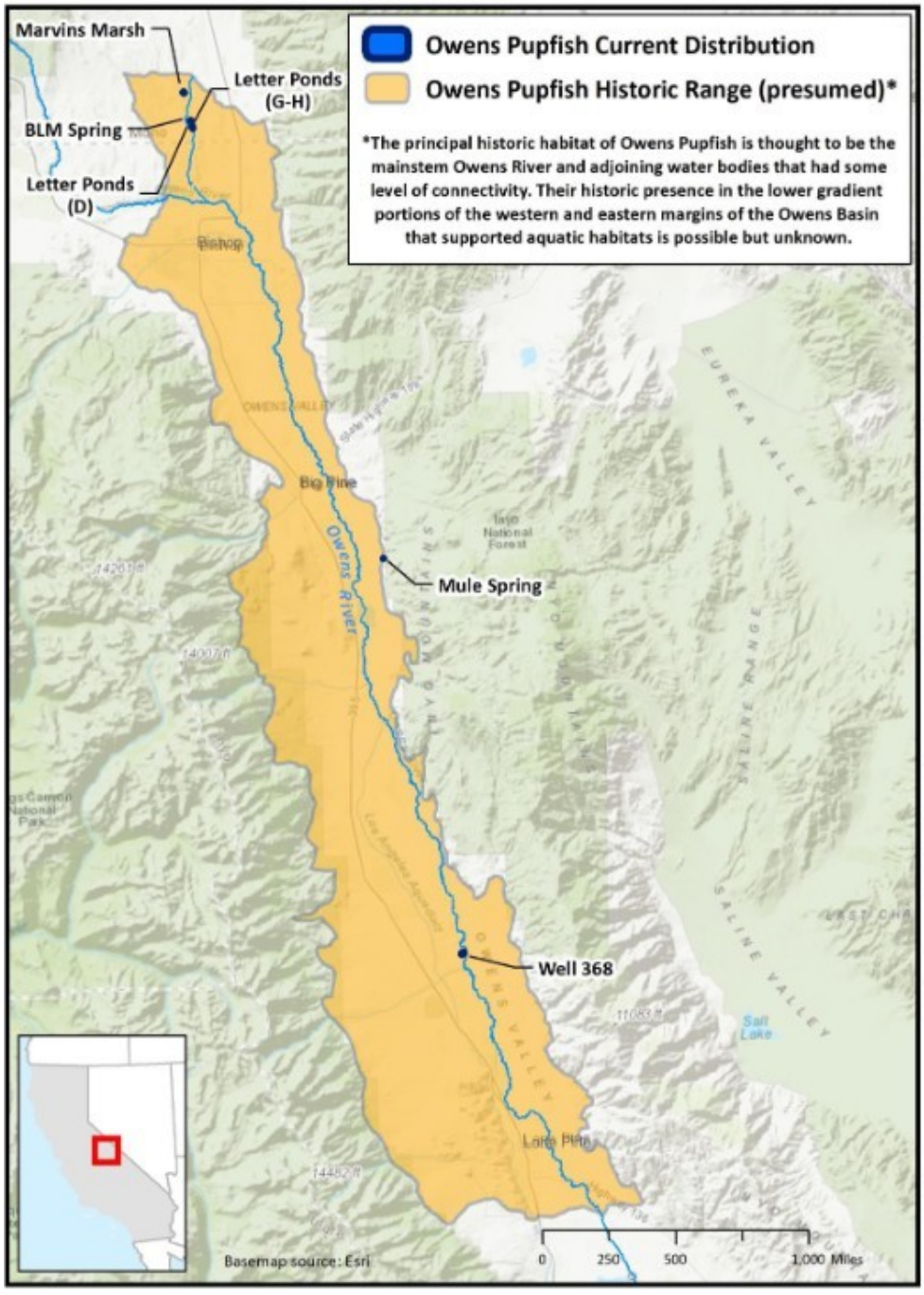
Source: Tasoff (2024)

The Bishop Paiute have cared for and been nourished by desert fish including the Owens pupfish (**Figure 6.3.7**, above) since time immemorial. The Owens pupfish (named for its playful nature) is a 2-inch long, silver-gray fish that turns a bright fluorescent blue during spawning season. Historically, the pupfish was a staple food item for the Paiute people in the Owens Valley, who caught the fish by the hundreds and dried and stored them. The Tribe continues to try to protect and care for these threatened fish but their habitat continues to shrink due to climate change, land use practices, and extensive water development. Owens pupfish are listed as endangered under both the federal and state Endangered Species Acts and are a California fully protected species, which is the state's highest level of legal protection (BPTEMO, 2024).

The historic range of the Owens pupfish is shown in orange in **Figure 6.3.8**, below. As of 2021, Owens pupfish were limited to a few areas designated with dark blue dots and a newly designated area called the River Springs Lake Ecological Reserve north of the region shown. In 2024, a 10-year Safe Harbor Agreement was signed between the Tribe, U.S. Fish and Wildlife Service, and the California Department of Fish and Wildlife, protecting the rights of landowners to disrupt pupfish habitat for the overall goal of increasing their habitat and population (BPTEMO, 2024). With this agreement in place,

the Tribe introduced pupfish to the refuge pond in their Conservation Open Space Area (COSA), which they had been planning and developing for over 20 years. In April 2025, they also introduced Owens pupfish to the Owens Valley Paiute-Shoshone Cultural Center aquariums.

Figure 6.3.8. Historic and Current Range of Owens Pupfish.



Source: CDFW (2020a)

Freshwater mussels

Figure 6.3.9. Freshwater Mussels in a Canal Dredge Pile.



Source: Klingler (2021)

Shell mounds of freshwater mussels (*Anodonta nuttalliana*) and surveys on the Bishop Paiute lands including the creeks and Owens Lake indicate the historic use of mussels as a food source. Mussels are no longer found in Owens Lake, but they have been found in the Bishop Creek canal, which diverts water from the Owens River for use by LADWP, as recently as 2014 (Blevins et al., 2017; Howard et al., 2015). Freshwater mussels have also been seen in LADWP dredge piles (Klingler, 2021). The shells in **Figure 6.3.9**, above, are from different age classes, indicating that mussels were reproducing in the recent past. Due to reduced numbers they are no longer used as a source of food for the Paiute people (Bengochia, 2021).

Owens Tui Chub

The Owens Tui Chub (*Siphateles bicolor snyderi* or *Gila bicolor snyderi*) is endemic to the Owens Basin, Mono and Inyo Counties. It was a food source for the Bishop Paiute people but is now found in only six sites, including the COSA, all created for the

preservation of the species on the Bishop Paiute lands. The COSA Tui Chub are hybridized. The Toikona Tui Chub is the original species and is now only found in isolated conservation areas to prevent hybridization (CDFW, 2020c).

Owens speckled dace

The Owens speckled dace (*Rhinichthys osculus ssp*.) fish historically occupied most small streams and springs in the Owens Valley. By the 1980's the stream-fed ponds and springs that the Owens speckled dace lived in were depleted or destroyed by the construction of and pumping for the LA aqueducts, and they were extirpated from most of their historic range. The COSA on the Bishop Paiute lands is one of three remaining, isolated habitats for these culturally important fish (Mussmann, et al. 2020).

Game species

The Paiute still hunt both large and small game and have noticed a decline in culturally important species. Rabbits, especially black-tailed jackrabbits and cottontail rabbits, used to be plentiful in the area. The Tribe has seen a decline in both species. As the area has suffered from drought and desertification, food on which the rabbits depend has become less available (Bengochia, 2021).

Mule deer are a culturally important species for the Bishop Paiute Tribe. Mule deer are in decline across the west, their migration patterns and food availability impacted by drought and other aspects of climate change (Aikens et al., 2020). In 2017, 120 mule deer that were migrating to their winter grounds in the Valley ran into persistent snow and ice sheets, not normally found in the area, and slid to their deaths. This type of event has only happened twice before that the Tribe knows of and never on this scale (Brown-Williams, 2017).

In 2020 the Bishop Paiute Tribe entered into an agreement with the California Department of Fish and Wildlife allowing the Tribe to take 16 deer for cultural education purposes. This agreement was the first of its kind and it recognizes the Tribe's authority to protect wildlife resources (CDFW, 2020b).

Additional impacts on wildlife

Some of the other impacts to wildlife the Tribe is experiencing include:

- declining numbers of native fish overall, such as Owens pupfish, Owens Tui Chub, Owens speckled dace, Owens sucker, and Toikona Tui Chub,
- increasing stream temperatures,
- increasing bacteria levels (*E. coli*, cyanobacteria) in surface waters on the Reservation and associated adverse effects on local wildlife,
- decrease in bird species such as yellow-headed black bird, red-winged black bird, eagles, and swallows,
- decline in numbers of bats,
- increasing observations of beaver activity which the Tribe is currently researching.

The Tribe has also observed increases in non-native species that have the potential to take the place of native species as the climate of the Owens Valley warms and dries, such as:

- Barred Owl,
- Black Witch moth (native to Mexico),
- Bullfrogs and mud snails,
- Rainbow trout, largemouth bass, catfish, and perch.

The Bishop Paiute lands provide habitat for many threatened or endangered species such as Western Meadowlark (*Sturnella neglecta*), Owens Valley vole (*Microtus californicus ssp. vallicola*), a myriad of insects and spiders, and many other animals. The Northern Harrier (*Circus cyaneus*) and Red Shouldered Hawk (*Buteo lineatus*) are year-round residents, breeding in Owens Valley and foraging in meadows. As discussed earlier, the meadows that these species rely upon are threatened by climate change impacts that continue to lower the water table.

Wildfire

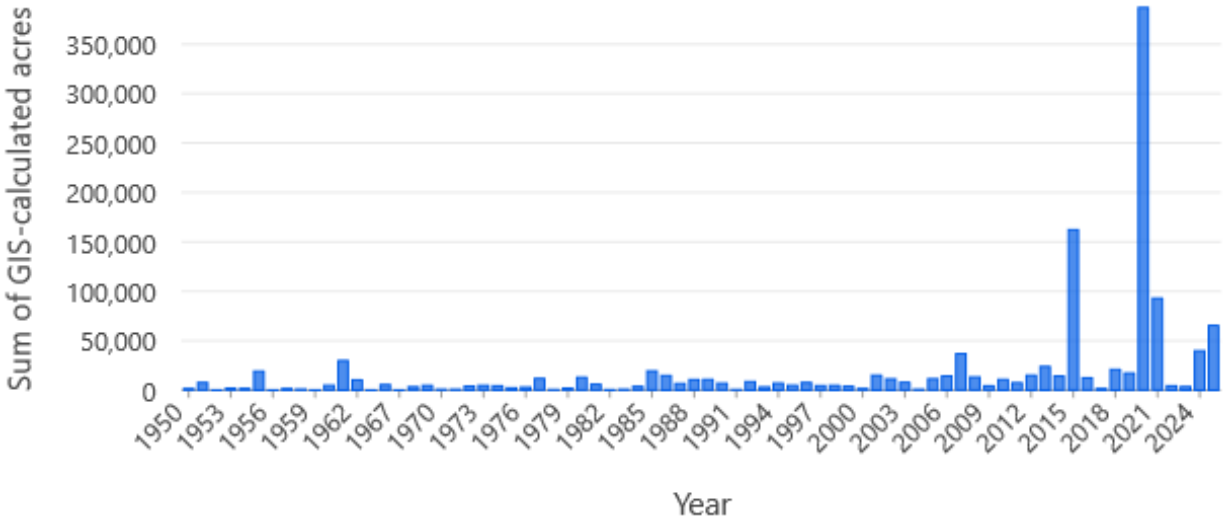
The incidence of large forest fires in the western United States has increased since the early 1980s (Wehner et al., 2017). Fire season in California starts earlier and ends later each year (CAL FIRE 2021). Since 2007, there have been 23 fires over 100 acres in size within 30 miles of the Bishop Paiute Tribe Reservation (**Table 6.3.2**, below). The Reservation is in an area designated as a High Fire Severity zone (BPT, 2018).

Table 6.3.2. Fires Over 100 Acres in Size Within 30 Miles of the Bishop Paiute Reservation, 2007 to 2025.

Year	Fire	Acres Burned
2007	Inyo Complex (#1)	35,000
2008	Bluff	767
2008	Big Trees	125
2009	Fort	1,500
2009	Blackjack	271
2009	Forks	2,811
2011	Center	441
2011	Buttermilk	206
2011	John	5,800
2013	Windy Peak	681
2014	Bridges	113
2015	Round	6,537
2016	Rock Creek	123
2018	Pleasant	2,076
2019	Taboose	10,268
2020	Creek	379,842
2020	Beach	3,800
2020	Iris	125
2021	Calvert	258
2022	Airport	4,140
2025	Silver	1,611
2025	Sage	260
2025	Pack	1,974

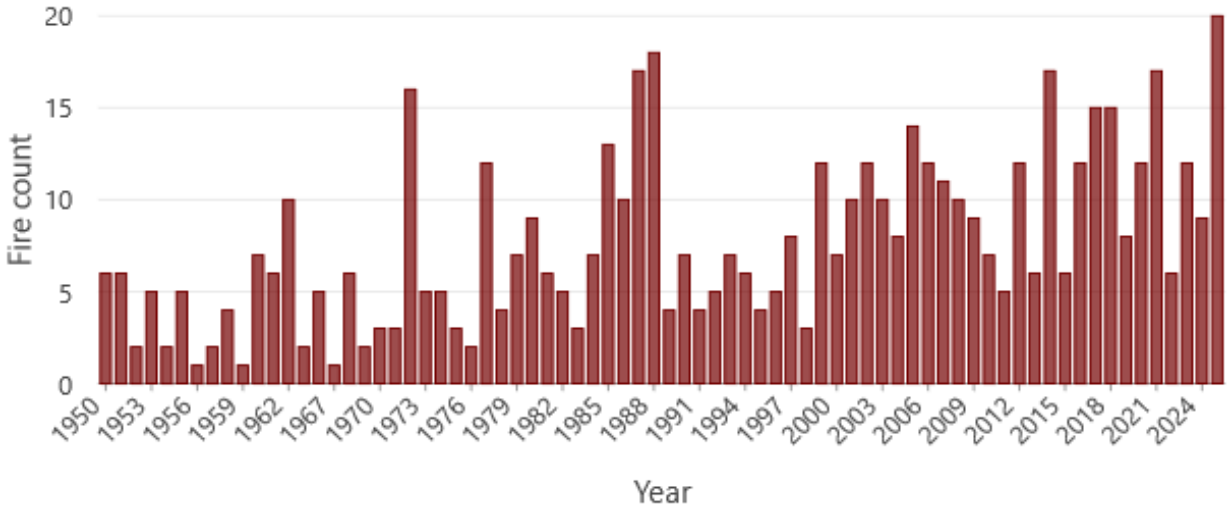
Source: CAL FIRE (2026)

Figure 6.3.10. Sum of GIS-calculated Acres Burned Annually by Wildfires Within 100 Miles of Bishop's Reservation, 1950 to 2025.



Source: CAL FIRE (2026)

Figure 6.3.11. Number of Wildfires Within 100 Miles of Bishop's Reservation, 1950 to 2025.

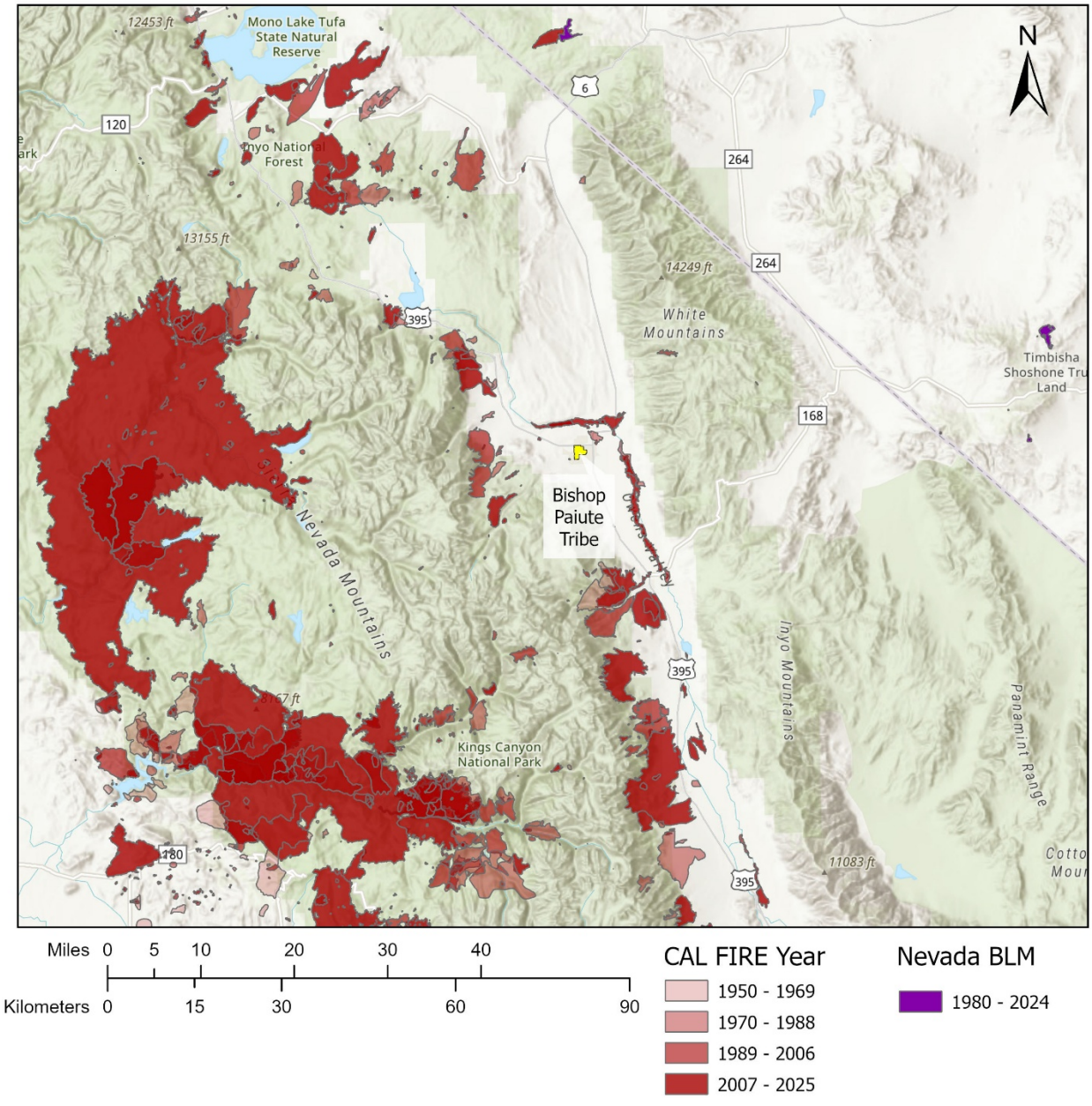


Source: CAL FIRE (2026)

Figure 6.3.10 (above, top) shows that the number of acres burned annually by wildfires in the region affecting the Bishop Paiute Tribe (BPT) has exponentially increased in the last 10 years. **Figure 6.3.11** (above, bottom) shows that the number of wildfires

impacting the BPT each year has also increased since 1950. The map in **Figure 6.3.12** shows fires that impacted the current Bishop Tribal lands from 1950 through 2025. More recent fires are shown in darker red, and the Bishop Paiute Tribe's Reservation is shown in yellow in the center.

Figure 6.3.12. Fires Impacting Bishop Paiute Tribe, 1950 to 2025.



Source: CAL FIRE (2026); BLM (2026); Esri, TomTom, Garmin, FAO, NOAA, USGS, ©OpenStreetMap contributors, and the GIS User Community.

While the Reservation itself has not been burned by large wildfires, there have been impacts to soil, riparian habitat, air, and water quality (BPT, 2018). Fires increase soil erosion, particularly in denuded watersheds. Wildland fires that eliminate forest areas affect soil and watershed value and are destructive to both terrestrial and aquatic habitat.

Years of drought, declining snowpack, over pumping of groundwater, and increasing temperatures, combined with more than a century of fire suppression and attendant changes in forest composition, have significantly increased fire severity, frequency, and size throughout the Eastern Sierra (Dettinger et al., 2018). The Tribe has noted that the build-up of dead trees in the National Forest area at Indiana Summit and an increase of weeds, shrubs, and other flashy fuels have increased fire danger for the Tribe (BPT, 2020).

Many mountain meadows below the elevation of 7,500 feet, including the meadows of the Eastern Sierra, are not truly natural but were influenced for millennia by tribal burning practices. Native people altered the size and composition of meadows through periodic burning. Setting fires in the areas surrounding the meadows discouraged the encroachment of more wet-tolerant vegetation. Periodic burning within the meadow boundaries influenced the species composition, density, and abundance of native plant populations. Certain meadow plants such as deergrass, yampahs (a genus of wild carrot) and clovers were favored and maintained through burning (Anderson, 2005). Burning was also used to increase foods such as wild onions and elderberries, and to clear out the underbrush to bring in new growth for the animals. The Owens Valley Indians also grew tobacco and burned the fields where the tobacco grew (Padilla, 2004).

Historically, the Paiute conducted cultural burns on their ancestral lands. The population of the Bishop area has grown over time and federal land agencies and LADWP control all the lands the Tribe used to steward, except the Reservation itself. On the Reservation, the reduction of agricultural lands and densification of homes and dwellings (2000 members live on just 879 acres) have created a matrix and distribution

of fuels that are unsafe to control with broadcast burns (BPTEMO, 2026) The size of controlled burns on the Reservation are limited by discontinuous land use parcels and land assignments, proximity to hazards such as trees, buildings and power lines, and in some cases lack of staffing or a tribal fire department. Allowable burning on the Bishop Reservation is limited to 50-foot (ft) by 50-ft plots, 100-ft ditch lengths, and 4-ft by 4-ft piles with 10-ft clearances, by applicants volunteering to participate in the Tribe's burn permit rules. Burns can occur on the "yes" burn days during allowable burn hours as determined by the BLM, U.S. Forest Service, and GBUAPCD (the surrounding land agencies). The approved burn permit application, 2023 version, is online and approved by the Bishop Paiute Tribal Administration. Roughly 100 permits to burn excess vegetation are issued on the Bishop Reservation each year since the program's inception in 2003 to satisfy the Tribe's agreement with the Bishop Rural Volunteer Fire Department.

Wildfire smoke impacts

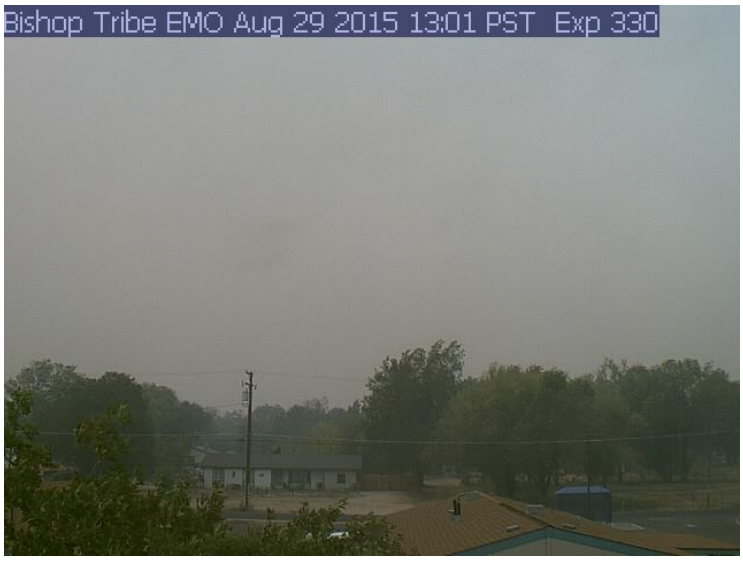
The topography of Owens Valley in part determines the wind patterns which deliver wildfire smoke to the Bishop area. Wildfire smoke on the Reservation is typically reflected in the Tribe's particulate monitoring data from the continuous monitoring station. These data, collected since 2004, are archived by the U.S. Environmental Protection Agency (EPA) and are publicly available.

In 2006, the Bishop Tribal Council adopted the CA state standards for PM10 and PM2.5 (less than 2.5 micrometers in diameter) for twenty-four-hour (24-hour) periods. One purpose of the air quality monitoring program is to determine whether and when the Tribe's Air Quality Standards for PM10 and PM2.5 are exceeded in a 24-hour, midnight-to-midnight period. Short-term exposures to PM2.5 have been associated primarily with worsening of respiratory diseases, including asthma and chronic obstructive pulmonary disease, leading to hospitalization and emergency department visits (CARB, 2021).

Another direct impact of smoke is visibility. Visibility was limited to less than 1 mile during the worst hours of the 2015 Rough Fire, as captured by the Tribe's west-pointing visibility camera in **Figure 6.3.13**, below. Twenty-four-hour average PM2.5 concentrations at the Reservation during the 2015 Rough Fire exceeded the Tribal

standard of 35 micrograms per meter cubed (µg/m^3) for four consecutive days and were the highest hourly PM2.5 concentrations recorded by BPT yet. On 32 of the 35 days that it took to reach containment of the fire, smoke was visible at 6 miles; on the worst days, smoke was visible within 1 mile and obscured 6-mile landmarks. Wind roses demonstrate that unlike storm fronts bringing dust, air mass shifting even in the non-predominant wind direction may play a role in regional wildfire smoke distribution.

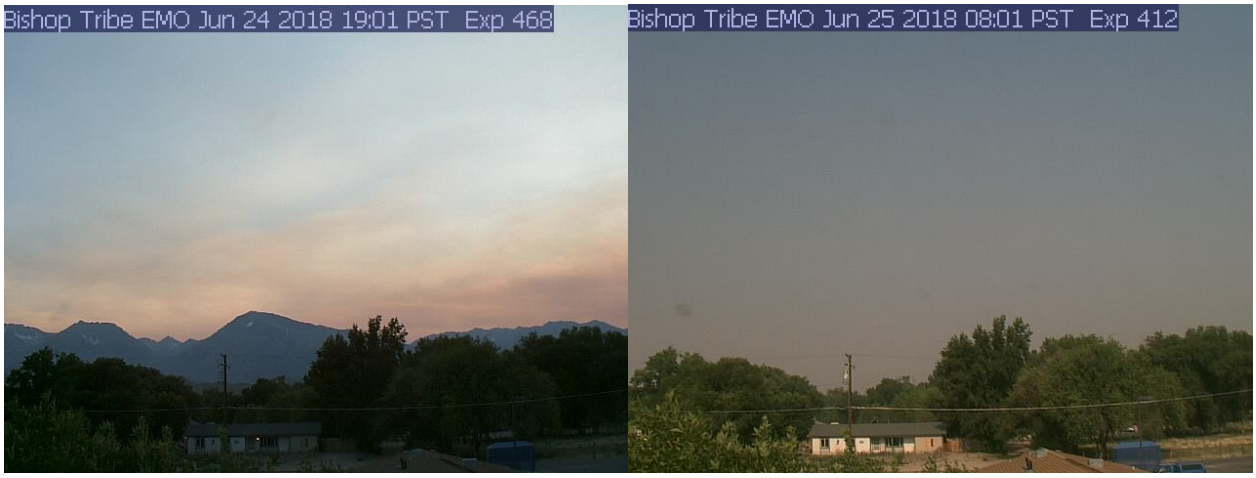
Figure 6.3.13. Visibility on the Worst Day of the 2015 Rough Fire.



Source: BPTEMO (2026)

During the 2018 wildfire season, 22 separate air quality standard exceedances occurred across 13 days on the Reservation, including the Tribe's first 24-hour values in the "Unhealthy" AQI range for PM10 due to combined wildfire effects. **Figure 6.3.14**, below, is an example of the overnight effect of smoke settling in the valley during the Lions Fire.

Figure 6.3.14. Smoke Settling Over the Owens Valley During the Lions Fire, June 24 and 25, 2018.



Source: BPTEMO (2026)

Figure 6.3.15. Photo of the 2018 Pleasant Fire.



The Pleasant Fire, a cold-season fire, burned along the Owens River just northeast of Bishop and the Reservation. Source: BPTEMO (2026)

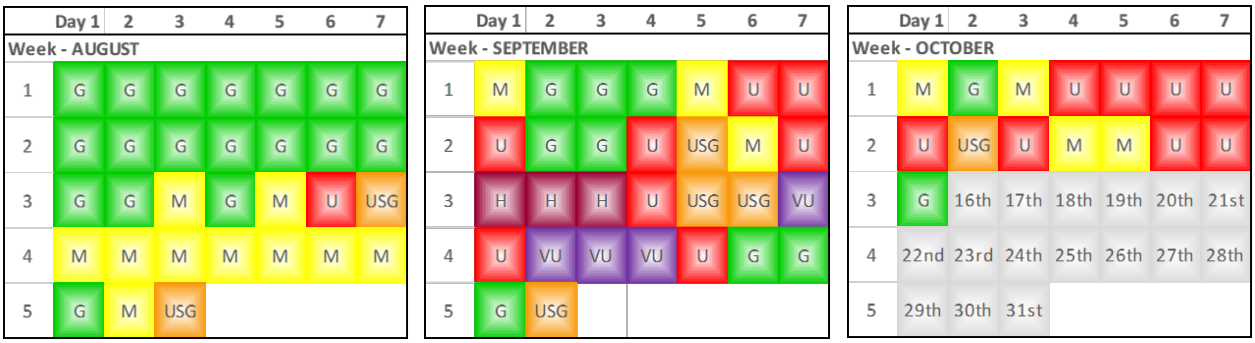
In October 2019, the wildfire season overlapped with the autumn storm season, and the smoke combined with dust from an early storm gust front caused a PM10 24-hour exceedance (50 µg/m^3) on the Reservation.

In 2020, during the historic Creek Fire (and SQF or Sequoia Complex), there were 39

days with single or combined exceedances on the Reservation. The highest PM10 levels reached the upper limit of the monitor. There were more than 17 days of "Unhealthy" air, four days of "Very Unhealthy", and three days of "Hazardous" air. Fire danger in the 2nd half of 2020 was declared so high that the public were not allowed to enter most areas of Inyo National Forest after sweeping closure announcements by federal forestry managers. The persistence of warm, stagnant conditions well into October 2020 and nighttime inversions contributed to the duration of smoke levels. **Figure 6.3.16**, below, shows the Air Quality Index (AQI) chart made in mid-October for this smoke event (based on PM concentrations recorded at the Tribe's air monitoring station).

In 2021 there were 12 wildfires ranging in size from the 25-acre Pine Fire to the 963,306-acre Dixie fire that caused wildfire smoke exposure to the Tribe (BPT, 2021c). The 24-hour standards for both PM10 and PM2.5 were exceeded in August, September, and October on the Reservation, with both values exceeding 100 µg/m^3 in August and September.

Figure 6.3.16. AQI for the Reservation Based on Bishop Paiute Tribe's Air Monitoring Station, August through October 2020.



The calendar days shown here are color-coded according to the following AQI categories as defined by the U.S. EPA: Good (green), Moderate (yellow), Unhealthy for Sensitive Groups (orange), Unhealthy (red), Very Unhealthy (purple), and Hazardous (maroon). More information on this index can be found at www.airnow.gov/aqi/aqi-basics/. Source: BPTEMO (2026)

Figure 6.3.17. Image of the 2022 Airport Fire.



The Airport Fire, as captured from Tribal headquarters with a southeast-pointing air visibility camera, was an example of a rapidly suppressed nearby grassfire. Source: BPTEMO (2026)

Most recently, the Garnet Fire, which started on Labor Day weekend 2025, doubled in size during the first week and reached just short of 60,000 acres by the middle of September. By September it was mostly contained according to details from Sierra National Forest daily reports. Like previous fires on the west side of the Sierra Crest, West winds and diurnal air shift patterns brought smoke to the Reservation area during the first and second weeks of September, with heavier smoke during the night and early morning hours (BPTEMO, 2026). On Sunday, September 7th, 2025, the 24-hour midnight-to-midnight AQI based on PM2.5 was “Unhealthy”/red, and going into the first hours of September 8th, there were some hours of “Very Unhealthy”/purple at the 24-hour scale on a rolling average basis. Air Resource Advisors for U.S. Forest Service who are assigned to selected fires create daily smoke forecasts and sometimes use the BPT air monitoring data as part of their determinations. **Figure 6.3.18** below is an excerpt from one of their Smoke Outlooks for September 9th, 2025.

Figure 6.3.18. Smoke Outlook for Bishop Region, September 9, 2025.



Source: BPTEMO (2026)

Other air quality impacts

On the Bishop Paiute Reservation, impaired air quality due to PM10 is episodic. The 2018 PM Trends Analysis demonstrated that the highest PM10 one-hour (1-hr) concentrations were associated with winds or storm fronts. Wind-driven PM10 episodes may reach the Reservation from the Owens Dry Lake, nearby barren areas, or from as far as Mono Lake shore.

The majority of sub-exceedance PM2.5 concentrations, based on comparison to the Tribe's 24-hour midnight-to-midnight daily average standard, are driven by winter inversions trapping residential woodsmoke. Smoke from cold-season wood burning for home heating is an area-wide phenomenon which includes the Reservation. Many

Valley residents heat their homes with wood or pellet stoves. Backyard and wood burning are a staple cold-season activity which supports fuels reduction and home heating on the Reservation. BPTEMO has coordinated backyard burning permits for residents with the Bishop Rural Volunteer Fire Department since 2003. Efforts were recently furthered by the Tribe's own wood splitting yard program, initiated in 2024, and Hazardous Fuels Reduction activities (active previously in 2001, 2009, and again since 2019; mostly via CAL FIRE). Typical fuels on Tribal residence properties include willow coppices, fallen branches, tree stumps, and leaves from trees such as locusts and large cottonwoods and some conifers, field grasses, invasive weeds, and riparian vegetation.

Summary

Climate change impacts the culture, lives, environment, and health of the Bishop Paiute Tribe. The Bishop Paiute people continue to work to protect and enhance the natural resources and habitat of the Owens Valley. Because climate change is deeply affecting the environment and altering and disrupting the ecosystems within and around the Owens Valley, the Bishop Paiute community is actively working to understand, adapt to, and mitigate the effects of climate change and other impacts to their lands. Their goal is to continue to manage and protect their traditional lands and limit the impact climate change is having on the Bishop Paiute people's right to hunt, fish, and gather from their land—something that is integral to their culture, well-being and livelihood.

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Suggested Citation:

Bishop Paiute Tribe (2026). Impacts of Climate Change on the Bishop Paiute Tribe. In: OEHHA 2026 Indicators of Climate Change in California.

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Appendix

The following information was included in the main body of the previous version of Impacts of Climate Change on the Bishop Paiute Tribe (2022). As discussed in the **Background** *section of this report, the Bishop Paiute Tribe is not as directly dependent on the Owens Valley groundwater basin as other tribes to their south. While it does not comprise one of their greatest direct climate change concerns currently, they are still involved in conversations and agreements that affect Owens Valley groundwater as part of the broader region. They work to support the Lone Pine Paiute-Shoshone Tribe to their south, who faces more direct impacts to land, water, air, and correspondingly the health of their culture and people, due to LADWP water extraction. Therefore, this section is included in the Appendix.*

Owens Lake water management background

Owens Lake held water continuously, and at times overflowed to the south, for at least 800,000 years prior to 1913 (Smith et al., 1993). In 1913, the Los Angeles Department of Water and Power (LADWP) began pumping Owens Lake, which at the time spanned 108 square miles (approximately one third the size of Lake Tahoe), to provide water to Los Angeles. By 1926, the lake was dry (Reheis et al., 1995). In 1970, a second aqueduct that mainly pumps groundwater from the Owens Valley for use in Los Angeles was added. Water export prior to state-ordered control measures in the 1990s intensified the effects of periods of low or no precipitation in the Eastern Sierra.

Prior to the 1997 State Implementation Plan, Owens Lake produced 94% of the inhaled PM10 in the Owens Valley (US EPA, 2017). Currently, lakebed levels are modulated in response to Air Pollution Control District control measures. **Figure 6.3.A-1** and **Figure 6.3.A-2**, below, show the Lake as it has been in recent years; partially inundated. In the 2016 State Implementation Plan Supplement, the district divided the region into two areas. The northern area, encompassing the Bishop Paiute Reservation, is in attainment of PM10 standards while the southern area containing Owens Lake is in nonattainment (Owens Valley Planning Area). Bishop does not suffer from the same degree of PM10 pollution as its southern neighbors, except during occasional wind-driven dust events.

Figure 6.3.A-1. Image of Water in Owens Lake As Seen From an Air Quality Camera on January 26, 2026.



Owens Lake has been partially filled since 2017. Source: GBUAPCD (2026)

Figure 6.3.A-2. Aerial Image of Owens Lake.



This image shows an aerial view of Owens Lake published in 2025. The inundated area changes over time. Circle markers are for National Ambient Air Quality Standards PM10

monitoring stations around Owens Lake. Hatch markings indicate an area 3 km from the 3,600 ft elevation regulatory shoreline. Source: NASEM (2025)

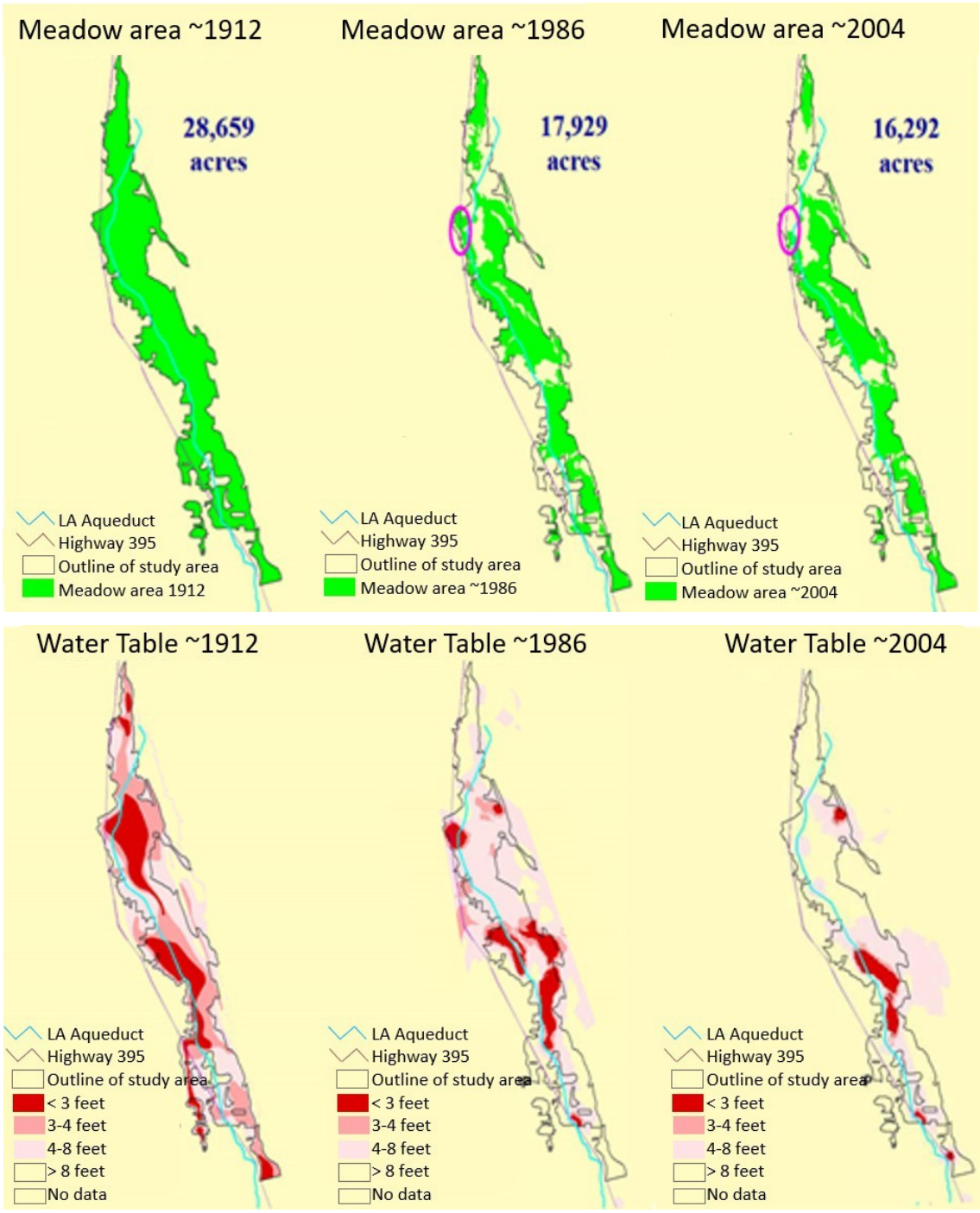
Cumulative impacts to the Owens Valley ecosystem

Ecosystems which tribes in the Payahuunadü depend on have suffered from water deficits during years of low precipitation exacerbated by the anthropogenic drought caused by pumping of the Owens Valley groundwater for use in Los Angeles. The entire region experienced a 6-year drought (1987–1992), during which annual precipitation was below the 50-year median of 7.12 inches (USGS, 1998). Elmore et al. conducted a 16-year study which documented an increase in the depth to the groundwater table—associated with increased groundwater pumping—and analyzed changes in vegetative cover. The study found plant cover to be correlated with groundwater depth, indicating that pumping exacerbates drought impacts to vegetation in the Owens Valley (Elmore et al., 2006).

As the Owens Valley climate continues to change, becoming warmer and dryer, the Valley meadows are disappearing, and the Tribe is seeing a desertification of the area. The Tribe knows that with sufficient water in the area, the meadows and grasses would thrive again (Bengochia, 2021). As shown in **Figure 6.3.A-3**, below, reductions in meadow vegetative cover have occurred alongside dropping water table levels. In 1912, a former United States Geological Survey (USGS) hydraulic engineer created maps showing ground water depths and vegetation types (Lee, 1912). Digitized versions of these maps are used here to compare ground water and meadow ecosystems. The maps in **Figure 6.3.A-3** allow a comparison of the area occupied by meadows in 1912, 1986, and 2004. The 1912 map shows the baseline of the grasslands. The 1986 and 2004 maps, based on monitoring by LADWP, show substantial grassland loss within the area known as Blackrock 94, which is highlighted in pink and shown in a photograph in **Figure 6.3.A-4**.

Due to groundwater pumping, water tables have gotten deeper and areas with shallow groundwater (less than 3 feet) have decreased substantially. The lack of groundwater corresponds to the lack of meadow in the same area.

Figure 6.3.A-3. Changes in Owens Valley Meadows (Top) and Depth to Groundwater (Bottom).



Top: areas occupied by meadows are in green and Blackrock 94 is circled in pink. Source: Manning (2012); digitized maps from Lee (1912)

Figure 6.3.A-4. Blackrock 94 Area in June 1988 (Top) and June 2007 (Bottom).



In 1988 the area had 33% vegetation coverage, dominated by green grass with 4% shrubs. By 2007 vegetation coverage was reduced to 15% in the same area, consisting of around 11% shrubs and around 3% grass. Source: Manning (2012)

Maps more recent than 2004 showing data that can be compared to **Figure 6.3.A-3** are not currently available. This is partly due to changes in the methods of data collection. It is noteworthy to mention that some groundwater data recently collected from County of Inyo Water Department suggests that from 2021 to 2022 the average basin groundwater table was reduced by an average of approximately 2 feet (ICWD, 2021b). The Owens Valley is a closed basin that has been drained over the past 100 years and the continuation of pumping is leading to a reduction of vegetation diversity including culturally important plants in the Payahuunadü.

Though it is generally rare in California, alkali meadow is a major vegetation type in Owens Valley, and on the Bishop Paiute Reservation. The Owens Valley has 67% of

the alkali meadow in California. In the 1980s, LADWP biologists mapped at least 70,000 acres of Valley floor as dominated by California native grasses, supported by Owens Valley's naturally shallow groundwater (Davis et al., 1998). These meadows are home to species of cultural importance and conservation concern, both plants such as the Owens Valley checkerbloom and the Inyo County star tulip, and animals such as Owens Valley vole, northern harrier and red shouldered hawk (Elmore et al., 2006).

Meadows are a biodiverse habitat that sustain common as well as rare species. Owens Valley meadows are dominated by one or both native perennial grass species: saltgrass (*Distichlis spicata*) and alkali sacaton (*Sporobolus airoides*). Both are hardy species, with roots growing to approximately 2 meters. Other common grasses in meadows include Beardless wildrye (*Leymus triticoides*), Baltic rush (*Juncus balticus*), scratchgrass (*Muhlenbergia asperifolia*), basin wildrye (*Leymus cinereus*), and, to a lesser extent, alkali cordgrass (*Spartina gracilis*). Irises, lilies, and broad-leaved herbaceous plants intermingle with the grasses.

Other meadow species include:

- Alkali mallow (*Malvella leprosa*)
- Fish Slough milk vetch (*Astragalus lentiginosus ssp. Piscinensis*)
- Hall's meadow hawksbeard (*Crepis runcinata ssp. Hallii*)
- Inyo County star-tulip (*Calochortus excavatus*)
- Nevada blue-eyed grass (*Sisyrinchium halophilum*)
- Owens Valley checkerbloom (*Sidalcea covillei*)
- Saltmarsh bird's-beak (*Cordylanthus maritimus* Nutt. ex Benth.)
- Stinkweed (*Cleomella*)
- Wild licorice (*Glycyrrhiza lepidota Pursh*)
- Yerba mansa (*Anemopsis californica*)

Native shrubs include:

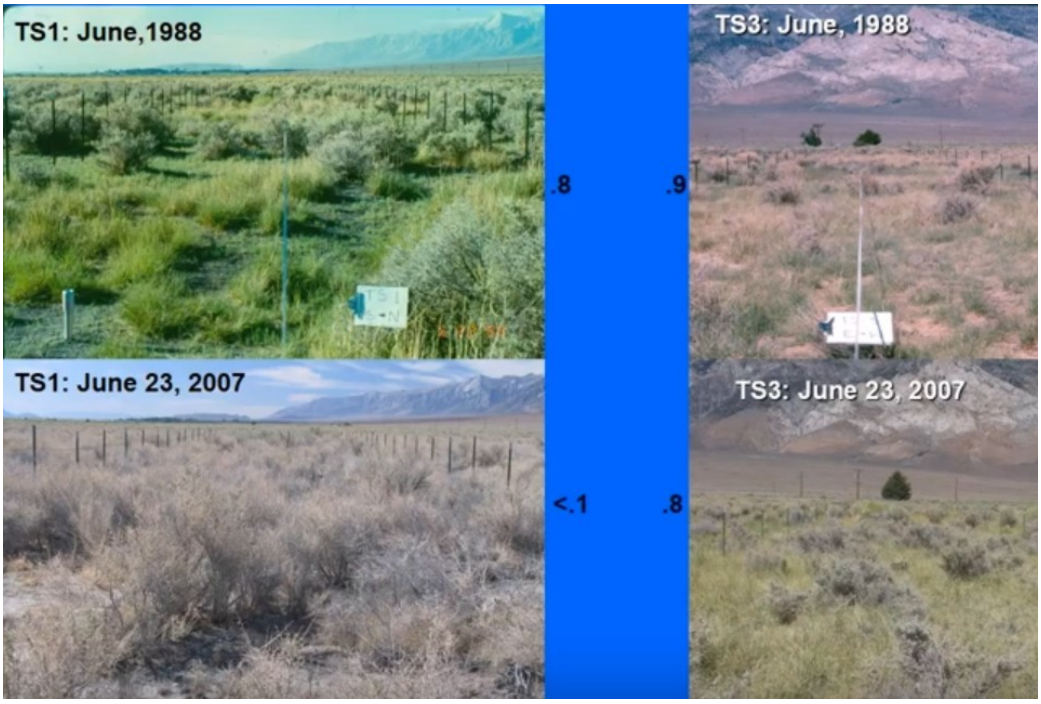
- Rabbitbrush (*Chrysothamnus nauseosus*)
- Nevada saltbush (*Atriplex lentiformis ssp. torreyi*)

- Greasewood (*Sarcobatus vermiculatus*)
- Sagebrush (*Artemisia tridentata*)

Of these species, the annual species *Malvella*, *Cleomella*, *Cordylanthus* are less tolerant of changes to water and are more likely to be lost as meadows are deprived of water. The Bishop Paiute Tribe has translocated many of these species to the COSA to attempt to preserve them.

As non-native vegetation dominates, the Valley is less resistant to fire. The roots of meadow grasses have evolved to tap into the historically shallow (8 feet) ground water of the area, while the roots of the encroaching shrubs can burrow deeper for water. In early July 2007, the Inyo Complex fire burned over 35,000 acres including a vegetation study area. **Figure 6.3.A-5**, below, shows two sites in the study area (TS1 and TS3) in 1988, when the grass-to-shrub ratios were similar in both locations (0.8 in TS1 and 0.9 in TS3).

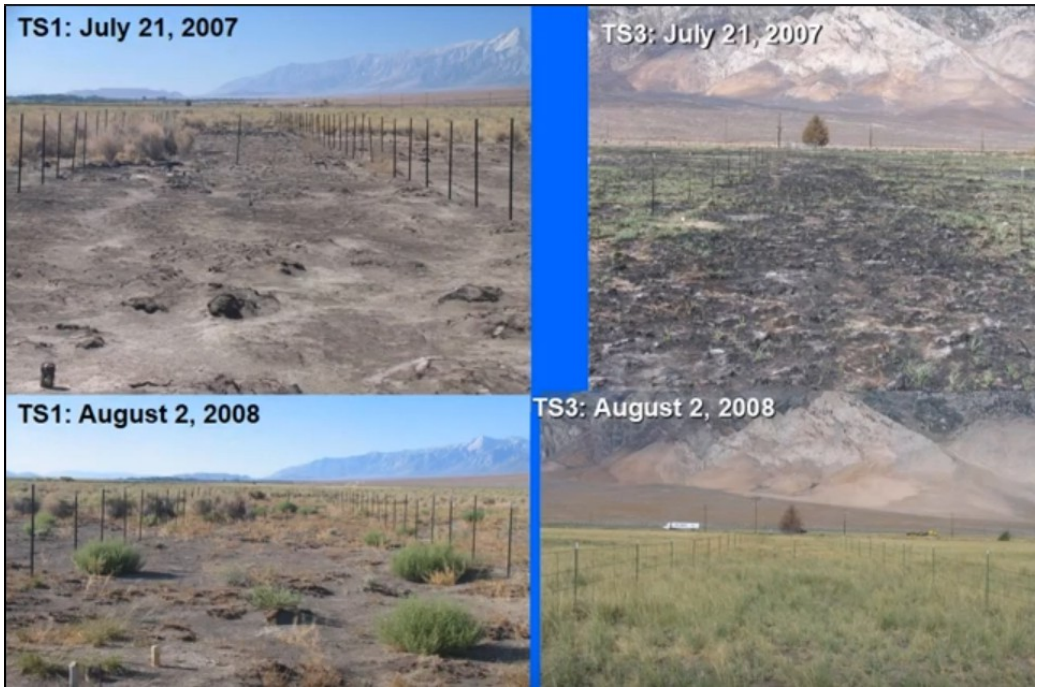
Figure 6.3.A-5. Study Areas TS1 and TS3 Pre-fire.



The numbers shown in the middle panel next to each photo are the grass-to-shrub ratios: for TS1, 0.8 in 1988, <0.1 in 2007; for TS3, 0.9 in 1988, 0.8 in 2007. Source: Pritchett and Manning (2009)

By 2007 site TS1 had been over pumped, and this anthropogenic climate change impact had promoted the growth of shrubs such as tumbleweed, resulting in a grass-to-shrub ratio of less than 0.1. In site TS3, an area that had been better managed and allowed more water, native grasses were nearly as abundant as they were in 1988. The top photos of **Figure 6.3.A-6,** below, show both the TS1 and TS3 areas soon after the Inyo Complex burned through the area. A year later (bottom photos) area TS1, which had been populated by non-native shrubs, still looked barren while area TS3, populated by native grasses, had nearly recovered.

Figure 6.3.A-6. Areas TS1 and TS3 After the Inyo Complex Fire.



Source: Pritchett and Manning (2009)

6.4 Impacts of Climate Change on the Karuk Tribe

Self-described as "fix the world people," the Karuk Tribe has relied on fire and ceremony to manage their lands since time immemorial. The threats of climate change, acting alongside non-climate factors, are an opportunity for the Tribe to return to traditional management, which includes the use of 22 key cultural indicator species to gauge ecosystem health and to guide appropriate action.

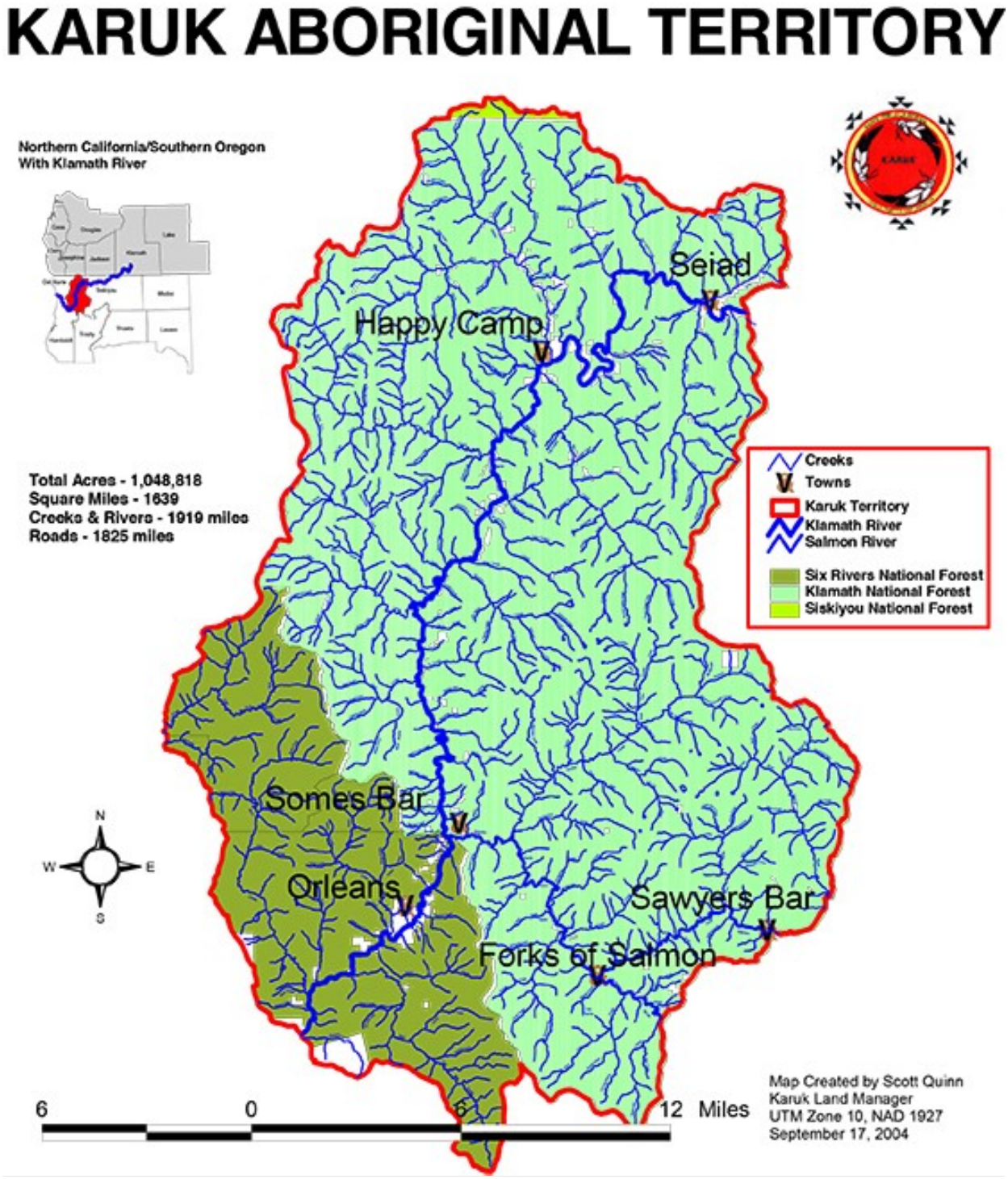
This chapter was originally published in the 2022 Indicators of Climate Change in California report and has not been updated for this edition. Data and references reflect conditions as of 2022.

Background

The Karuk Tribe is a federally recognized Tribe comprised of Karuk araráhih (upriver people) located along the Klamath River in the northwestern corner of the state, in Humboldt and Siskiyou Counties. The Karuk Tribe is one of the largest tribes in California with 3,744 members and 5,271 descendants (Karuk Tribe Enrollment Department).

Since time immemorial, the Karuk have lived in the Klamath-Siskiyou Mountains in the mid-Klamath River region of northern California (**Figure 6.4.1**, below). With an Aboriginal Territory that includes over a million acres, the ancestral Karuk people resided in more than one hundred villages along the Klamath and Salmon Rivers and tributaries. Thriving with a subsistence economy supported by rich natural endowments and a strong culture-based commitment to land stewardship, Karuk environmental management has shaped the region's ecological conditions for millennia. Through carefully observing natural processes, the Karuk have developed traditional management regimes based on a landscape-level ecosystem approach. Self-described as "fix the world people," the Karuk continue ceremonies that restore balance and renew the world.

Figure 6.4.1. Map of Karuk Aboriginal Territory.



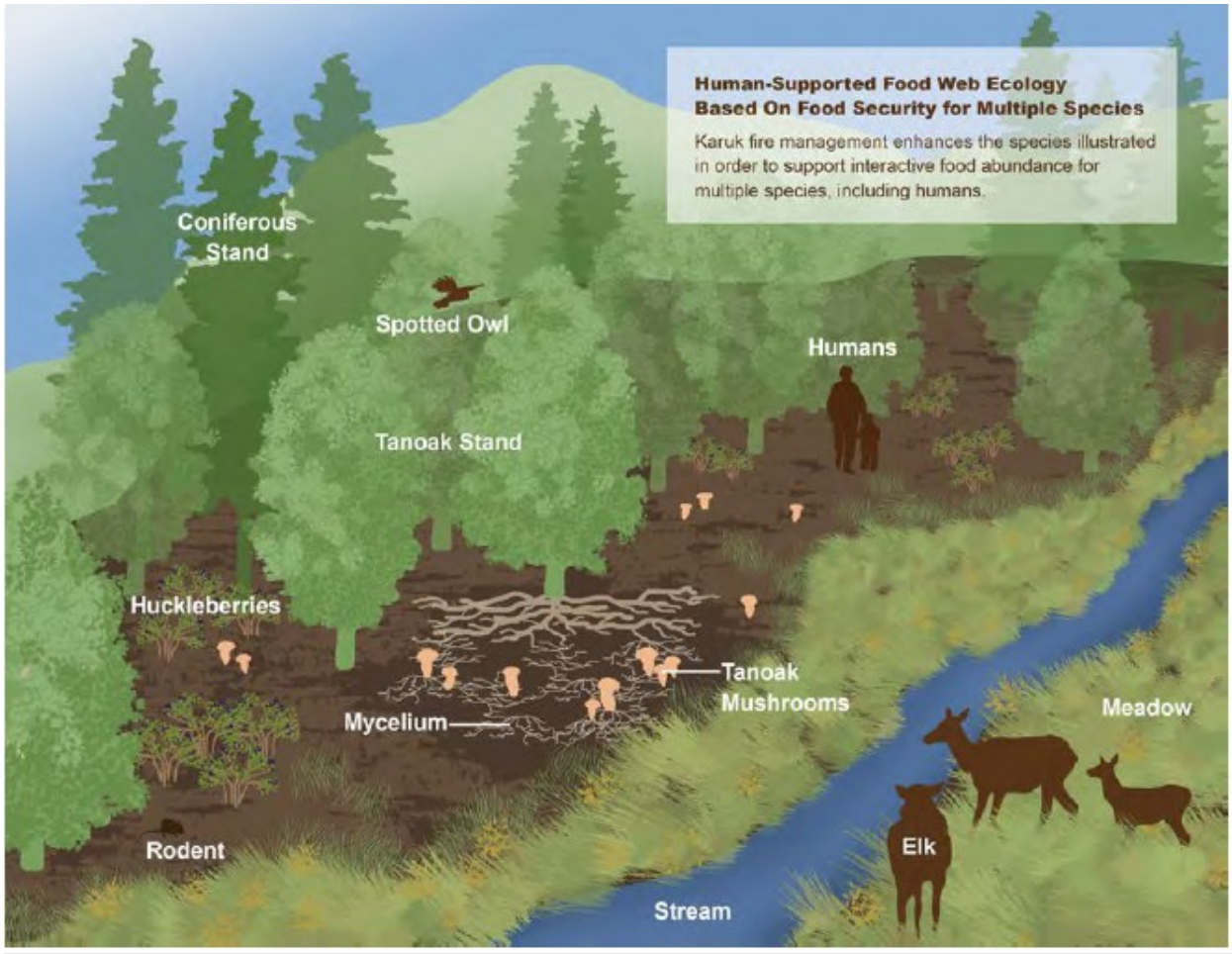
Source: Karuk Tribe (2016)

The Karuk People have historically been wealthy from tending of the land. Traditional ecological knowledge provides the Karuk with foods—including acorns, salmon and deer—and fibers such as hazel, willow, and bear grass which they use as materials for their well-known basket-weaving skills. Medicinal plants were also abundant. This rich and diverse cultural landscape was made possible through the use of fire and ceremony.

The mid-Klamath ecosystem has co-evolved with the Karuk people and culture over millennia. Multiple species of importance to the Karuk people play vital roles as cultural indicators for appropriate human actions within the Tribe's system of traditional management. For countless generations, Karuk people have observed the behavior of particular plants and animals to understand ecological dynamics and have used this as a guide for necessary human management. The return of particular migrating birds signals the timing of the eel run, the appearance of Pleiades in the night sky denotes the time for cultural burning, while the behavior of other species warns of danger. This knowledge gained from attending to the land over generations is inscribed in ceremonies and prayers.

Karuk culture is directly reliant on fire as a tool to manage the environment for cultural sustenance and well-being. Karuk fire management practices include burning at a specific season, frequency, and intensity at a variety of severities. This frequent, low-intensity fire is linked with various fire-adapted vegetation communities and is necessary for the maintenance of cultural resources. Fire is especially critical for restoring grasslands for elk, managing food sources including tanoak and black oak acorns, maintaining quality basketry materials, producing smoke that shades the river for fish, and more. While fire can be incredibly dangerous, it is an inevitable part of natural ecosystems, especially in lightning-prone forested areas such as the mid-Klamath. Forested areas in northern California have become adapted to the frequent occurrence of relatively low intensity fire from human and natural ignitions for more than the past 1,000 years. Karuk's use of fire has been central to the evolution of the flora and fauna of the mid-Klamath (see **Figure 6.4.2**, below).

Figure 6.4.2. Karuk Cultural Burning Produces Species Abundance.



Credit: Figure courtesy of Kirsten Vinyeta

Source: Karuk Tribe (2019)

Gold mining started on the Klamath and Salmon Rivers around 1850, ushering in Settler Colonialism for the region and its devastating effects to the people and land. The Karuk People have always resisted Settler Colonialism, whether through armed rebellion as with the 1855 Red Cap War, legal action and protests such as the G-O Road Struggle and the Un-Dam the Klamath Campaign. The longstanding human-ecological relationships and practices have been interrupted by European settlement and its consequences: attempted genocide, displacement, resource extraction and the

imposition of non-Native land management policies and ways of understanding the world. The policy of fire suppression has been especially significant. While these interruptions have been substantial and have taken place over an extended period of time, cultural and ecological information is retained today in ceremonies, stories, collective memory and the land itself.

Karuk Tribe and climate change

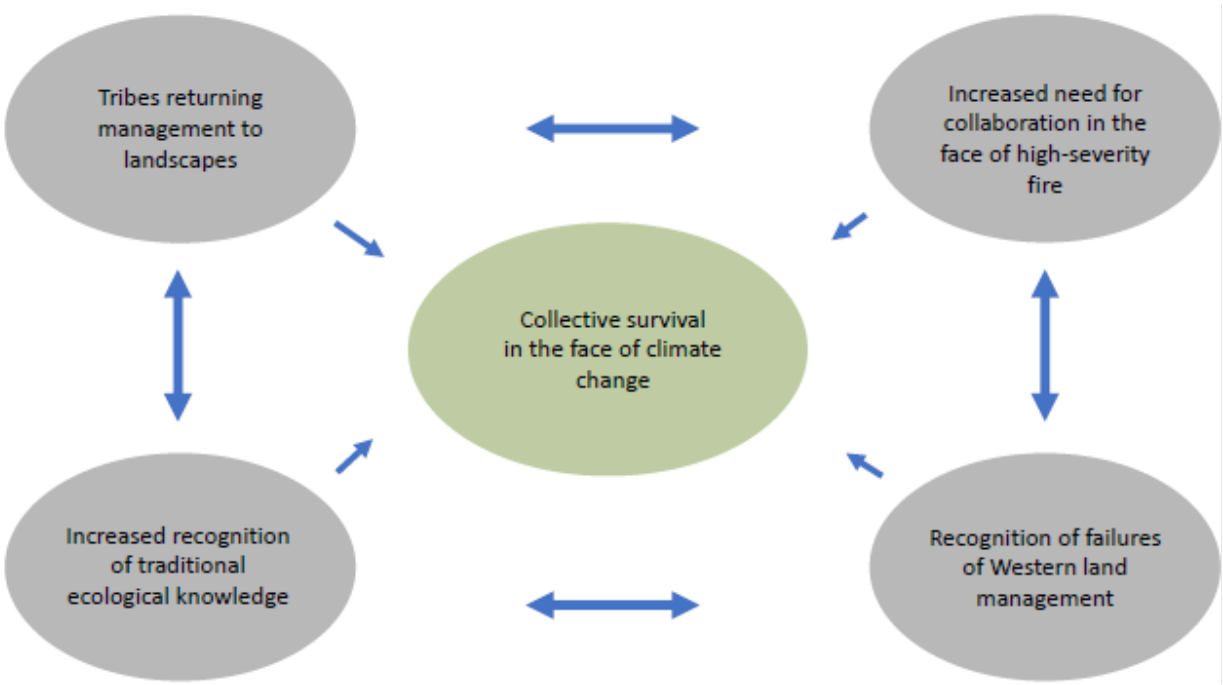
Within Karuk aboriginal territory, the effects of climate change are immediate and occurring now. Climate change poses a threat not only to the Klamath ecosystem, but also to Karuk culture, which is intimately intertwined with the presence, use and management of cultural use species. The Karuk are fortunate to retain relationships with hundreds of species they consider their relations: foods, medicines and fibers that are embedded within cultural, social, spiritual, economic and political systems, and daily life. Impacts to such culturally significant species in the face of climate change thus have more direct impacts on the Karuk people than on communities that do not have such intimate connections in the natural world. Part of the increased vulnerabilities Karuk people face as the climate changes are a direct result of the strength of these connections. For example, the loss of acorn groves that have been family gathering sites for generations is much more than an economic impact. In addition, the social justice challenges that have impacted the Tribe since European influx are ubiquitous today in the form of low economic opportunity and restricted access to traditional cultural resources, employment, schools, food sources, medical facilities, and emergency evacuation routes in this remote area.

Climate change is viewed by the Karuk as the product of unsustainable Western land management practices and the rise of political and economic systems for which indigenous people hold little to no responsibility. The impacts of the changing climate interact with existing ecological stressors such as water diversions and fire suppression.

Nevertheless, the crisis posed by climate change presents a strategic opportunity for tribes to retain cultural practices and return traditional management practices to the landscape, and for all land managers to remedy inappropriate ecological actions. There is increasing recognition of the importance of indigenous burning as an ecosystem

component and restoration technique. Traditional ecological knowledge, the need for collaboration in addressing high severity wildfire, and a recognition of the failures of Western land management, have combined to create an exciting political moment in which tribes are uniquely positioned to lead the way toward collective survival in the face of climate change (see **Figure 6.4.3**, below). In the mid-Klamath region specifically, many goals in the Forest Service's own management plan can be best achieved through restoring Karuk tribal management.

Figure 6.4.3. Climate Change as a Strategic Opportunity.



This diagram illustrates how tribes can lead efforts toward collectively addressing climate change.

Credit: Sara Worl

Source: Karuk Tribe (2019)

The Karuk people have long been part of the ecosystem. Adapting to climate change is about restoring human responsibilities and appropriate relationships with species and ecosystem processes. Karuk tribal knowledge regarding the use of fire can be utilized to manage cultural resources, promote biodiversity, and mitigate catastrophic wildfires,

thereby protecting public as well as tribal trust resources. The Karuk Tribe's work on restoring traditional fire regimes holds the potential to inform both climate adaptation and mitigation efforts, given that wildfires themselves generate carbon emissions, and a reduction in high severity fires could result in a reduction in forest emissions.

The Tribe's adaptation approach to climate change centers around the revitalization of Karuk cultural management, the restoration of traditional fire regimes, the reduction of impacts from intervening factors, the expansion of Karuk tribal management authority and capacity, community engagement and public education, increased interjurisdictional coordination, and expanded research and monitoring. Utilizing Karuk Traditional Ecological Knowledge alongside western science, climate adaptation will center on the revitalization of 22 focal species as cultural indicators for human responsibilities and necessary human management actions. "These species have stories to tell, lessons in terms of how to get back to traditional management. They serve as indicators of relationships, responsibilities and of when and where to burn" (Bill Tripp, Deputy Director of Eco-Cultural Revitalization).

Climate change and its impacts

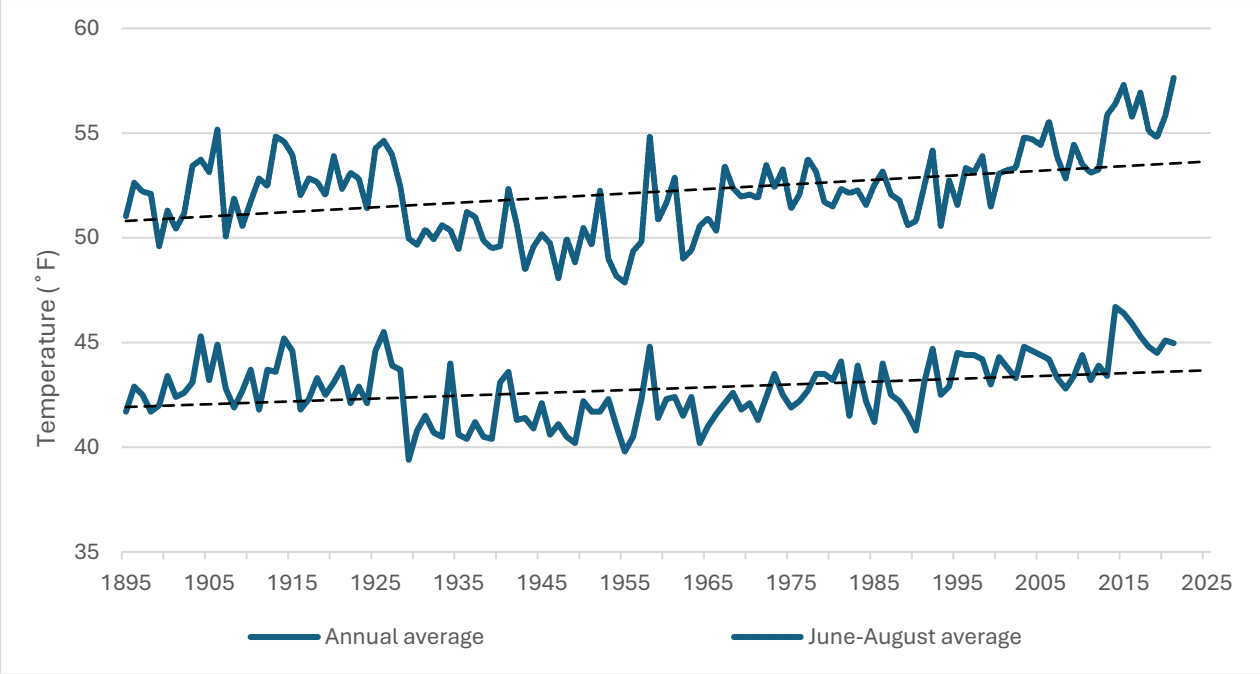
Trends in the Pacific Northwest Region of the United States include rising air temperatures, changing patterns of precipitation, and associated changes in snowpack, soil moisture, length of growing season, fire behavior and more. Similarly, the mid-Klamath region of California has experienced warming, changes in precipitation patterns, increased droughts, increased frequency and severity of wildfires, and disease and pest outbreaks in forests. Observed changes and impacts are summarized below. Unless otherwise stated, the Karuk Climate Adaptation Plan is the basis for the information presented (Karuk Tribe, 2019).

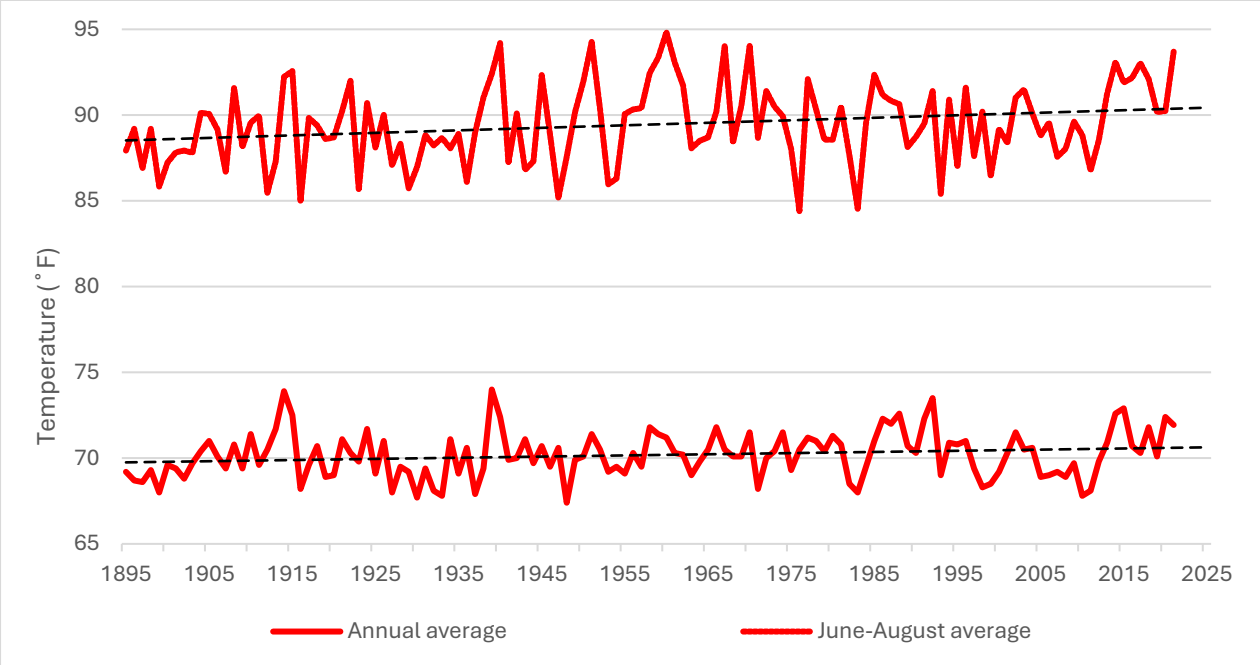
Changing temperature patterns

Air temperatures have been increasing in California over the past century (see the *Air Temperature* chapter). Common measures of air temperature include annual average air temperatures, nighttime summer and winter minimum temperatures, number of days per year that exceed 86 degrees Fahrenheit (°F), number of frost-free days (a measure

of the length of growing seasons), and measures of extreme heat events. Both across California and in the North Coast region specifically, these temperature increases have been greatest in the summer months. Minimum nighttime temperatures have been increasing faster than either maximum daytime highs or average temperatures. Not only are there overall increases in air temperatures across these measures, but more variable temperature patterns are observed. Future projections in temperature-related metrics are presented in the Adaptation Plan.

Figure 6.4.4. Average Temperatures at Orleans, CA.





The top graph shows average annual minimum temperatures, or nighttime temperatures, from 1985 to 2021. The bottom graph shows average annual maximum temperatures, or daytime temperatures, from 1985 to 2021. Source: PRISM Climate Group (2022)

Temperature data for Orleans, California are presented in **Figure 6.4.4**. Warming trends are evident. Notably, minimum temperatures, which occur at night, have risen at more than twice the rate of maximum temperatures. Temperatures during the warmer months rose at a faster rate compared to yearly rates: maximum temperatures for the months June through August warmed almost 2.2 times faster than maximum temperatures averaged over the year, and minimum temperatures for June through August warmed more than 1.6 times faster (PRISM Climate Group, 2022).

The Adaptation Plan reported the total number of days above 86°F (30°C) as 49.8 days for 1971 to 2000, and the number of days without freezing temperatures as 282.5 days. For the period between 1991 and 2020, these have increased to an average of 99 days per year above 86°F (30°C) and 340 days per year above freezing (32°F (0°C)) (PRISM Climate Group, 2022).

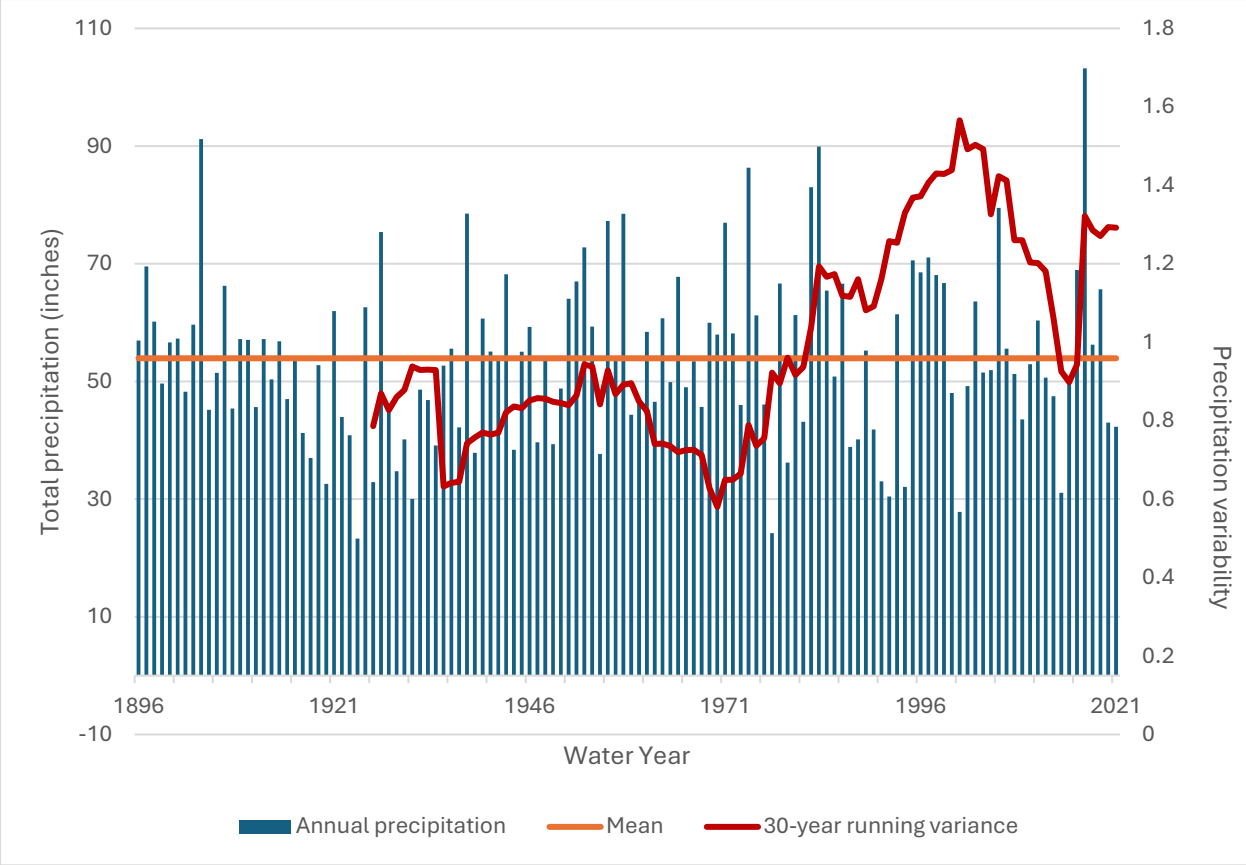
Warmer temperatures have been associated with changes in hydrology, including decreased snowpack (particularly at low elevation sites), earlier snow melt and spring runoff, decline in total runoff occurring in the spring, rising river and stream

temperatures, and increased variability in streamflow. These changes have occurred in conjunction with changing precipitation patterns, discussed in the next section.

In addition, warmer temperatures may increase the spread of tree diseases (such as sudden oak death) and pest infestations (such as bark beetles); delay autumn migrations of certain species such as black-tailed deer; increase fire risk as vegetation dries with reduced soil moisture and increased evapo-transpiration. Rising temperatures also pose health concerns, including heat stress and heat-related deaths, respiratory effects from increased pollution and pollen, and from food and water contamination, particularly from toxic algae.

Changing precipitation patterns and drought

Figure 6.4.5. Annual Precipitation at Orleans, CA from 1895 to 2021.



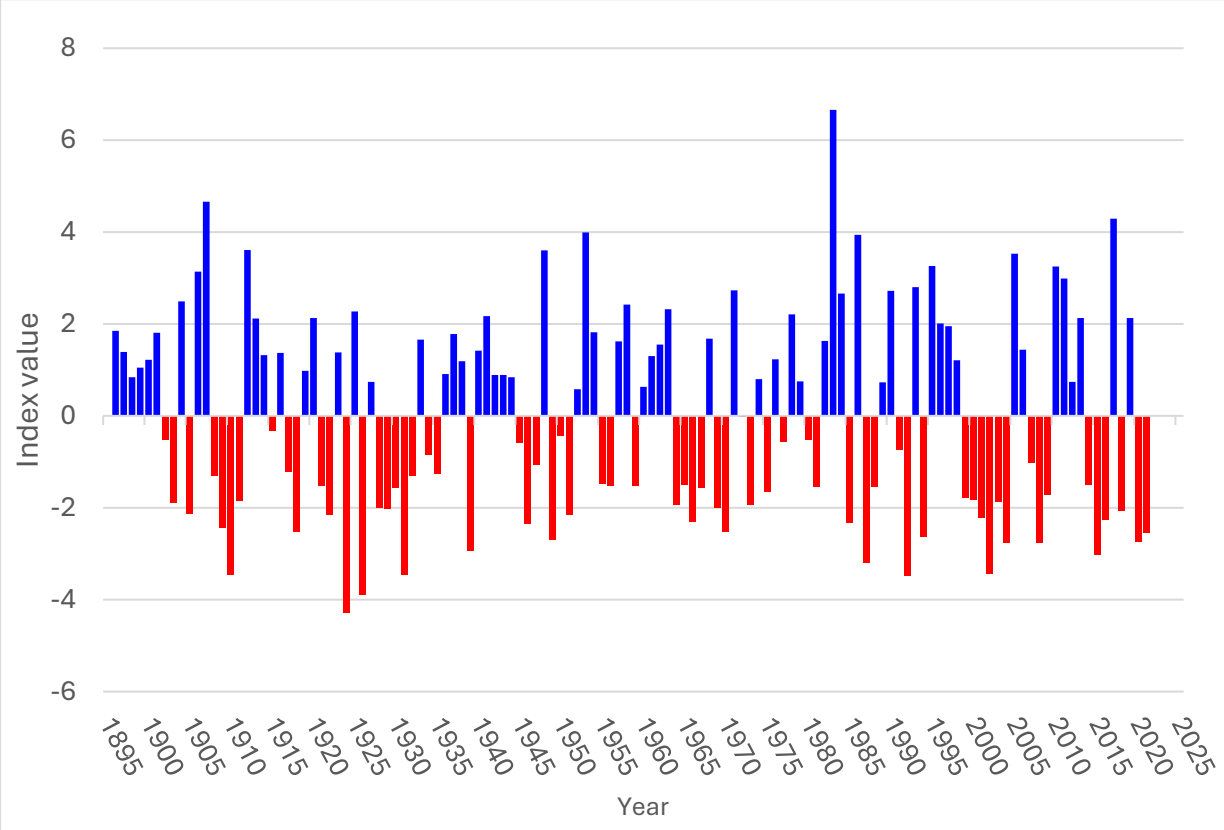
Source: PRISM Climate Group (2022)

Precipitation patterns are changing in the Klamath basin and across the Pacific Northwest. Key measures of precipitation include total annual precipitation, timing of winter and summer precipitation, and the total amount of precipitation in individual storm events. Annual precipitation measured by water year in Orleans, California, is presented in **Figure 6.4.5,** above. Year-to-year precipitation is highly variable, while showing no trend in the annual amount over time.

Warmer winter temperatures result in more precipitation falling as rain instead of snow. For the North Coast as a whole, the average spatial extent of snow on April 1st has declined from 60% to 50% at elevations above 3,000 feet from 1951 to 1980 and 1981 to 2010, with the greatest loss of snow occurring in the Klamath-Siskiyou Mountains. In Karuk Aboriginal Territory, the average snow water equivalent (a measure of snowpack) on April 1st from 1971 to 2000 was 10.3 inches. This is predicted to decline significantly by the end of the century.

Figure 6.4.6 presents a commonly used metric to track drought, the Palmer Drought Severity Index. The index reflects relative dryness based on readily available temperature, precipitation and soil water content data. Positive values (blue bars) denote wet years; negative values (red bars), dry years. Values below negative three (-3) represent severe to extreme drought. Twelve of the last 20 years were dry, with two severely dry years in 2002 and 2015.

Figure 6.4.6. The Palmer Drought Severity Index Showing Drought Patterns at Orleans, CA from 1895 to 2021.



Source: WRCC (2022)

Changing patterns of precipitation, along with warming, translate into decreasing flows and increasing stream temperatures. Prolonged drought will generally reduce stream flows and may cause permanent streams to become intermittent. Flows in the Salmon and Klamath Rivers are projected to decline, while stream temperatures are projected to increase, affecting habitat for aquatic species such as salmon. Low summer base flows exacerbate toxic algae bloom conditions and increase the likelihood of tribal members' exposures to the toxin microcystin through contact with contaminated water or consumption of food and water.

Less precipitation – particularly in the form of snowpack – can lead to vegetative stress, for example weakening sugar pine. Drought will lead to more severe wildfires and their

cascading impacts on habitats in the region. There is concern that less predictable and reduced precipitation may constrain windows to apply fire.

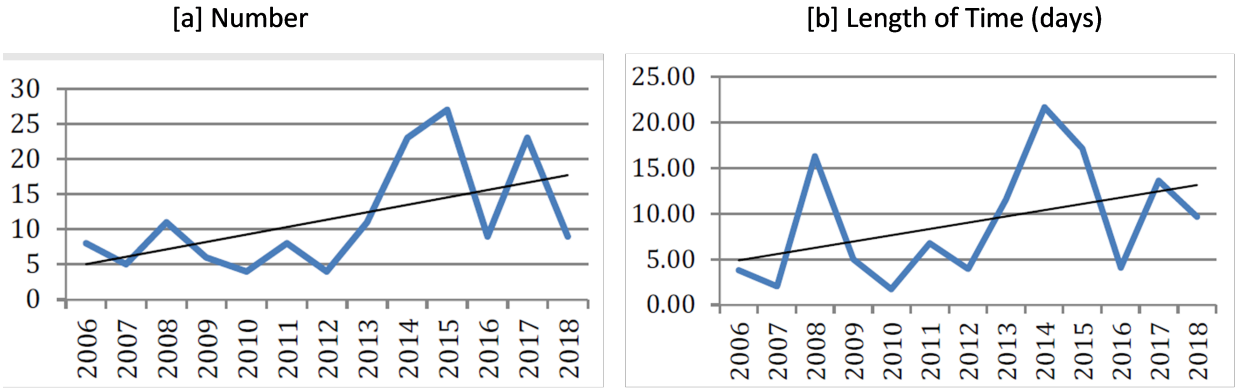
Changing patterns of fire behavior

The Klamath Basin has experienced increasingly frequent, large-scale, intense fires in recent years as a result of both climate change and increased fuel loads resulting from federal land management practices and the cessation of indigenous burning. Invasive species such as scotch broom, star thistle, Himalayan blackberry, non-native grasses and many others are well established within Karuk Aboriginal Territory, adding to the fuel load. Many of these invasive plant species exacerbate fire behavior through the production of long flame lengths.

Changing patterns of fire behavior are among the most pressing of the local dimensions of climate change within Karuk Aboriginal Territory. As shown in **Figure 6.4.7**, the number and length of time of fire weather watches or “red flag warnings” between 2006 and 2018 in the two fire zones that make up the Territory have increased. A Red Flag Warning is issued for weather events which may result in extreme fire behavior that will occur within 24 hours.

The increasing frequency of high severity fire threatens individual species, alters the habitat, and disrupts ecosystem dynamics. Fires cause direct mortality to plant and animal species, reducing the availability of food sources; they consume snags and logs used by woodpeckers for nesting, roosting, and foraging. Fires during the flowering and fruiting season may affect harvest and plant reproduction. Trees stressed by fire injury are susceptible to bark beetle and other insect infestations which, in turn, can increase future fire severity.

Figure 6.4.7. The [a] Number and [b] Duration of Fire Weather Watches/Warnings, Fire Zones 204 and 280.



Source: Karuk Tribe (2019)

Fire suppression actions have produced adverse impacts. The firefighting tactic of "burning out" along the fire lines creates areas of very high severity fire. Timber fallers often intentionally cut chinquapin and black oaks preemptively because they may have cavities in which fire can smolder; these cavities are important habitat for Pacific fisher. In the immediate aftermath of high severity fires, activities such as salvage logging and associated road building can impact forest stands.

High severity fires in the Klamath region pose immediate health implications during emergency situations, as well as impacts on physical and mental health from smoke exposure. Exposure to smoke is strongly associated with increasing respiratory symptoms which tend to occur during the fires; the deterioration of existing respiratory diseases, hospital admissions, and deaths from respiratory causes impact the tribal community.

Fires also impact critical tribal infrastructure including the electrical grid, transportation systems, water supply, communication systems, and emergency services.

Impacts on human health and well-being

The Klamath River and its tributaries, forests, grasslands and high country are essential for the cultural, spiritual, economic and physical health of Karuk people. Among the

physical health impacts of warming temperatures are: heat stress (many homes do not have air conditioning systems, and those that do are at risk of power outages); increasing rates of asthma and allergies due to increased particulate matter and pollen; and food and water contamination from toxic blue-green algae. Increased residence time of water in the Copco and Iron Gate Reservoirs in the mid-Klamath basin due to drought and low summer flows create ideal growing conditions for the algae (Microcystis aeruginosa) that produces microcystin, a liver toxin. Exposures to the toxin can occur through consuming contaminated water and traditional foods, recreation, bathing or cleansing, and ceremonial activities. The World Renewal Ceremonies in which the medicine man traditionally bathes and drinks Klamath River water overlaps annually with the highest levels of microcystin.

There are serious negative health consequences of smoke inhalation. Large-scale, high severity fires burn much longer than traditional cultural burns, leading to more significant health impacts. In addition to smoke exposures, other potential health concerns include disrupted access to emergency vehicles and to medical care. Poor visibility during periods of thick smoke creates hazardous conditions for air craft operations for firefighting as well as for emergency medical transport. Additional damage to important gathering sites can occur from firefighting tactics. Wildfires are in and of themselves disturbing events in which people may lose or fear the loss of their homes and important sites in the landscape, and normal home and work routines as well as cultural and subsistence activities are disrupted. Irritability or “cabin fever” can set in when people need to stay indoors for prolonged periods.

Biophysical changes across the landscape – including those related to climate change – have affected access to many important food, fiber and medicinal resources. Salmon, acorn, elk, deer, berries and teas are among the traditional foods that are vitally important to the Karuk people, and their consumption prevents diet-related diseases such as diabetes and heart disease. About 50% of tribal members in Karuk Aboriginal Territory secure food by hunting, fishing or gathering; 40% reported climate and availability as barriers to acquiring sufficient healthy quantities.

Access to an intact natural environment and participation in one’s culture are widely

recognized as vital for psychological well-being. Cultivating, harvesting, processing, preserving and consuming traditional foods and medicines provide the framework for the Karuk eco-cultural socialization process and religious belief. These practices perpetuate Karuk traditional ecological knowledge and confirm Karuk occupancy on the land. Sharing food is a social obligation, and food related activities strengthen intergenerational relationships within families and the community. Such activities include the Pikyávish ("Fix the World") Ceremonies which are carried out to ensure abundant harvests and restore social and personal balance, and the First Salmon Ceremony, which invokes the spring salmon run.

Not only are ties to the natural world particularly strong for many Native people, but there are extensive disruptions of social, cultural and spiritual systems from ecological change and denied access to management. Karuk Tribal members have expressed grief, shame, stress and powerlessness from the loss of species, and from their inability to manage the ecosystem in accordance with their cultural practices and spiritual responsibilities. The cultural impacts of climate change are just the latest in a long thread of stressors affecting the mental and emotional health of the Karuk araráhih. Indigenous people in the U.S. already contend with the daunting task of processing centuries of historical trauma resulting from colonialism, a fact that has led to high rates of substance abuse, suicide, and violence within indigenous communities (Karuk Tribe, 2019). Many tribes and tribal organizations are turning to traditional healing practices to restore mental health and spiritual well-being to their communities.

Impacts on vegetation and wildlife

As described above, climate change is altering habitat conditions in Karuk territory. As a result, the biodiversity of ecosystems is threatened. The impacts of climate change are compounding those resulting from non-climate related stressors such as dams, fire suppression, and timber harvesting.

Karuk land management reflects a culture-centric perspective on vegetation zones, organized by elevation bands with different timing and purpose in relation to fire management: low elevation forest below the zone of smoke inversions; middle elevation forest within the zone of smoke inversions; and high elevation forest above the

elevational gradients in which smoke inversions occur. Additional habitat zones are riverine, riparian, grasslands and wet meadows. These seven habitat zones are experiencing climate change related impacts that include: changing patterns of precipitation, increasing temperatures, decreasing winter snow pack, changing fire behavior, increasing frequency of high severity fires, drought, and species invasions.

While different habitat zones face distinct threats in light of the changing climate, it is important to recognize their connections to one another. For example, wet meadows supply water to lower elevations where tanoak stands are critical winter foraging habitat for elk who are in turn needed to sustain wolf populations. Each habitat zone is influenced by fire regimes, which have been altered by fire exclusion practices. Fire regimes impact the tanoak stand dynamics of low elevation forests which help shape riparian and riverine habitats. Fire management has shaped the structure and composition of middle elevation forest zones and has been used to lower stream temperatures.

This section summarizes the impacts of climate change on vegetation and wildlife in the seven habitat zones, as described in the Karuk Climate Adaptation Plan. Certain plant and animal species of importance to the Tribe play vital roles as cultural indicators to guide appropriate human actions. Many species occur across multiple zones or move across zones seasonally. These 22 cultural indicator species are mentioned in the relevant habitat zone discussion in this section. The Appendix describes each species, organized by habitat zone. More details can be found in the Karuk Climate Adaptation Plan (Karuk, 2019).

Low elevation forests

The low elevation forest habitat lies below the elevational zone (roughly 500 to 3,000 feet) in which smoke inversions form within Karuk ancestral territory and homelands. This habitat zone is characterized by the presence of tanoak trees (xunyê’ep) and contains an abundance of other species of direct importance for Karuk food, fiber and medicine. Species in this zone are also important for their use as clothing, regalia, and implements, as well as for their role in shaping ecosystems and in informing where and when to burn. The cultural indicator species in this elevation zone are tanoak (xunyêep),

tanoak mushrooms (xáyviish), elk (íshyuux), huckleberry (púrith), pileated woodpecker (iktakatákaheen), and wolf (ikxâavnamich). The presence of these cultural indicator species – particularly plentiful tanoak mushrooms and abundant tanoak acorns – is an indicator of balanced ecosystem process and function.

Tanoak forests face primary climate threats from increasing temperatures, decreasing precipitation, lower soil moisture, increased frequency of high severity fires, and expanding forest pathogens such as *Phytophthora ramorum*, which causes sudden oak death (SOD). The SOD pathogen – which has destroyed millions of oak and other trees and caused twig and foliar diseases in other plant species across California since the 1990s – and other lethal invasive forest pathogens can increase fire danger in coming years.

The composition and overall stand structure of low elevation tanoak forests are the direct result of their long-term intensive management by Karuk people through the use of fire. Frequent fires have traditionally been used to limit the encroachment of competing shrubs and conifer species, providing the open structure that is important for many other species including madrone, white oak, princess pine, pileated woodpeckers and elk. Today, these low elevation forests have been significantly impacted by conifer encroachment, targeted herbicide treatment to reduce competition with conifer plantations, and the past 100 years of fire exclusion. In these stands, meadows are non-existent, conifers such as Douglas fir encroach upon oaks, huckleberries are highly dense but without berries, and elk are not present. Other non-climate stressors to tanoak forests include firefighting activities that can damage the tanoak's mycelium net, as well as salvage logging and associated road building following high severity fires.

In addition to the direct importance of this habitat zone to particular species, the stand dynamics and fire regimes of low elevation tanoak forests significantly shape riparian and riverine health.

Middle elevation forest

The middle elevation forest zone is characterized by the elevational band (roughly 2,500 to 4,500 feet) in which smoke inversions form. Species occurring within this cultural management zone are important for Karuk people as a food source and for use in

regalia. Pine roots and needles are used in basket making and are represented in ceremony as the tree of life. The cultural indicator species in this habitat zone are chinquapin (sunyíthih), black oak (xánthiip), pacific fisher (tatkunuhpíithvar), porcupine (kaschiip), and black tailed deer (púufich).

Middle elevation forests with black and other oaks, chinquapin, Douglas fir, hazel, and gooseberry would traditionally be burned every five to seven years. Federal fire management over the past century has led to declines in black oaks and other fire-dependent species and facilitated the growth of conifers, leading to the alteration of the structure and composition of this forest zone and making it vulnerable to high severity fires. A century of fire exclusion and a changing climate has impacted the practice of setting fires on Offield Mountain with the full moon in August as part of the World Renewal Ceremonies. This practice reduced the potential for high severity, high impact events, protecting the village sites below. August fires also cooled riverine systems at the peak of summer temperatures, triggering upstream salmonid migration and cooling the system for fish runs already in the river.

Changing patterns of precipitation and temperature, increased frequency of high severity fire, and species invasions, especially from forest pathogens such as the sudden oak death pathogen (*Phytophthora ramorum*), are climate-related threats for this habitat zone. Forest pest dynamics that appear to be driven or enhanced by climate change in the Klamath Region include the fir engraver beetles that are associated with Shasta Red Fir mortality and *Phytophthora ramorum*.

When it comes to restoration of cultural fire regimes, sites with the combination of huckleberry, chinquapin, and black oak are key sites for management. While sugar pine is often seen at higher elevations, it can occur in middle elevation zones. Sugar pine in this zone is a key indicator of cultural vegetation characteristics, denoting places for management. In ancestral practice, sugar pines were the most prized ignition source, especially because of their yield of pitch and needles. The presence of pines in specific landscapes shows human management. In many cases these remnant pine stands are located in areas central to landscape/resource specific ignition patterns (Tripp et al., 2017).

High elevation forest

High elevation forests occupy the zone above which smoke inversions form. It is also defined as forests above the chinquapin band and extending into the high country (defined elsewhere as montane and into the subalpine zone). Processes within this habitat zone are critically important to the health of other parts of the ecosystem. Like their lower elevation counterparts, the high elevation forests within Karuk ancestral territory and homelands are biologically rich and incredibly species diverse. Key Karuk foods and cultural use species in this zone include the sugar pine, gooseberry and beargrass (which especially occurs towards the coast where fog is present). The shrub form of chinquapin may be found at these elevations. Karuk cultural burning enhances species in the high elevation forest zone, making nutrients available in soils, releasing the seeds from sugar pine cones, stimulating growth and flowering of beargrass, and minimizing fuel loads to protect from high severity fires. Cultural burning at roughly five- to ten-year intervals across the landscape creates multiple gathering areas for beargrass.

The high country is key for Karuk cultural and spiritual activity. Especially during summer, families and individuals journey from lower elevation zones to harvest and process foods, materials and medicines, to hunt, fish, and pray. Karuk people have traditionally used fire to tend this habitat zone. Burning in these areas often occurs along trail networks, targeting meadow areas and patches of particular food and cultural use species such as huckleberry. Some foods, fibers and medicines of particular importance in this zone are wild onion, beargrass, huckleberry, princess pine, Oregon grape, and sugar pine. Much of Karuk high country is under wilderness designation, with fire suppression as a primary intervening stressor; logging is also a stressor.

High elevations forests are being impacted by changing patterns of precipitation and temperature, and the resulting changes in snowpack, soil moisture levels, and fire frequency and seasonality. While this forest zone benefits from regular low severity fire, high severity fires can, in the long term, convert the forest to brush fields. Species invasions and forest pathogens including White Pine Blister Rust and Port Orford Cedar Root Rot are also of concern. Using fire in high elevation forests is critical for getting back to historic fire regimes and an overall manageable, fire-safe system, particularly in

light of the increasing pressures from decreased snowpack, drought, and fungal pathogens.

Ironically many of the most culturally and spiritually important places throughout Karuk Territory have been the site of particularly intense alteration as a result of fire suppression. One example is the construction and operation of observation stations or “lookouts” to detect and report fires beginning in the 1920s. Some of these were constructed on tribal sacred sites used as prayer seats, thus affecting tribal land use practices, especially traditional setting of fires at culturally significant habitats. In other instances, the use of bulldozers to create fire lines has destroyed not only physical tribal artifacts, but also the vegetation mosaic of the ridge system which had served as an archive of land stewardship and part of cultural knowledge. The Tribe has lost the ability to learn from the ancestors and the land.

Wet meadows

Karuk ancestral territory and homelands contain a number of wet meadow systems scattered throughout the higher elevation forest and high country. The cultural indicator species for this zone is the leopard lily (Mahtáyiith).

Climate related drivers including changing patterns of precipitation, temperature, fire and species invasions are the dominant threats to these systems. Wet meadows are a highly threatened ecosystem with a severely reduced range due in particular to fire exclusion. In the absence of fire, the encroachment of conifers into wet meadows leads to a cycle in which the water table drops, the meadow dries up, and the drier soils become more conducive to Douglas fir and other hardwood trees that were formerly excluded by high soil moisture. Numerous wet meadows within Karuk ancestral territory and homelands are being lost through this process, especially at the middle to high elevations. Non-climate stressors to wet meadows include channelization from grazing, as well as the introduction of invasive species from grazers.

Wet meadows not only provide critical habitat for many species of importance – including bear, trailing blackberry, Mariposa and Panther lilies, wild turnip, and multiple kinds of Indian potatoes (e.g. *Brodiaea coronaria*) – they are critical for hydrologic, ecological and fire dynamics across the landscape, especially in lower elevations. Wet

meadows supply water and provide higher summer base flows and cold water to lower elevation riverine and riparian systems; for example, the Haypress meadow complex supplies cold water to the Wooley, Ti, Irving, Stanshaw, and Sandy Bar watersheds.

Riverine systems

Karuk ancestral territory and homelands encompass several hundred miles of riverine habitat along the middle portion of the Klamath River, the lower portion of the main stem Salmon River, and many key tributaries. Species from riverine systems hold significant cultural or spiritual significance and provide over 50% of the calories and protein of traditional Karuk diets. They are also important for food, culture and ceremonies. The cultural indicator species for the riverine zone are spring Chinook salmon (Ishyá'at) and Pacific lamprey (akraah).

Riverine systems are especially at risk due to changing patterns of precipitation, increasing temperatures, and decreasing winter snow pack. These changes directly impact stream flow and water temperatures. Elevated stream temperatures can cause fish mortality, support fish pathogens and diseases, and enhance the suitability of the habitat for non-native fishes.

Non-climate stressors that threaten riverine systems result from non-Tribal management actions, including: dams (such as Iron Gate) that trap sediment, block access to cold water habitats, and stop processes that shape habitat and cool water downstream; fire suppression, which has removed the cooling effect of smoke on river waters during critical periods for Chinook fall migration and spawning; and water quality impairments from agricultural inputs, fire retardants, logging activity and others.

Riparian systems

Riparian areas – lands along water courses and water bodies – are key sites for many food, fiber and medicinal species of importance to Karuk people.

Species from riparian systems serve as indicators of healthy systems; they signal when management steps, including burning, need to be taken. The riparian zone cultural indicators are the Pacific giant salamander (púfpuuf), aquatic garter snake (asápsuun), beaver (sahpihnîich), and yellow-breasted chat.

Riparian habitat is threatened by changing patterns of temperature, precipitation, fire behavior and species invasions. Prolonged drought, which reduce stream flows, may cause permanent streams to become intermittent; increasing temperatures may dry forest floors, thus reducing the area of moist refugia in the terrestrial riparian zone; more severe winter or spring rains may cause flooding events that increase siltation and alter aquatic riparian habitat structures; and warmer climates may increase the spread of diseases and increase the susceptibility of amphibians and other species to diseases. Aside from climate stressors, riparian systems are already threatened in the mid-Klamath area by dams, water diversions, species invasions, logging, roads and fire suppression. The health of riparian habitat zones is important for the functioning of riverine and forest systems.

Grasslands

Grasslands, also known as prairies or glades, historically occurred in mid to upper montane areas on ridges, in both large and small patches. Until about 1850, grasslands were so extensive they covered nearly one-fifth of California. Today a majority of the grasslands that once existed within Karuk Aboriginal Territory have disappeared due to lack of fire. Frequent burning is required to maintain the open prairie structure. Burning prevents conifer encroachment and enhances conditions for key food species, such as many of the species known as Indian potatoes (tayiith). The presence of Indian potatoes indicates where the Tribe traditionally burned and managed grasslands. Traditional Karuk knowledge about grasslands is still being recovered.

Grasslands have been historically significant for many species of broad-leaved herbs, native annual and perennial grasses, insects, birds, mammals, reptiles, and amphibians. Among these are important Karuk foods such as elk, as well as iris and other grasses used for twine, and Indian potatoes. Indian potato and bumblebees are the two cultural indicators for this habitat type.

With the changing climate, drought and species invasions are a particular concern in this habitat type. Probably the main non-climate stressor to grasslands comes from their severely reduced range due to fire exclusion and from the transport and spread of non-Native species. Grazing is another key intervening stressor for grassland systems.

Summary

Karuk araráhih have co-evolved with the mid-Klamath ecosystem and its diverse landscapes since time immemorial using multiple species of importance as cultural indicators for various traditional management practices. The Tribe has managed the landscape with controlled burning for countless generations, however the policy of fire suppression at the state and federal levels interrupted these practices and ultimately led to greater wildfire risk. The effects of fire suppression and other non-climate stressors – notably the construction of dams and logging – along with a changing climate, have altered habitat conditions and disrupted ecosystem process in Tribal territory. The Karuk Tribe and its Natural Resources Department are actively working to understand, adapt to, and mitigate the effects of climate change. As the landscape and cultural indicator species are impacted by the effects of that changing climate, the Karuk people will continue to adapt using the environmental stewardship knowledge collected over countless generations of Karuk araráhih to protect their landscape, resources, culture, and the health of their people.

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Suggested citation:

Karuk Tribe (2026). Impacts of Climate Change on the Karuk Tribe. In: OEHHA 2026 Indicators of Climate Change in California.

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Appendix. Karuk Cultural Indicator Species by Habitat Zone

For countless generations, Karuk people have observed the behavior of particular plants and animals to understand ecological dynamics, and as a guide for necessary human management. Cultural and ecological information is retained today in ceremonies, stories, collective memory and the land itself. Today, the Karuk Tribe is centering on the revitalization of 22 focal species, described below, as cultural indicators for human responsibilities and necessary human management actions in the face of climate change. The descriptions and images are taken from the Adaptation Plan.

Low elevation forest

Figure 6.4.A-1. Cultural Indicator Species in Low Elevation Forest Habitat



Source: Karuk Tribe (2016)

Xunyêep (Tanoak, *Lithocarpus densiflorus*) is an ecologically, culturally, and economically important species. Tanoak acorns (xuntápan), a staple food for Karuk

people, traditionally constituted a high percentage of the calories and protein of their diets. The roots of tanoak trees support the growth of another important food, tanoak mushrooms. Xunyêep is a key cultural indicator for when and where to use fire. There are specific times to burn in a tanoak stand to maximize the quality and abundance of the acorn yield, not only for people but other species including deer, elk and many birds.

The most critical environmental factor determining the fate of tanoaks is fire. Another factor is the spread of the sudden oak death pathogen, which increases in warmer and wetter environments.

Púrith (Evergreen Huckleberry or *Vaccinium ovatum*) is an important Karuk food source with many nutritional and health benefits. Púrith is a slow-growing, shade-tolerant understory shrub that is most abundant in forests with a higher level of canopy cover. Flower and berry production increases with light and soil moisture where forest gaps have been produced by moderate disturbance related to fire, timber harvest, or thinning. Infections by the sudden oak death pathogen (*Phytophthora ramorum*), while not lethal, produce lesions that reduce their suitability for tribal use. The infections may also prompt land managers to remove infected plants to protect tanoak stands. Warmer and wetter environments are likely associated with increased spread of the pathogen, and the lack of cultural fire appears to increase púrith's vulnerability to the disease.

Huckleberry is a cultural indicator for when and where to burn. Burn timing is indicated by the burn timing of tanoak acorn, which is in turn related to insect management. Emerging scientific studies indicate the presence of chinquapin may be a sign as to where one should burn for huckleberry. The Tribe defines púrith as a key cultural indicator of socio-ecological resilience of sustainable harvest and landscape management to ensure food security for both humans and animals that consume huckleberry.

Xáyviish (Tanoak Mushroom, *Tricholoma magnivelare*) is prized as a traditional food and medicine. It is also highly prized in the global market, making it vulnerable to overharvest by outsiders. In Northern California, xáyviish can be found scattered or growing in groups in well-drained soil or duff under tanoak, golden chinquapin, madrone, or pine trees with which it forms a mycorrhizal, symbiotic relationship. In

addition to rainfall, this mushroom requires low temperatures, and a pattern of warming and cooling. Tanoak mushrooms are connected to tanoak trees, elk, huckleberry, deer, wolf and chinquapin and other species in complex ways. The presence of plentiful tanoak mushrooms is an indicator of treatment success from the standpoint of soil impacts and host tree retention.

High-severity fires burn or destroy mycelial mats, preventing them from fruiting into harvestable mushrooms and compromising the survivability of the population. Xáyviish may struggle to repopulate areas if entire stands of host species have been destroyed by high severity fire. Additionally, the moisture and cool temperatures that xáyviish depend on may be less available in forests with repeated high-severity fire.

Xáyviish is threatened by logging machines, which have damaged or severed the mushroom's mycelium, and harvesting of the mushrooms for economic gain. This species serves as an important indicator of responsible human use. While Karuk tradition emphasizes reproductive success by picking mushrooms with at least 50% of the veil open to assure the release of spores, and allowing access by other species before human use, economic gain is maximized when the mushrooms are picked with their veils closed.

Iktakatákaheen (Pileated Woodpecker, *Hylatomus pileatus*) is seen as an ecosystem engineer that creates cavities that can then be used by up to 20 species of birds and mammals. It also promotes nutrient cycling in the forest through its excavations. The process of harvesting the species for regalia is intricately tied to land management. The largest woodpecker in North America, Iktakatákaheen typically resides in older deciduous or mixed deciduous-coniferous forests. High severity fires consume snags and logs used by pileated woodpeckers for nesting, roosting, and foraging, and reduce insect populations as well as nut and berry sources that are vital to the woodpecker diet.

Íshyuux (Roosevelt Elk or *Cervus occidentalis*) are important for their use as food, clothing (hides), regalia, and implements, as well as for their role in shaping ecosystems. The management of elk populations, and the protection and restoration of habitats that elk depend on are of vital importance to the Karuk Tribe. The reproductive needs for elk are an important cultural indicator for management. Íshyuux require a

mosaic landscape that combines open areas for foraging, and forested areas for cover. Much of the habitat for winter range and calving is now overgrown with mid-mature dense stands and plantations due to fire exclusion. Following a mixed (moderate to high) severity burn in a riparian area in 2015 (in the West Simms unit), elk moved in and started calving in it almost immediately. Differences were significant between the cultural prescribed fire and impacts of an adjacent wildfire.

Ikxâavnamich (Wolf, *Canis lupus*) once inhabited Karuk territory, but by the 1920's were decimated by Euro-American hunting, trapping and poisoning. It is likely to make a return to California as a result of federal protections. The wolf is important to Karuk tribal spiritual practices and ecosystem stability. Intricate relationships exist between wolves and other species in the low elevation forest zone, including elk, deer, tanoak, huckleberry, chinquapin and tanoak mushroom. Ikxâavnamich habitat tends to be more prey-dependent than land cover-dependent. In the West, wolves are known to follow large ungulate herds from their lowland wintering grounds to their upland pastures. Burns that destroy entire stands may force ungulates to seek new forested areas, straining the herd and thus affecting wolves' diets. Ikxâavnamich creates its own den in meadows near water, rock outcroppings, under tree roots, or even old beaver lodges. Wildfire could kill pups in the den or elsewhere. To succeed as a pack, wolves need large, remote areas free from much human disturbance.

Middle elevation forest

Figure 6.4.A-2. Cultural Indicator Species in Middle Elevation Forest Habitat



Source: Karuk Tribe (2016)

Tatkunuhpíithvar (Pacific Fisher, *Pekania pennant*) has experienced significant declines in Karuk territory. The fur of tatkunuhpíithvar is traditionally used in Karuk regalia. It is well represented in world renewal ceremonies as the quiver that carries the arrows used to wake up the world. Tatkunuhpíithvar represents the need for balance among dense and open habitats with large fire scarred growth hardwoods. It prefers hardwood forests with significant canopy cover, with large trees and snags where it converts large cavities into a den. The species is currently facing habitat losses due to habitat changes resulting from both climate and non-climate stressors: fire management, high severity fires, insects and pathogens, logging, and rodenticide poisoning from marijuana farms.

Sunyíthih (Chinquapin, *Castanopsis chrysophylla*) is an evergreen member of the beech family that can grow quite tall and live up to 500 years. Also known as a high elevation species, its presence at other elevations indicates places where one may want to treat for huckleberry. The nuts of sunyíthih are important to the Karuk traditional diet

and also provide food to many bird and mammal species. Sunyíthih is particularly competitive in dry, infertile sites. On sites with more moisture and fertile soil conditions, disturbance such as fire is necessary to preserve a chinquapin forest component. Rarely does chinquapin occur in pure stands. Sunyíthih provides important cover for birds and small to medium mammals. Fisher and martens may use them for their natal dens. Diseases and insects have little impact on giant chinquapin, although it is susceptible to heartwood-rotting fungi such as *Phellinus igniarius*; the filbert worm (*Melissopus latiferreanus*) may impact reproduction. Chinquapin has recently been identified as a host of sudden oak death pathogen.

Kaschiip (Porcupine, *Erethizon dorsatum*) are critical food sources for mountain lions and pacific fisher. Kaschiip's quills are used by Karuk people in basketry and regalia. Ideally the quills are harvested via non-lethal methods, and then the porcupine is re-released. Kaschiip has historically held important ecological roles as a species that maintains oak woodlands and reduces conifer encroachment. The Karuk Tribe aims to restore a healthy local porcupine population, which may in turn assist the recovery of other habitats and species (Karuk DNR, 2010). Weavers reported seeing many porcupines in black oak stands while gathering as late as the early 1970’s. Seeing a porcupine in Karuk Territory today is a very rare event. As a result of habitat loss, naturally low reproductive rates, and former Federal and state eradication programs to protect timber harvests, porcupines are now rare in much of California. The porcupine diet consists of herbaceous plants, twigs, and particularly in the winter, coniferous bark and needles. Fires can affect porcupine food sources and habitat, increase the chances of porcupine predation, and kill individuals who are unable to escape.

Xánthiip (Black oak, *Quercus kelloggii*) occurs in mixed-conifer forests as well as in mixed hardwood forests. In the highly diverse Klamath-Siskiyou area, black oak has many overstory plant associates. While tanoak acorns are the most prized among Karuk people, black oak acorns are also an important traditional food. Having various acorn sources in the forest ensures dietary diversity and resilience in the event of impacts to any one species.

Historically, black oak stands were ignited at a massive scale in February to promote

early spring greens and to protect the most susceptible slopes above the villages from excessive fuel accumulation in the summer months. California black oak appear highly adapted and may experience range expansion as a result of predicted increases in temperature and fire activity. High severity fires may destroy acorn bearing stands of black oak that are culturally vital. There is some speculation that increasing temperatures could influence acorn production. Sudden oak death (*Phytophthora ramorum*) is a major climate stressor for this species and is already impacting black oak in coastal regions.

Púufich (Black Tailed Deer, *Odocoileus hemionus*) is among the most important traditional Karuk foods and sources of utilitarian and ceremonial items. In 2005, over 65% of Karuk households reported hunting púufich for food. The meat, sinew, bones, hide/skin, fur, antler, and hooves have been used extensively for traditional functions. The Deerskin Dance, which is part of Karuk World Renewal Ceremonies, depicts how burning for deer relates to salmon migration and woodpecker habitat and other connections. Deer health and abundance, as well as their movement and habitat selection across the landscape are indicators of appropriate fire management activities. Karuk management of this species includes the use of fire to promote rotational grazing and to draw them away from freshly sprouting basket materials. Tribal management also pays closer attention to allowing for opportunities for reproduction and promoting genetic mixing.

Smaller patches of high severity fire that maintain more open shrub, fern, forb, and grasses promote higher quality forage and dispersal for deer. By contrast, high severity, large-scale fire may burn a significant portion of black-tailed deer's home range and reduce cover from predators. Oak groves burned by such fires can reduce deer diets rich in acorns. Existing stressors include agricultural expansion, habitat loss, disturbance of migration, fire suppression, and barriers (such as fencing, roads and reservoirs). Warming temperatures can affect the availability of food sources and alter patterns of seasonal migration. Delayed autumn migrations may leave púufich at greater risk of sudden winter storms and predation. Warming temperatures and increased humidity may increase spread of parasites and bacteria to which púufich are vulnerable.

High elevation forest

Figure 6.4.A-3. Cultural Indicator Species in High Elevation Forest Habitat



Source: Karuk Tribe (2016)

Ússip (Sugar pine, *Pinus lambertiana*) occurs in mixed-conifer forests. In Karuk country, it is of particular value when occurring within or adjacent to tanoak or black oak stands. It reproduces via large, heavy seeds held within cones. It can take sugar pines around 150 years to become good cone producers. The seeds are not highly mobile, and unless moved by animals do not stray far from the parent tree. Sugar pine is often viewed as a high elevation species, but when found at other elevations, it serves as an indicator of specific management actions. It is used by Karuk people for ceremonial and subsistence purposes. The snags possess high quality “black pitch” which is not only a traditional form of money but is also utilized in the ignition of cultural burns. Sugar pine groves were family owned and managed for nuts (food), pitch (medicine), and roots (basketry).

The presence of sugar pine is a notable indicator of past fire management actions and may be associated with other culturally relevant information or activity. Ússip are often found in strategic places on ridges where they would have been managed to serve as ignition sources. Today it is rare to find an open grown sugar pine tree that is accessible for nut collection. Trees grown in the open develop differently than woodland grown trees, typically developing full crowns and a wide branch structure with large limbs

growing from further lower on the trunk. As a future indication of landscape scale fire regime restoration, pine trees with large branches less than 15 feet from the ground and adequate limbs to climb from there will be important.

Decreased snowpack, earlier spring snowmelt and warmer temperatures threaten the health of sugar pines directly or make them susceptible to beetle infestations and fungal pathogens. High severity fires can not only decimate individuals and stand but also limit seed dispersal and establishment in burn areas.

Panyúrar (Beargrass, *Xerophyllum tenax*) is a perennial, subalpine herb that inhabits upper slopes, often near or beneath coniferous forests. Beargrass flower stalks are browsed by ungulates such as deer and elk. It is an important plant species for Karuk basket weavers and regalia makers. Blades are considered best for basket weaving the first year after a fire. Panyúrar is traditionally burned every three to seven years, especially in the fall following World Renewal Ceremonies when people bring fire down from the high country. Burning for panyúrar is part of landscape dynamics, and necessary for returning fire intervals across the larger landscape. Along with other important cultural species including hazel, panyúrar grows back particularly strongly after low to medium intensity fire. A combination of frequently burned beargrass and filtered light through a moderately dense canopy maintains an open understory free of brush and other materials typical of fueling large wildfires. The conditions this type of burning maintains can also promote species like salal and saddler oak which are important for gathering and browse for large ungulates. Burning too hot can make basketry materials brittle. High severity fires can burn duff into soil deep enough to destroy beargrass rhizomes; damage to forest duff from very hot fires can delay or prevent the re-establishment of beargrass.

Wet meadows

Figure 6.4.A-4. Cultural Indicator Species in Wet Meadow Habitat



Source: Karuk Tribe (2016)

Mahtáyiith (Leopard Lily, *Lilium pardalinum* ssp. *Wigginsii*) is the cultural indicator for wet meadows. Mahtáyiith is among the most prized bulbs in the Karuk diet. It is dug in the fall and is traditionally cooked in an earth oven like many other bulbs. In the Klamath Mountains, leopard lily is found in high country wet meadows, especially on serpentine soils. This rare and endangered herb grows from bulbs that are small and often clustered and typically blooms in July. Fire of varying intensities removes competing shrub and tree vegetation which would promote lily flowering.

Riverine systems

Figure 6.4.A-5. Cultural Indicator Species in Riverine Habitat



Source: Karuk Tribe (2016)

Akraah (Pacific lamprey or eel; *Lampetra tridentata*) are related to humans as a food source, related to fire cycles for their well-being, and related to bears and birds upslope by virtue of taking nutrients back up the hill to feed plant life, similar to salmon. They have a long life cycle in which adults live in the ocean and return to freshwater to spawn. The larvae reside and filter feed in silty or sandy substrates for up to seven years before migrating to the ocean. Adult Pacific lamprey follow the scent of pheromones released by juvenile lamprey (ammocetes), not necessarily returning to their natal river systems. This highlights the importance of ammocete habitat in the Klamath, which depends on sediment deposition and fire processes to create favorable conditions. The Scott River, the largest source of fine sediment to the main stem Klamath above the Trinity River, is a snow pack driven river system that is threatened by climate change. Furthermore, Iron Gate Dam has cut off the sediment supply to the upper Klamath River.

Ishyá'at (spring Chinook salmon, *Oncorhynchus tshawytscha*) is a key cultural indicator sensitive to stream temperatures. Their presence is an indicator of both riverine and forest habitat quality. Fresh, cool water temperatures are critical to Ishyá'at, as are spring to early summer high water flows they need to reach summer holding areas, to access spawning grounds, and to reproduce. Climate change and changing weather patterns such as drought cycles and high severity storm events have had direct

implications on the species. On the Klamath, "spring creeks" that originate in volcanic terrain are perfect for production of juvenile salmon because of their stable flows and cold water temperatures year-round. However, nearly all spring creeks on both the Klamath and Shasta are locked up behind dams.

Riparian systems

Figure 6.4.A-6. Cultural Indicator Species in Riparian Habitat



Source: Karuk Tribe (2016)

Púfpuuf (Pacific Giant Salamander, *Dicamptodon tenebrosus*), while not a Karuk food source, is central to Karuk culture. They are a keeper of water that is critical to life. In Karuk beliefs, púfpuuf is a spiritual being who transformed into a salamander to monitor spring and creek water quality and quantity. Their presence is indicative of a healthy riparian and aquatic fresh water ecosystem. Púfpuuf is perhaps the most important cultural indicator for identifying the need for emergency management actions. Karuk traditional practitioners report that if púfpuuf is in peril, we are on the verge of system collapse, and the immediate application of fire is recommended to lower acutely high air and water temperatures.

Asápsuun (Aquatic Garter Snake, *Thamnophis atratus*) is a cultural indicator of healthy aquatic and riparian systems. As fire regimes are restored in Orleans and the Black Mountain area, paying attention to this species may become more important. Asápsuun is an aquatic snake that uses water for both foraging and protection. In Karuk

territory, people have reported seeing fewer and fewer "water snakes," a fact that they attribute in part to the impact of fire suppression on aquatic systems. With climate change, increased temperatures may dry forest floors and reduce moist refugia for this species in terrestrial habitats.

Sahpihnîich (Beaver, *Castor canadensis*) alters ecosystems in ways that benefit other species. Karuk people value beaver as a teacher of how to intervene in natural processes for the greater good. Sahpihnîich is considered nearly locally extirpated and in need of reintroduction. Habitat destruction and degradation, and a lack of riparian vegetation (their food sources) are climate change-related threats to the species. Restoring historic fire regimes will benefit sahpihnîich by promoting the growth of riparian vegetation and reducing the threat of high severity fires. Sahpihnîich can play a role in drought mitigation by storing water and maintaining areas of open water. Their dams can moderate stream temperatures, reduce peak flows in flooding events, create complex aquatic habitats for many other species, trap suspended sediment, and restore incised streams to more complex channel and ponds systems.

Yellow-Breasted Chat (*Icteria virens*) is a migratory bird that nests in the spring. In Karuk stories, it is welcomed as the true harbinger of spring. Karuk culture says the chat is tied to the responsibility of humans to realize that something has to be done about fire. The return of the chat and other birds to nest is a signal to stop burning. Chats are numerous in Northwestern California, with the highest densities found along the Klamath and Trinity Rivers. The chat depends on riparian areas, especially sandbars, with willow trees. It nests in dense thickets and uses larger trees as singing perches. A return of cultural burning at proper intervals will maintain riparian willow and cottonwood habitats. Maintaining riparian floodplain habitat by discouraging channelization of streams will also benefit chat. Chat may also be susceptible to changing wind conditions along migration routes to and from the tropics. The yellow feathers of its breast have traditionally been a part of tribal regalia.

Grasslands

Figure 6.4.A-7. Cultural Indicator Species in Grassland Habitat



Source: Karuk Tribe (2016)

Tayiith refer to a variety of geophytes (including *Brodiaea* spp., *Dichelostemma* spp., *Triteleia* spp., *Calochortus* spp., *Lilium* spp., and *Fritillaria* spp.) commonly called Indian potatoes. The Karuk people harvest their bulbs and tubers for consumption. *Brodiaea coronaria* serves as a good indicator for other Indian potato species, as it tracks soil moisture. Indian potatoes grow in prairies and meadows in a variety of settings. Historically, species of Indian potato grew thick as grass in certain valleys in California. Karuk and other Native Californians know proper harvesting techniques that further proliferate these species by promoting bulblet production. As with many prairie and meadow species, Indian potatoes have experienced declines as a result of land cover change, fire suppression, and a reduction in the ability of indigenous peoples to steward the landscape. Burn timing in regard to this species needs to be refined to account for harvest timing and invasive species.

Bumblebees (*Bombus* and other genera) are important within grassland habitats in Karuk Aboriginal Territory. While bees require grassland habitat which is fire dependent, the specific relationships between bees and fire is less well understood. Loss and fragmentation of grassland habitat, as well as grazing, reduce nesting and foraging habitat quality for bees This is a species for which more traditional knowledge and

scientific attention will be beneficial in the changing climate.

6.5 Impacts of Climate Change on the Mono Lake Kootzaduka'a Tribe of California and Nevada

Changes in air temperature, drought, and hydrology have impacted Mono Lake, the Kootzaduka'a homelands (*Kootzagwae)*, plants, animals, and the health of the Kootzaduka'a.

This document is written by Dean Tonenna, Tribal Elder of the Mono Lake Kootzaduka'a Tribe of California and Nevada and is based on his observations of climate change in Kootzagwae.

The Mono Lake Kootzaduka'a Tribe of California and Nevada have resided in the Mono Lake–Yosemite region since time immemorial. The Kootzaduka'a Tribe's homelands are based around Mono Lake and extend north to Bodie Hills, south to the Mono Divide, east into western Nevada, and west into the Yosemite region. The Tribe has worked towards federal recognition since the mid-1970s and continues efforts to obtain land in the Mono Lake area.

Mono Lake is the heartland of their territory and the islands in the Lake are their place of origin. This saline, terminal Lake is the physical, cultural, and spiritual center of the Kootzaduka'a. Mono Lake and the natural resources within are important resources for the Kootzaduka'a. Alkali flies (*Ephydra hians)* and both residential and migratory birds inhabit the Lake and surrounding areas and have long served as important food sources for the Kootzaduka'a. The Kootzaduka'a name means "The ones who eat kootzabe". Kootzabe is the pupa of the alkali fly, an important, nutritious, protein-rich, and clean food source for the Tribe. The Kootzaduka'a also use Lake water for healing and cleaning.

The Los Angeles Department of Water and Power began diverting water from the tributary streams of Mono Lake in the early 1940s. Water diversions have caused several environmental issues and made the region more vulnerable to the effects of

climate change. Mono Lake has experienced lower water levels, exposed dry lakebed, increased salinity, and higher water temperature.

Figure 6.5.1. Exposed *Kootzabbaa* (Mono Lake) Lakebed and Loss of Habitat for the *Kootzabe* at Black Point.



Photo by Dean Tonenna

Lower Lake levels leave dry lakebed exposed, posing a health hazard to the Kootzaduka'a (**Figure 6.5.1**). Particulate matter in dust picked up from the dry lakebed by wind can cause respiratory issues and aggravate certain respiratory conditions. The windiest days have the most potential for dangerous air quality, yet they are the most favorable days to harvest kootzabe. Tribal members are increasingly faced with a conflict: protecting their physical health or preserving their spiritual and cultural practices.

Lower Lake levels impact alkali fly and bird habitats and populations. Shallow-water tufa towers (mineral formations) are used by the alkali fly throughout their life cycle. More tufas are now out of water, reducing egg-laying sites and drying areas used for harvesting and processing kootzabe. Falling water levels have also created land bridges to bird nesting islands, increasing their vulnerability to predators. Severe droughts and

water exports have increased Lake water salinity, which has impacted the productivity of alkali flies by slowing growth, reducing body size, and decreasing survival. This reduces the food supply for birds that rely on the Lake as a seasonal and year-round habitat. The increased salinity also poses a hazard to human health, as Lake water has been traditionally used as medicine and is now unsafe for consumption and contact.

Warmer air temperatures and increasingly extreme swings between wet and dry conditions affect every aspect of the Tribe. Having limited access to cooling centers, Tribal members report that recent heat in the Mono Basin is unlike anything they've experienced before. At the same time, intensified wet–dry swings and more variable snowpack and snowmelt runoff make it harder for the Tribe and ecosystem to adapt. Prolonged droughts and hotter conditions contribute to depleted groundwater, stressed plants and wildlife, larger wildfires, and low water levels at Mono Lake.

Pinyon pine trees are a culturally significant resource affected by drought. Drought hinders sap production and thus their defense against pests like bark beetles. The Kootzaduka'a use sap for medicine and Pinyon nuts, an important food for the Tribe, are smaller and not as plentiful.

Tribal members have a harder time coping with more frequent and intense wildfires and wildfire smoke (**Figure 6.5.2**). Their homes are very susceptible to damage in moderate fire conditions and do a poor job keeping wildfire smoke out. Tribal members cannot escape the smoke and its health hazards by staying inside, and it can be difficult to travel somewhere else for relief. There is also generally no infrastructure to help efficiently fight fires and brush engines must be used in these areas. High intensity wildfires can also destroy native plant communities that the Tribe uses for food, medicine, and for other cultural practices.

The Mono Lake Kootzaduka'a Tribe relies upon their homeland and the environments contained therein to satisfy their physical, spiritual, and cultural health across generations. Climate change impacts on the totality of the environment in the region affect the direct connection between the Tribe, the plants, the animals, Mono Lake, and the whole environment itself.

Figure 6.5.2. Wildfire Smoke Traveling South to *Kootzagwae.*



Photo by Dean Tonenna

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6.6 Impacts of Climate Change on the Nevada City Rancheria Nisenan Tribe

The Nevada City Rancheria Nisenan Tribe faces increasingly severe drought and wildfire, and the degradation of important habitats, sources of water, food, material and medicine. They see an overlap in the consequences of climate change, colonization, genocide, and hydraulic mining in their region.

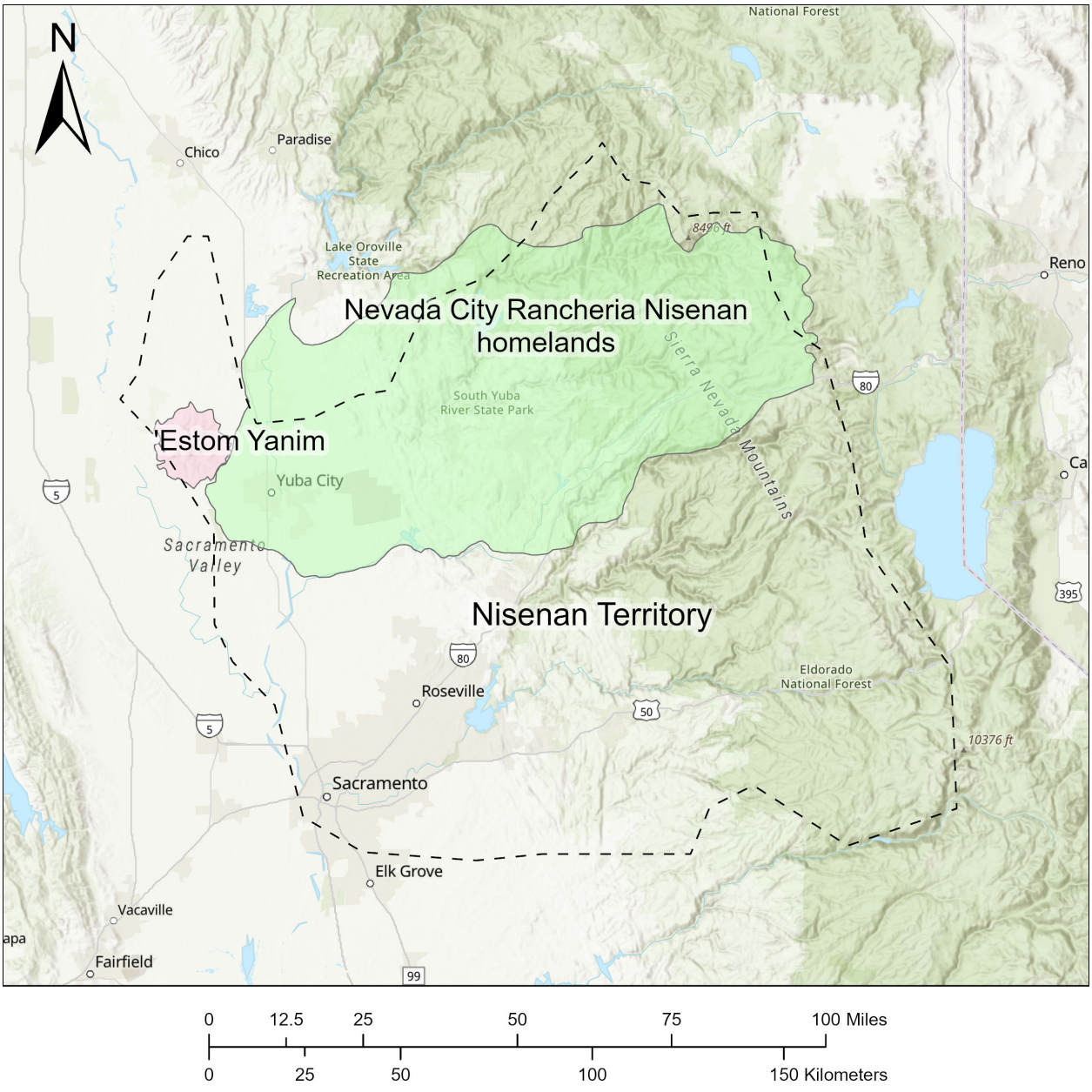
Background

The Nevada City Rancheria Nisenan have lived in their Ancestral Homelands, situated in Northern California, since time immemorial. The southern boundary of the territory begins below the Cosumnes River. From there, it runs east to Kyburz and includes both banks of the Sacramento River to the west. From Kyburz, the boundary winds its way north to Gold Lake then west along ridges and canyons to the south fork of the Feather River. From there, it moves southwest to the Sacred Mountain, 'Estom Yanim (Marysville Buttes) and finally, finds its way back down the Sacramento River (**Figure 6.6.1**).

In the past, Nisenan lived in towns made up of extended family groups of different sizes and led by a Huk (Headman) or Mayan (Headwoman). Like many other tribes throughout the United States, the Nisenan have been misidentified and mislabeled. The Nisenan have been lumped together under inaccurate labels such as "Maidu", "digger" and "southern Maidu". However, the Nisenan are a separate Tribe with their own Cultural lifeways, their own leaders and holy people, a distinct geographic territory and their own ancient and unique language.

Within the greater Nisenan territory are diverse groups speaking their own dialect, bound within their own geographies and unique Cultural identities. The Nisenan people who today identify with the Nevada City Rancheria come from two language "districts" that encompass a territory with a vast east to west orientation. Beginning on the valley floor and moving up the foothills in elevation, the Tribe took advantage of the abundant landscape and ecological diversity.

Figure 6.6.1. Nisenan Homelands.



Source: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community (2025)

The California Gold Rush caused environmental and social devastation to the Nisenan people and homelands, the effects of which persist to this day. Prior to 1849, the population of Nisenan residing in the area was very conservatively estimated to be

around 7,000 people (Johnson, 2018). Natural resources, such as elk, deer, salmon, trout, freshwater eel, acorns, grass seeds, edible bulbs and roots, mushrooms, fruit, basketry materials, and wood were abundant enough that the Nisenan people were able to support a society of up to 20,000. By 1867, the population was estimated at less than 500. Miners and settlers devastated the people, the animals, and the land in a very short amount of time.

Nevada City Rancheria was the name of the Federally Recognized Nisenan Reservation located just outside of Nevada City on Cement Hill. In 1964, the Reservation and the Tribe were wrongfully terminated. The Nevada City Rancheria Nisenan are working to have their Federal Recognition restored.

Climate change and the Nevada City Rancheria Nisenan

The Nevada City Rancheria Nisenan have lived through great changes in the environment before. Through stories that have been passed down through generations about the land, the animals, and the best way to be in relationship with the world around them, the Nisenan have always stewarded the land and cared for it and it has cared for them in return. They have survived through periods of extreme heat, extreme cold, and near-starvation.

While the Tribe believes that what they are seeing today in their Homelands is unprecedented and concerning, they feel that using the phrase “climate change” glosses over what is truly happening. They feel it is more accurate that globally, and as evidenced locally, extraction of minerals and other materials for a profit, damming of rivers, removal of large mammals and other key species, and removal of tribes that stewarded the land are the direct and ongoing causes of large-scale environmental change. The Tribe has observed direct harm brought upon the land and local Indigenous people during the California gold rush and in the 124 years since then. They note that conservation groups and Western scientists frequently choose one species or topic to focus on instead of addressing the broad trend: environmental destruction for economic profit is causing cascading harm.

The Tribe feels it is most accurate to address the changes holistically, using narratives which draw from thousands of years of relationship with the land. The following

perspective is shared by Tribal Spokesperson and Council Member, Shelly Covert, and reflects lived experiences across generations.

I'm seeing with my own eyes the moment we are all in. It's profound for me. There is what's obvious: as I walk outside on the asphalt, seeing dead friends [roadkill animals] *on the side of the road. Seeing the runoff going into the streams. Where there used to be a coyote den and now there's not. If you haven't been here long enough to see the change, you don't know how it used to be and how much has been lost. If you don't know, then how can you care? You don't see the heavy foot of mankind on nature. We just impacted our food source for three seasons by ruining the place where the deer used to graze and now they've gone somewhere else, far away. There are reactions for every action, and you only need to spend a little time in nature to know that and to see what we've done.*

I sit in a unique position to have heard so many stories from my Ancestors about when they were little, and the stories that they heard from their Ancestors. But I don't even have to go that far back – the change is already visible just from my own childhood to today, and I'm not that old. We used to live to be over 100 years old; think about how useful that was, to have five or six generations alive at the same time, sharing their knowledge. Old Betsy on the reservation lived to be 112 years old, and another Ancestor lived to be 124. If 18 was the median age for having a baby, then they could have had seven generations alive at one time. I can barely fathom that. More recently, we did briefly have five generations when grandma was still alive and there was a baby born—but imagine having seven generations alive to pass down stories. The different generations were all living in the same household and sharing wisdom. We don't do that anymore. How far we are from living in one place and taking care of it, understanding it and passing that knowledge on. Without that tradition, what are the backdoor ways we could get people to learn these stories and promote the Earth? Without that in place, living together and passing it on, I don't know the pathways back.

The biggest thing missing for me is that care and respect for the Earth. It's like grandpa used to say, "if you're doing something and it hurts someone else, don't do it." If you're using a resource and that is causing harm, don't use it. At the core of the conversation,

it is important to be as basic, as non-scientific as we can be. It is hotter now than before: what happened? We cut down all the big trees that were the engine for our clean air and water. We paved all the surfaces; we made things hotter with our pavement. We dumped chemical pollutants into our air and water and soil. We killed all the grizzlies who were here first, whose digging helped bring the water. There used to be so many more flocks of birds – those flocks are gone. There are so many factors that people can't see. We need to be using laymen's terms so that people can hear it, see it, feel it, and care. It's not caring if a driveway goes through a meadow because you think that driveway needs to be in a straight line. That meadow serves an important purpose and has been there forever. Go around it. It's ignorance, putting modern life on top of a planet that we don't understand and don't have a connection to anymore.

The Tribe, being poor and oppressed, ends up living in the most highly impacted places, at ground zero of climate change. Where the mountains were blown away for hard rock mining, where the forests were clear cut, the riverbeds blasted, the diggins: who's going to live there? The Tribe. Climate change is a long football throw and the Tribe was there at the start of the throw. If you're unfortunate enough to live where there is gold, or diamonds, or anything of value that they are going to extract, those tribes living there are going to experience it the worst. If you fell and lost the function of a lung, you are never going to be the same for the rest of your life. Everywhere that tribes have experienced resource extraction, it is like we have lost an organ, but we stay. We continue to live. We can't get up and run. After living through genocide, through environmental genocide, the people tend to stay in that spot.

The rest of the world is feeling the way, way long aftereffect of climate change. The genocide, the clearcutting, the original pollution of the environment is the source of climate change. When they do it, they think, "no one's gonna know about it, no one's gonna feel this." It is always going to be this way unless we can put our two ends together. I really believe we can have our cake and eat it too if we can get back to the laymen's way of caring for the Earth and each other, if we develop smartly. It's the genocide and deep environmental destruction. We can put bandaids on things but that's not fixing the problem. It's only going to get worse the more people are on the planet doing these things.

Modern privileges are at the tips of my fingers. I still engage in it every day. I'm not being judgmental. We don't have easy answers until we have constant reminders and things that we can do about it every single day. I get it, but I'm still participating in that cycle of the long throw. I'm helping to keep the ball aloft, just like we all are. We need think tanks, a catchy jingle, slogans, we need the equivalent of marketing teams.

I know we are brilliant enough to have our cake and eat it too. I have a dear friend who spends her whole life trying to have less impact, carpooling, making sustainable decisions; but if we all started taking shorter showers, that still wouldn't make the difference that we need. Huge corporations pulling water are the ones who need to change. The big players can make small changes and they will have a huge impact. It probably will take the laypeople questioning, demanding change, and working with the corporations and the scientists to neutralize this topic so that it is not so divisive. We need to take politics out of it. Stop fighting about it and ask what we can all give up a little bit. Put caps on corporate greed. The Tribe finally has some platform and voice, and we have to say something of value.

The sustainable economic resources that we had here, like the buffalo in the middle of the country, don't exist anymore in a truly sustainable way. Those resources from Creator would always be there for the tribes; people would always be there. We used to have such abundant elk, deer, salmon and fresh water. Now, there is not a single stream or river that you can drink from freely. They are all polluted with something. Bad air coming from the Central Valley and the cities tends to pocket over our foothill location. During the gold rush, if you got tuberculosis but you were rich, you could move to a different climate. Now, people can move to a place without climate impacts if they have enough resources. The resources that were extracted – gold and other minerals – those were all removed and sent elsewhere. But what is the cost of everything that they destroyed? We were to have the salmon here forever. Now that that is gone, and the planet has been overheated and everything has been extracted, the Nisenan are left here living on diggins and tailings piles. Most folks are getting their water from wells. Who knows what toxins are in your water, in the soil your kids are riding their bikes on. We have to go to the store to buy food and meat. There are no other options anymore. We have bad air quality because the big trees are all gone and the forests were not

managed. It is an ecological mess.

All of this has a dollar amount for mitigation. What would be our dollar amount for the air, water, soil, elk, and fish? When I was learning about tribal monitoring… and this is very difficult to talk about… I learned that there is even a dollar amount for our bodies. If there was a body found in a burial ground, and they wanted to put their highway over that burial ground, there was a dollar amount for each body that would be offered to the Tribe to move it. The modern understanding is that we need roads; but at what cost? If we could collectively go back in time and look at the impact of all those resources being gone, if we developed a formula to figure out the cost of what was lost over all those years, it would be staggering. It was important to them to get the gold. It was funneled out of the area and the people were left behind to deal with the environmental destruction and the atrocities that were enacted, the shattering of people with violence and sexual assault. How would we frame that question? What resources were taken and what kind of economy would we have today if we still had them? What has been the collective loss from tribal economies, and how much would it cost if we wanted to re-establish them?

This area used to have a lot of ring-tailed cats. I once saw a traditional cloak of a Nisenan Headman, and it was made of dozens and dozens of ring tails. There were enough to make a cloak out of them. They were abundant. I have never seen one. Back in the day, Tribal members were always collecting porcupine quills. My mom used to stop and look. She'd ask people, have you seen any porcupines? No one has. Have you seen any opossums? The speed of the change is multiplying.

We do have that memory.

Climatic indicators

The Tribe continues to be affected by the consequences of genocide and colonization on their people and their land to this day. In this context, the Tribe does not prefer the term "climate change" to describe changes observed in the local environment, as the term can shift the focus away from the primary causes of harm and destruction. The Tribe also does not prefer to isolate environmental data from their cultural and historical understanding of their Homelands. However, for the purposes of building bridges

between different perspectives, or as it is put above, “putting our ends together,” this report includes a few datasets illustrating changes in the physical system which relate to the Tribe’s experience to support a more holistic narrative. In addition to the topics included in the sub-sections that follow, there were others the Tribe wished to include to illustrate direct, local causes and effects, but which could not be found, including: the total acreage of forest cleared; the amount of water removed from the watershed by pumping or diversions; the change in fish populations due to dams, diversions, logging and mining; the total value of resources extracted from their Homelands; total length of barbed wire, fencing, and other constructed partitioning of landscapes and the impacts thereof; and the cumulative impact of the many holes dug by miners, from small to large, and movement of earthen materials in piles of all sizes across the landscape. Their hope is that through telling their story, western researchers are encouraged to expand the scope of their questioning and ways of seeing, and that additional datasets and topics will be explored and become available in the future.

For the following subsections, connections are drawn between individual datasets and the Nevada City Rancheria (NCR) Nisenan Tribe’s experience more broadly. These examples are not exhaustive and may not represent causality but rather serve to illustrate relationships and patterns observed across time.

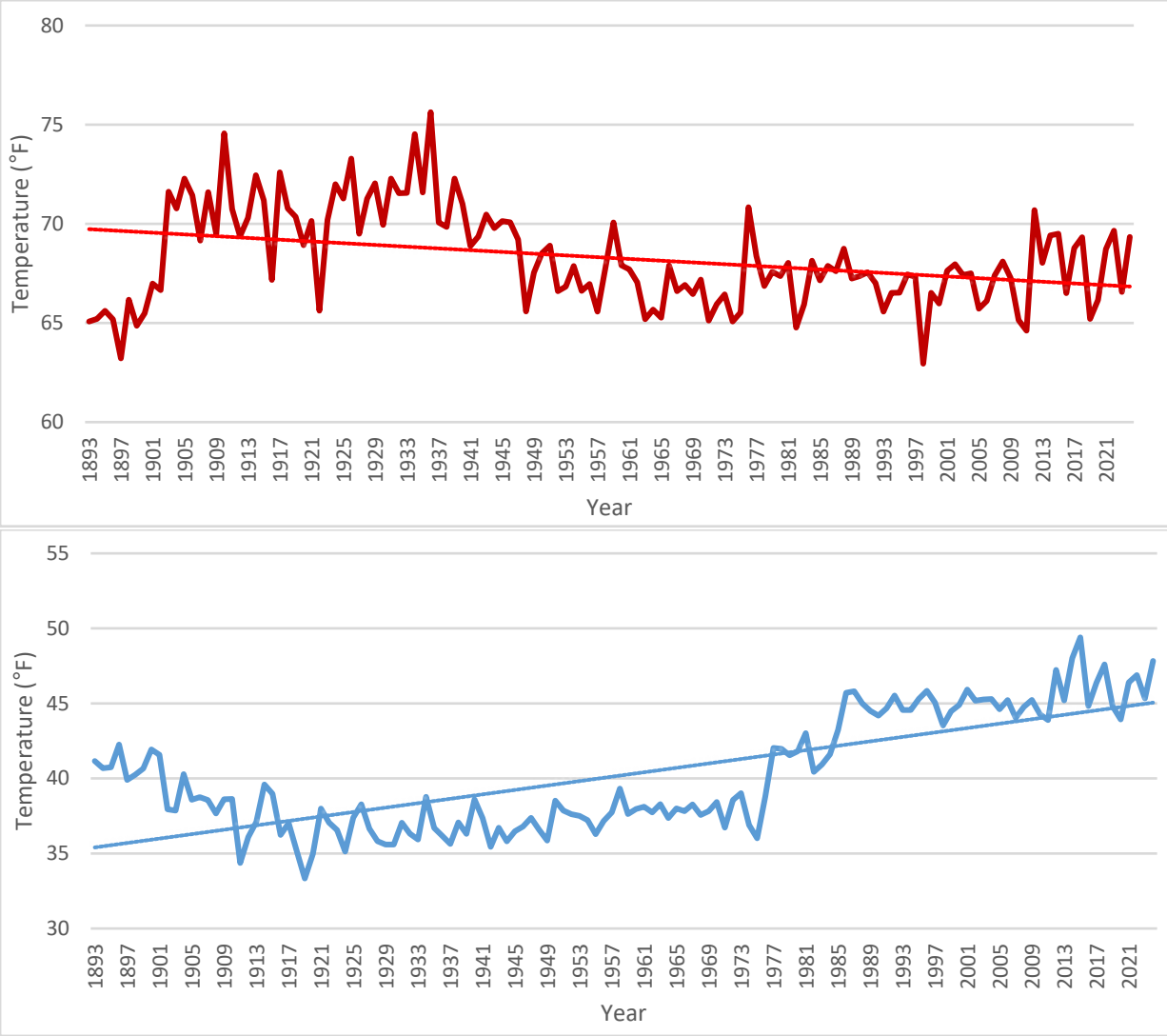
Air temperatures

Annual average temperatures from a weather station located on Gracie Road in Nevada City, a few miles from where the former Rancheria was located, were retrieved for the period from 1893 to 2024. **Figure 6.6.2**, below, shows annual average maximum (daytime) temperatures on the top graph and annual average minimum (nighttime) temperatures on the bottom graph, along with a dotted trendline for each. Daytime temperatures have decreased by 0.2 degrees Fahrenheit (°F) or 0.1 degrees Celsius (°C) per decade. Nighttime temperatures have increased by 0.7°F (0.4°C) per decade.

Nighttime warming may be associated with additional stress on plants, animals, and humans, especially during hotter periods of time when they cannot cool down sufficiently. It may present an additional threat to the health of elders and Tribal members who don’t have air conditioning, especially during heat waves or smoke days.

It may also contribute to factors such as drought and wildfire through increased evaporation and decreased persistence of snowmelt and streamflows during the dry season.

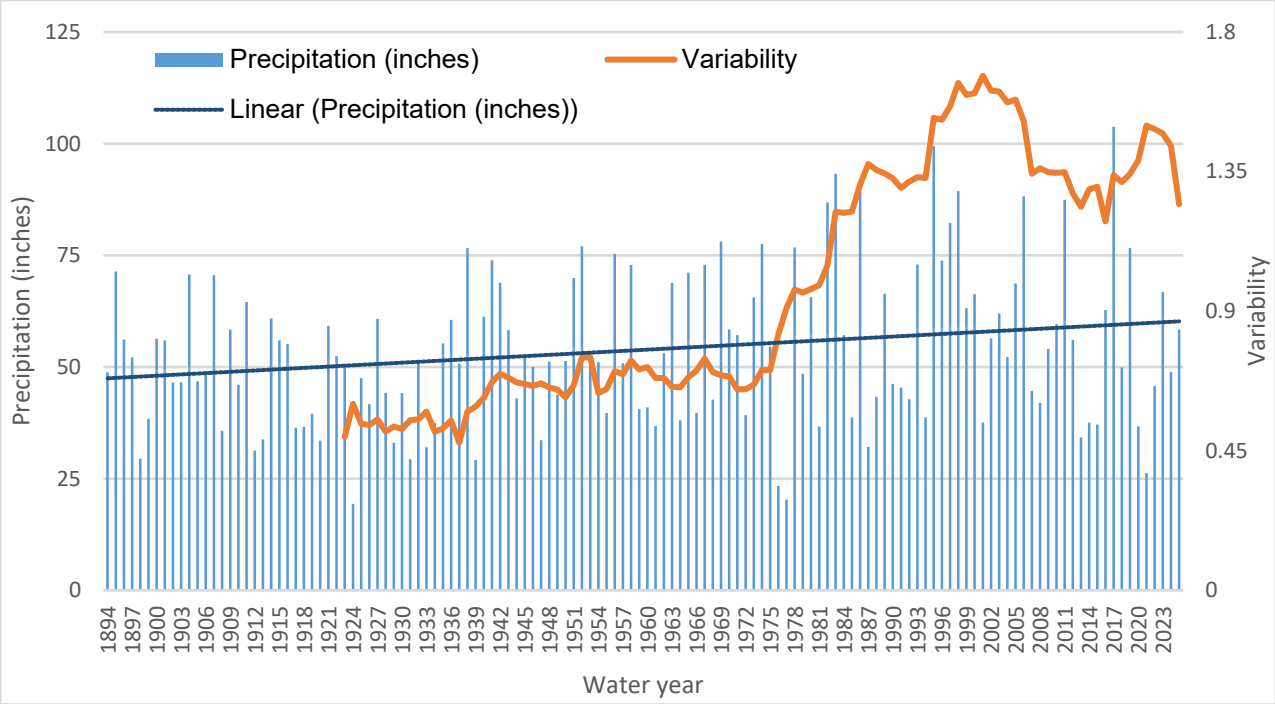
Figure 6.6.2. Daytime (Top) and Nighttime (Bottom) Temperatures in Nevada City from 1893 to 2024.



The dotted lines are the linear trend. Source: SCENIC (2025)

Precipitation

Figure 6.6.3. Precipitation in Nevada City from 1894 to 2024.



Blue bars represent precipitation (inches) for each water year (October 1st of the previous year through September 30th of the nominal year). The dotted blue line is the linear trend over time. The orange line shows precipitation variability: a ratio of 30-year variance divided by the total record variance. Values greater than 1 represent more fluctuation in rainfall totals, while values less than 1 represent more consistency. Source: SCENIC (2025)

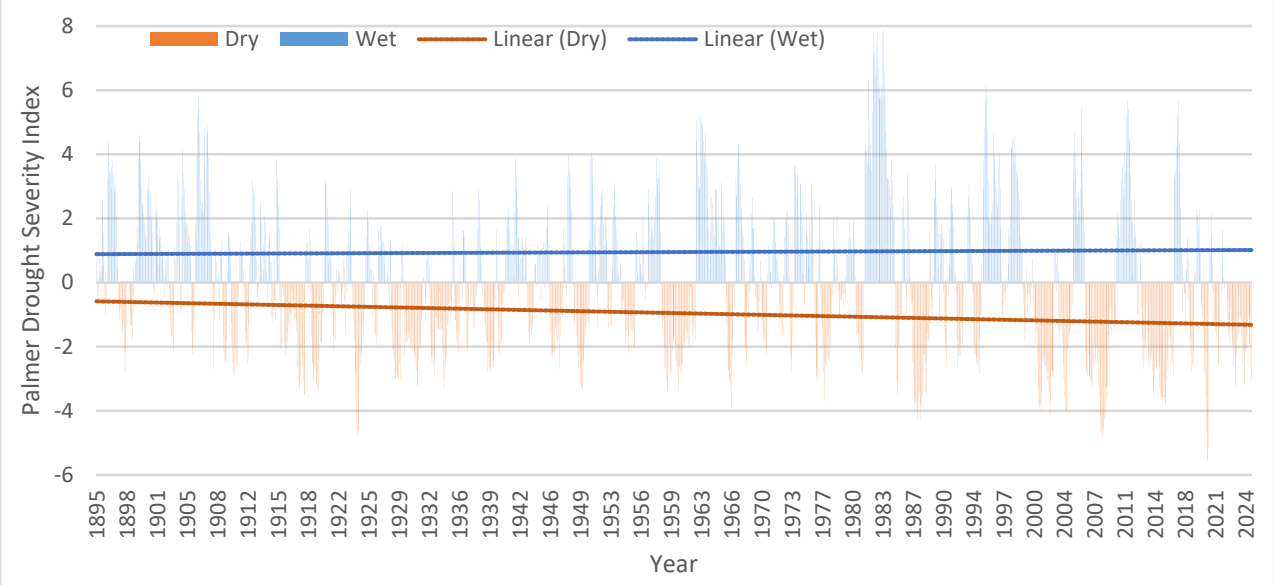
Precipitation data shown in **Figure 6.6.3**, above, were retrieved from the same station on Gracie Road and cover the same time as air temperature data in the previous section. Precipitation totals remained relatively stable before the 1970s, then became increasingly variable until approximately 2001. Precipitation has remained highly variable in recent decades, during which time the station recorded its highest rainfall on record (103.77 inches in 2017) as well as one of its lowest (26.28 inches in 2021).

Variability in precipitation impacts habitats such as wetlands, riparian areas, and the availability and quality of surface water. Prolonged dry periods decrease the ability of soils to absorb water, increasing runoff and flood conditions during large precipitation or snowmelt events. They may also select for the survival of invasive plants with a higher

drought tolerance, crowding out native species. During wet years, invasive, fast-growing vegetation such as Himalayan blackberry and Scotch broom, proliferate. These plants act as ladder fuels, facilitating the spread of flames from the ground into the canopy during wildfires. Their proliferation can quicken the spread of wildfires during dry years.

Drought

Figure 6.6.4. Monthly Palmer Drought Severity Index for Nevada City from 1895 to 2025.



Source: Abatzoglou et al (2025)

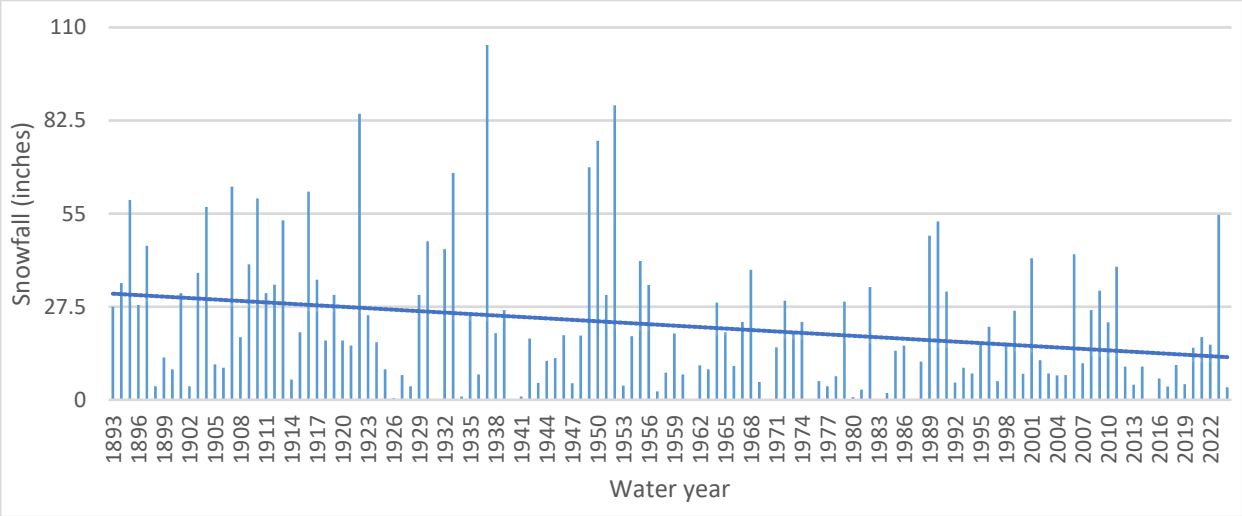
Along with precipitation data, drought metric data also support the observation that there has been greater variability in the hydroclimate in Nevada City since 1970, with increasing severity and frequency of both wet and dry extremes. **Figure 6.6.4**, above, shows the monthly Palmer Drought Severity Index (PDSI) in Nevada City from January 1895 to June 2025. PDSI is a scale derived from air temperature, precipitation, and the moisture-holding capacity of the soil to represent the relative wetness (10 being the wettest) or dryness (-10 being the driest) of a place over a specific period. Values less than negative four (-4) are considered severe drought while numbers greater than four (4) are considered severe flood.

Nevada City has had 17 months of severe drought in the 55 years since 1970 compared to only four months of severe drought in the 75 years before 1970, a fourfold increase. The most severe drought in their region occurred in 2020. Comparing the same periods of time, there have been 57 months of severe flood since 1970 compared to only 24 months of severe flood prior.

Snowfall

Figure 6.6.5, below, shows the amount of snowfall at the weather station on Gracie Road in Nevada City from 1893 to 2024. As with the precipitation data presented above (**Figure 6.6.3**), this data is calculated on a water year basis. The dotted line is the linear trend over time. Total snowfall has decreased by 1.3 inches per decade over this period.

Figure 6.6.5. Snowfall Totals in Nevada City from 1893 to 2024.



Source: SCENIC (2025)

Considering decreasing snowfall alongside increasing nighttime air temperature (**Figure 6.6.2** bottom graph) and increasing, though highly variable, precipitation (**Figure 6.6.3**), it is possible that precipitation has fallen more as rain and less as snow over time. It is harder for the environment to absorb and retain water from heavy rains than it is from the time-delayed release of snowmelt. This may contribute to the cycle of fluctuating wet

and dry extremes, and to the drying of creeks and streams earlier in the season, as the Tribe has observed.

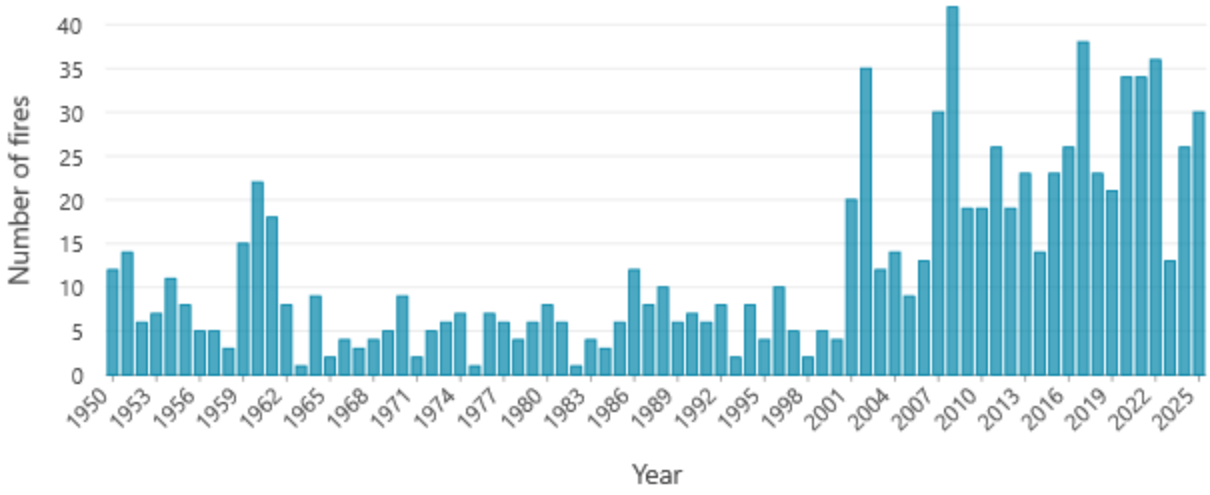
Wildfire

The NCR Nisenan have noticed an increase in fire severity and frequency that they attribute to the loss of Indigenous land stewardship, which included the practice of using frequent controlled fires. The NCR Nisenan regularly burned the duff and dead plant material from oak groves to enhance the production and quality of acorns by destroying oak weevil habitat. They burned meadows to enhance the production of seed-producing grasses and other native plants which were cultivated for food and medicine. They also burned large tracts of forest throughout their territory to maintain forest health and open areas for hunting game such as elk and deer. Their use of frequent, controlled fire decreased the overall fuel load and lowered the risk of large, catastrophic fires akin to what has occurred in the last decade. Maintaining meadows, wetlands, and healthy forests would have also increased the absorptive capacity of those habitats during wet years.

Below are two graphs derived from fire perimeter data from CAL FIRE. **Figure 6.6.6** shows the number of fires in Nisenan Homelands from 1950 to 2024. **Figure 6.6.7** shows the estimated acreage burned by fires which overlap Nisenan Homelands from 1950 to 2025. There is a noticeable increase in the number of fires around the year 2001, which also marks the beginning of some of the longest and most severe droughts on record for Nevada City (**Figure 6.6.4**). The year with the largest fires, 2020, was also the year of the most severe drought on record for the area.

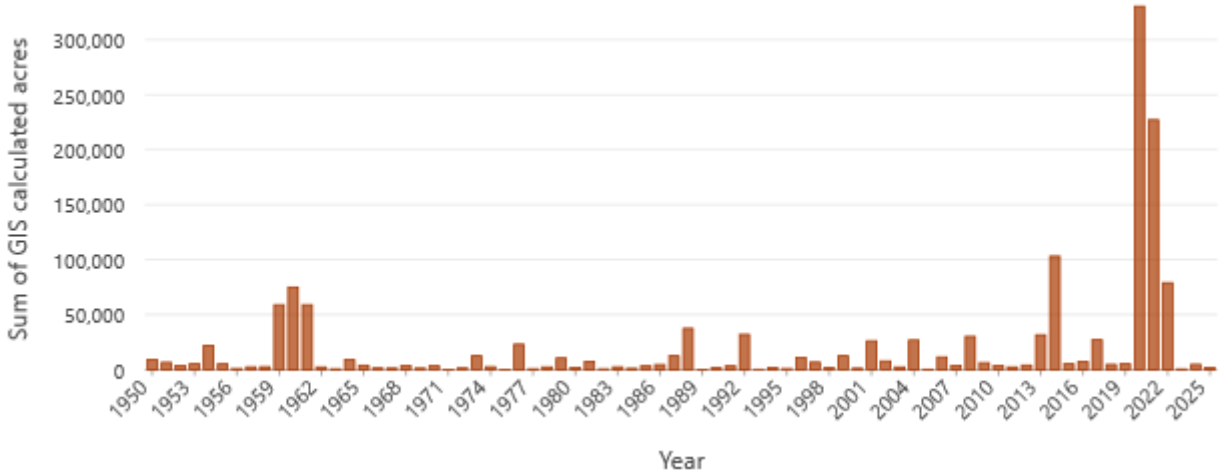
The same CAL FIRE data is shown on a map in **Figure 6.6.8** on page 173. The map displays all wildfire perimeters from 1950 to 2025 which have burned in Nisenan Homelands in a brown color scale. Darker shades of brown represent more recent fires. NCR Nisenan Homelands, specifically, are shown in green.

Figure 6.6.6. Number of Fires in Nisenan Homelands from 1950 to 2025.



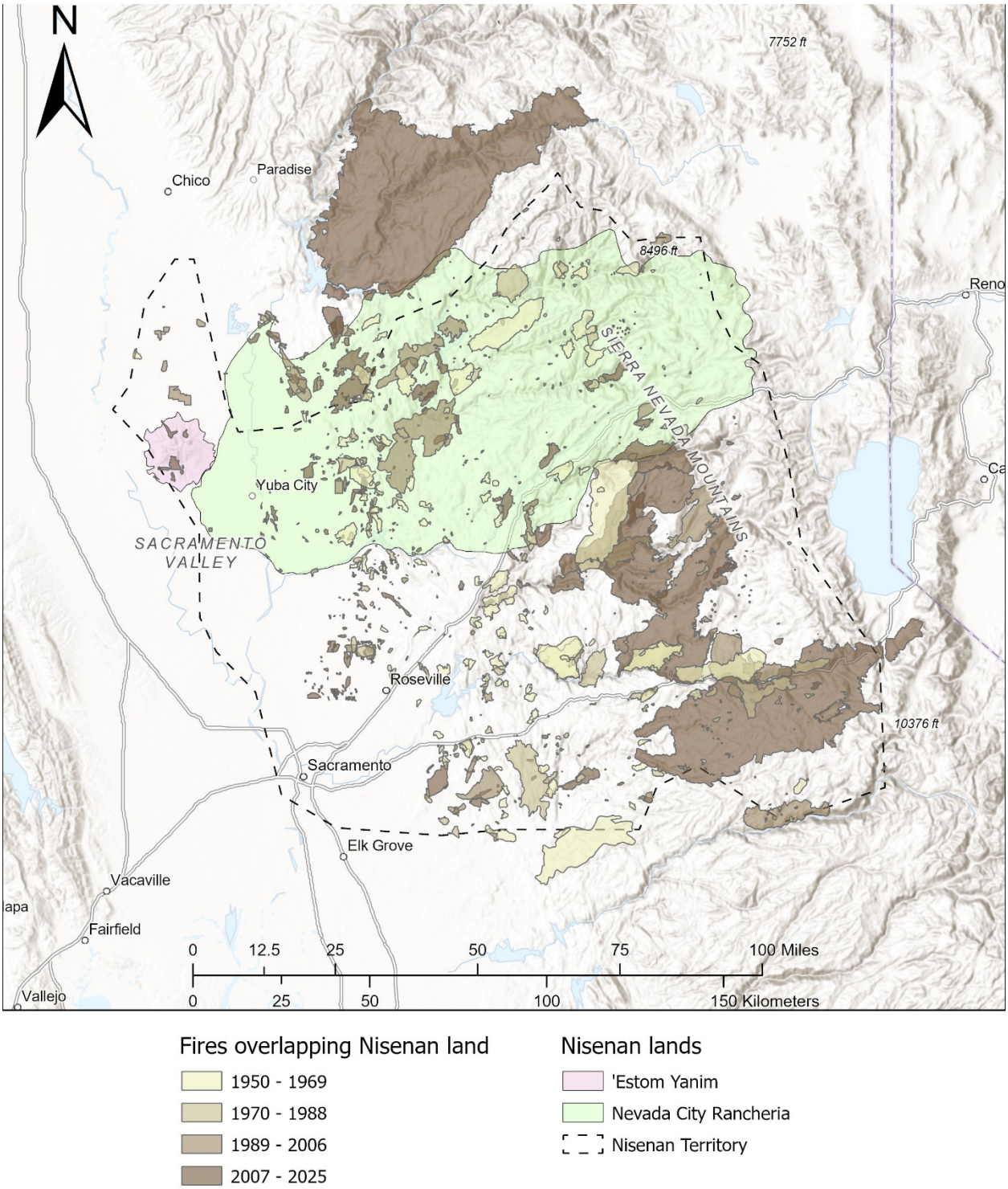
Source: CAL FIRE (2026)

Figure 6.6.7. Estimated Area Burned by Fires Overlapping Nisenan Homelands from 1950 to 2025.



This number is estimated using ArcGIS Pro, and includes the total acreage burned by the fire which is both inside and outside of the rough boundary of the traditional Nisenan territory.
Source: CAL FIRE (2026)

Figure 6.6.8. Fires in Nisenan Homelands from 1950 to 2025.



Source: Fire perimeter data from CAL FIRE (2026); other map data from Esri, TomTom, Garmin, NOAA, USGS, © OpenStreetMap contributors and the GIS user community (2026)

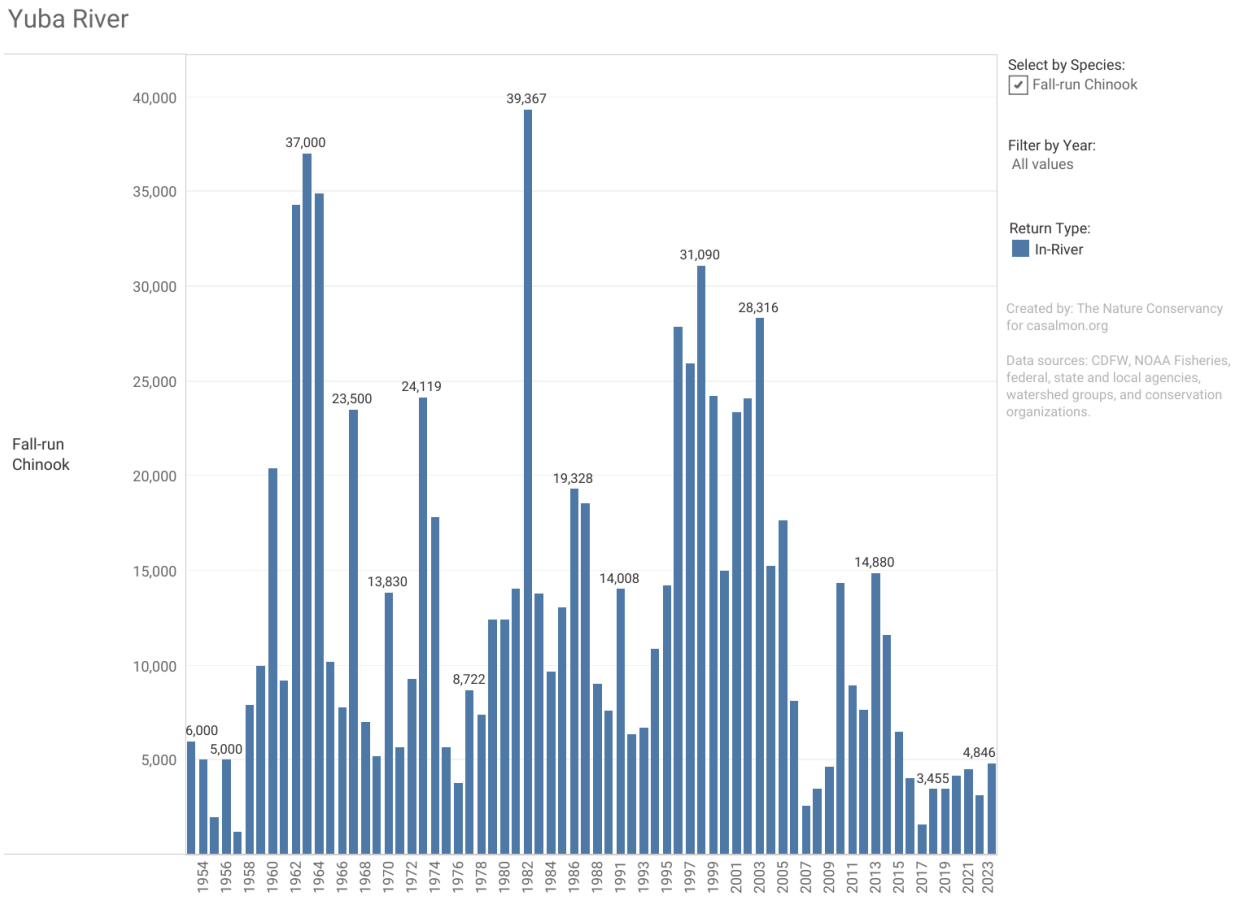
Wildlife and vegetation

Megafauna, especially the grizzly bear, are revered as Ancestors in NCR Nisenan Culture. Grizzlies, elk, and condors are three species of very high significance to the Nisenan which have been extirpated from their territory. The NCR Nisenan consider the impacts of climate change to be inter-related if not indistinguishable from the impacts of colonization and resource extraction in causing the loss of these and other important species. These species have prominent positions in NCR Nisenan oral histories and are considered to play a vital role in balancing the ecosystem.

Abundant runs of anadromous fish including salmon, steelhead and lamprey that once supported Nisenan people along the Yuba River are no longer available. Populations were drastically reduced by mining, dam construction, and overfishing throughout California's colonization and mining period, and now face additional threats from heat and drought. Chinook salmon, which are listed as threatened under the state and federal Endangered Species Act, have access to less than a third of their historic spawning range in the Yuba River (The Nature Conservancy, 2025). The accessible portion is in the lowest and hottest part of the watershed and suffers from ongoing gravel loss and poor water quality. The numbers of Chinook returning to the Yuba River continue to decline (**Figure 6.6.9,** below).

Along with the loss of important animals, the NCR Nisenan report the widespread loss of habitat for plant species which they rely on for food and medicine. Meadow and wetland habitats are significantly degraded due to the cumulative impacts of logging, mining, grazing, development, groundwater pumping, and increasing frequency and severity of hot drought. The majority of gathering areas that had been tended by the Nisenan for centuries if not millennia were either destroyed or seized by colonizers.

Figure 6.6.9. Annual Counts of Fall-Run Chinook Salmon in the Yuba River from 1953 to 2023.



Annual in-river returns of fall-run Chinook salmon to the Yuba River show substantial interannual variability, with an overall decline in recent decades. Data represents the counts compiled from multiple monitoring sources and represents the portion of the run with access to currently available spawning habitat within the Lower Yuba River. Source: The Nature Conservancy (2025)

Human/Tribal health & well-being

Heart disease, diabetes, and everything else that Tribal members are suffering from can be tied to an environmental devastation. We have cancer because of the toxics that we live in. We are sick from the fake food we eat, instead of being able to eat our traditional food. We are dehydrated all the time because everyone is on bad water. There is nowhere you can look at Tribal membership and see something ailing them that existed

before all of this. The ailments were different before. There is no answer. We are all on pharmaceuticals now. This is not even getting into the deeper spiritual layers. Stress is the true killer. Trauma responses. Fear. Just like drought and flood, these are indicators of the imbalance on the Earth being expressed in the people. We live so deep in this harm that we can t even see it. It s daily life now.

Four NCR Nisenan Tribal Council members and one Tribal Health Worker were interviewed individually on the topic of climate change and tribal health. All five pointed to hydraulic mining as a major ongoing environmental and human health concern. In the **Climate change and the Nevada City Rancheria Nisenan** section, which begins on page 161, Covert uses the analogy of a long football throw to show how the NCR Nisenan connect their experience of climate change on a local scale to the colonization of California and genocide of its original people in the pursuit of natural resource extraction. Thus, from their perspective, the legacy of mining must be considered as a health impact as well.

The legacy of mining which continues to impact Nisenan land and people includes: toxic heavy metals in surface soils and water; shafts of abandoned mines as visible or invisible hazards; destruction of meadow and riparian habitats through multiple mechanisms, leading to worsening water quality, especially during the dry season, and reduction in freshwater fish that were critical to the Nisenan diet and lifeways; and the adjacent destruction of forests for timber needed by miners, impacting plant and animal communities important to the NCR Nisenan. The Tribe is concerned about breast cancer in Nevada County, where incidence rates were third highest in the state for women between age 15 and 40, and fourth highest in the state for women under 50 between 2013 and 2022 (California Cancer Registry, 2025). Research in Nevada County and elsewhere has explored how arsenic and cadmium, two heavy metals frequently found in mine tailings, may be related to breast cancer development (Divekar et al, 2020; Florez-Garcia et al, 2023; Huerta et al, 2023).

Summary

The Nevada City Rancheria Nisenan Tribe inhabits their traditional Homelands in Nevada City, California and surrounding areas of the Sierra Nevada foothills. Their health is inextricable from the health of the land, water, air, and living beings around them; and all have been severely impacted by the cumulative impacts of climate change seen as inseparable from the impacts of colonization, genocide, and mining in their region.

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Suggested citation:

Nevada City Rancheria Nisenan (2026). Impacts of Climate Change on the Nevada City Rancheria Nisenan. In: OEHHA 2026 Indicators of Climate Change in California.

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6.7 Impacts of Climate Change on the Pala Band of Mission Indians

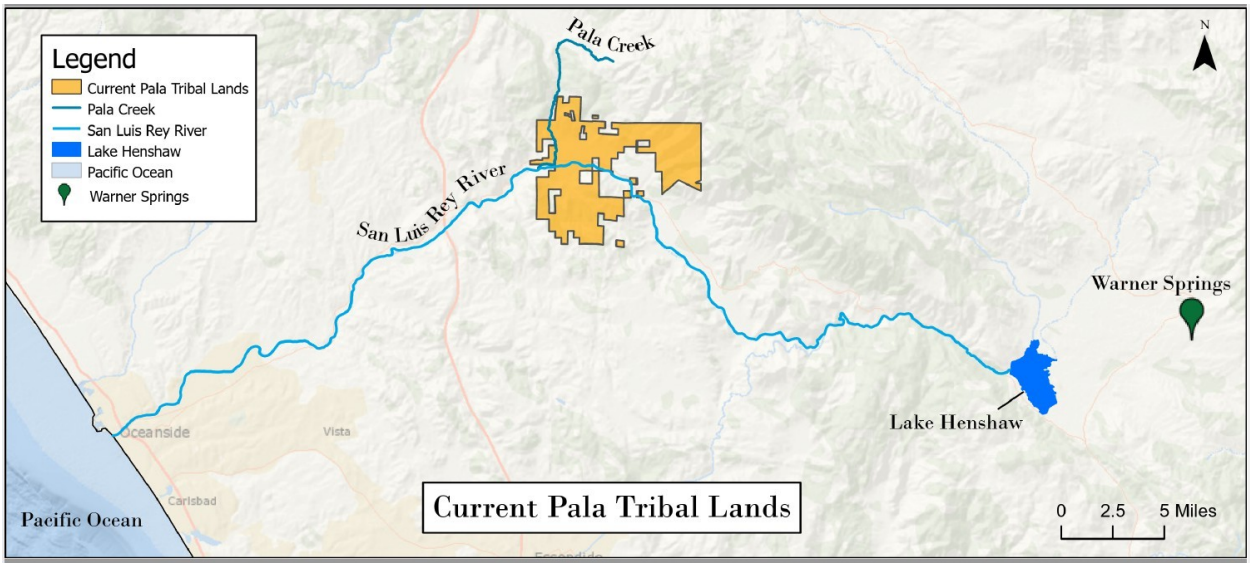
PALA BAND OF MISSION INDIANS

Rising temperatures, drought, wildfires, and flooding are threatening the physical, cultural, and spiritual health of the Tribe, its habitats and ecosystems, and its built environment.

Background

The Pala Band of Mission Indians is a federally acknowledged Native American Indian Tribe that has a current enrollment of approximately 1,000 Tribal members. The Pala Band has jurisdiction over the Pala Indian Reservation that was established in 1875. Approximately 1,500 people live on the reservation. The Pala Indian Reservation is located on approximately 14,000 acres in northern San Diego County, approximately 30 miles east of the Pacific Ocean (see **Figure 6.7.1**). The Pala Reservation sits next to the Palomar Mountain range that runs along 5,000 square miles of California desert. Adjacent to the reservation is the Cleveland National Forest to the north and east, and

Figure 6.7.1. Map of Current Pala Tribal Lands.



Source: Pala Environmental Department

private agricultural lands to the south and west. The reservation lies within an alluvial valley surrounded by steep granite mountains and is divided into two areas by the San Luis Rey River; these are referred to as the north side and the south side. The north side contains most of the homes and development; however, there are also approximately 100 homes and structures south of the river. Elevations range from approximately 340 feet above mean sea level (MSL) at the valley floor to approximately 1,250 feet above MSL in the northern and southern mountainous areas, with most residential, agricultural, and industrial activities occurring in the lower elevations of the reservation. Approximately 88% of the land is currently undeveloped. Land uses include agricultural, mining, pastureland, commercial businesses including gaming, and residential uses.

The South Coast of California where Pala is located is home to one of the world's biodiversity hotspots. Rapid development occurring in the areas surrounding the reservation has increased the burden on natural resources and degraded ecosystems and habitats. In particular, new housing developments west of Pala as well as the growing population in the nearby city of Temecula, north of Pala, have created issues with traffic and air quality.

Prior to the construction of the Lake Henshaw Reservoir and Dam in 1923, Pala had access to the San Luis Rey River's perennial water supply. A complex history of water diversion by new settlers and legal battles ultimately led to a Congressional settlement that was signed into law. The 1988 San Luis Rey Indian Water Rights Settlement Act (PL 100-675) quantified the Tribe's prior and paramount water rights and provided for the construction of water projects to facilitate the exercise of Pala's rights. The source of the reservation's domestic water supply, which is drawn from wells scattered throughout the reservation, is the aquifer and underground stream of the Pala Groundwater Basin. The Basin lies directly underneath the San Luis Rey River and the Pala village area. It is replenished by rain events and surface water flows from local creeks and rivers (Pala, 2017).

The people of the Pala Band of Mission Indians have lived from time immemorial in this

part of Southern California. Pala's Tribal members have a rich and diverse Tribal history with members that come from Cupeño, Luiseño, and Kumeyaay ancestry. They have endured and adapted to many significant impacts on their lands and community which have disrupted culture and traditions, political and social systems, and ecological environments for over hundreds of years beginning with the arrival of Spanish missionaries in 1769 (Goode et al., 2018). In 1903 the Cupeño Indians were forcibly removed from Warner Springs, shown on the map in **Figure 6.7.1**, and brought 40 miles west to Pala, joining with the Luiseño Indians already living there, ultimately combining to form the Pala Band. Ongoing development impacts the Pala community's ability to maintain traditional subsistence practices. The Pala people, however, continue to thrive, buoyed by their strong community and culture connectedness, co-existence with nature, and spiritual connections.

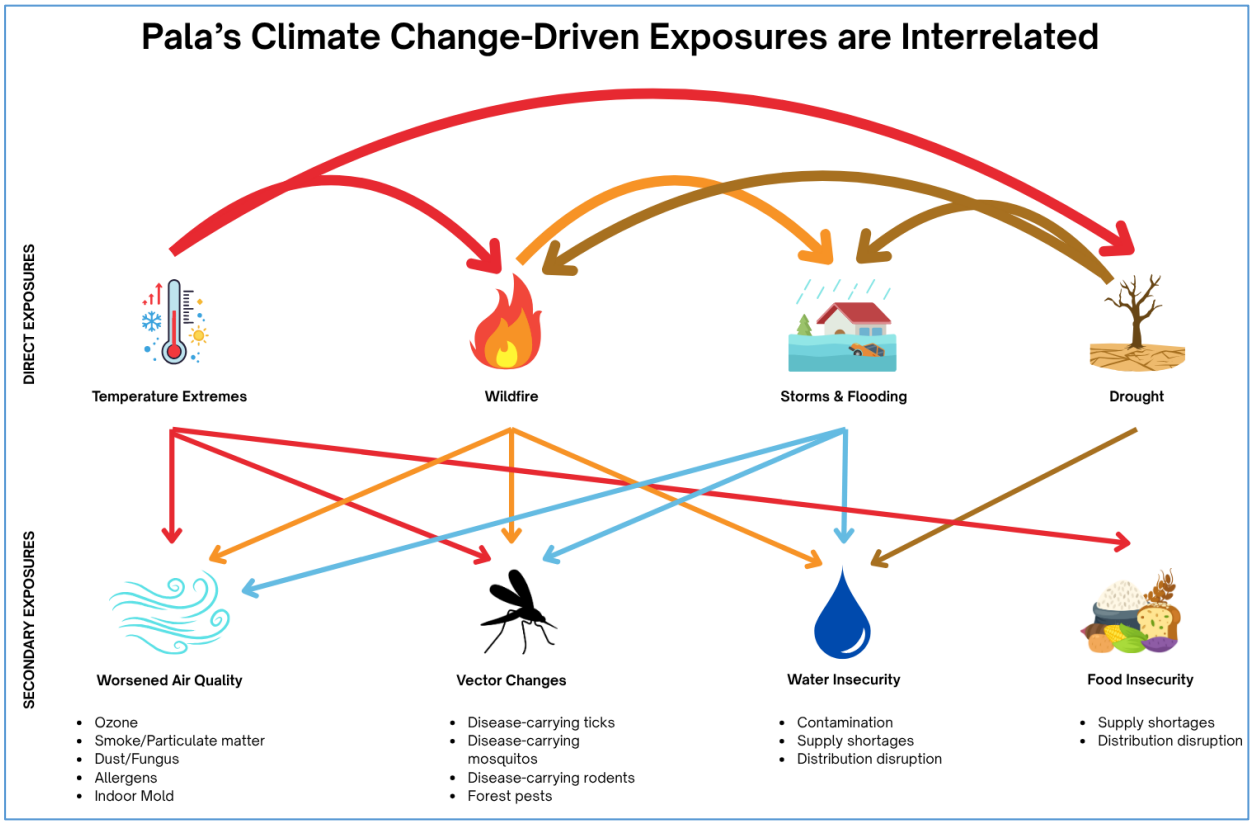
Climate change and the Pala Tribe

Pala's climate has been characterized by moist, mild winters and dry, warm summers, also known as "Mediterranean summers." Temperatures in the Pala Valley are historically relatively moderate, ranging from an average of 60 degrees Fahrenheit (°F) (15.5 degrees Celsius, °C) during the winter months to an average of 80°F (26.7°C) during the summer. Annual precipitation within the Pala Valley averages about 10 to 12 inches a year, and between 25 to 45 inches in the Palomar Mountains, 12 miles east of Pala. Roughly 75% of the annual precipitation falls within the basin between December and March (Pala, 2016).

Climate change impacts that the Tribe has seen threaten a variety of Pala's community assets and values, ranging from water resources to human health and Tribal sovereignty (Pala, 2019). Pala conducted a vulnerability assessment, based on Tribal science, knowledge and observations shared by Pala's residents, which matches the more recent scientific evidence and literature on the impacts of climate change. The Tribe plans to update its climate vulnerability assessment and adaptation plan in 2026 to incorporate the latest data. Extreme weather events, including heat waves and wildfires, have increased in frequency, if not intensity, since the publication of the 2019 assessment. Pala's location in the southwest region of the United States, within the

inland valley and mountainous areas of San Diego County, makes it susceptible to a variety of climate-related direct and secondary exposures (**Figure 6.7.2**, below). The secondary exposures (e.g., worsened air quality, water insecurity, etc.) occur as a result of direct exposures. The color of an arrow in **Figure 6.7.2** corresponds to the direct exposure from which it stems.

Figure 6.7.2. Interrelated Climate Change Exposures.



Source: Pala Environmental Department

There are characteristics of the area and of the Tribe that make Pala either more vulnerable to possible impacts of climate change, or more capable of adapting to these impacts. For example, Pala has buildings considered at high risk of flooding and critical facilities in a high-risk wildfire area (Pala, 2016), and nearly half of residents do not have air conditioning in their homes to buffer them from heat impacts. However, Pala also has more tree canopy cover, lower percentages of impervious surfaces, and a lower

urban heat island index than most census tracts in California, (Public Health Alliance of Southern California, 2018) which may help buffer residents from expected impacts of extreme heat. Having overcome ecological and human changes on their lands for thousands of years, the people of Pala have also demonstrated exceptional strength, resourcefulness, and resilience, in the face of continued and increasing climate change impacts.

Interrelated climate change impacts and cultural and spiritual health

At Pala, the people, the culture, and the environment are connected. Thus, it is impossible to tease out specific climate change impacts that affect cultural and spiritual health from those that do not. For example, the plants and animals that are being impacted by climate change are often used in traditional practices and ceremonies. When medicinal plants are impacted by climate change, the Tribe's traditional healing practices are affected. The absence of culturally important foods, such as acorns, limits their use in celebrations.

Habitable climate is critical to protecting Tribal sovereignty, culture, and community cohesion for the people of Pala. Extreme heat days can threaten cultural expressions and traditional ways of life at Pala, including disruptions to culturally and/or spiritually important activities such as traditional gatherings, annual ceremonies, traditional food foraging, performances by traditional bird singers, and basket weaving. As temperatures continue to rise, residents may opt out of these traditions, modify how they are conducted, or relocate their household out of the area; this affects community cohesion and cultural identity and sovereignty (Pala, 2019).

Increased temperatures also result in a variety of ecosystem disruptions. For Pala, that can mean declines or disappearance of culturally important plants and animals. At Pala, members of the community express concerns about culturally important plants including those required for baskets, ceremonial structures, or foods, such as rushes (*Juncus* spp.*)*, sourberry (*Rhus trilobata)*, acorns, sage (*Artemisia californica*), willow, and tobacco. Community members report that culturally important plants like basket rush (*Juncus textilis*) and ferns have also become harder to find (Pala, 2018).

Declining trees and plants impact resources that support the Tribe's cultural traditions. The coast live oak (*Quercus agrifolia*) is called wi'awlet in the Cupeño language. For many tribes, oak trees were a key source of nutrition (acorn mush or wi'wish) and are a symbol of life, growth, and the cycle of the seasons. Acorns continue to play an important role in ongoing cultural traditions, such as the annual Púyily 'Áy'enish (Big Meal, A Great Feast) gathering held at Pala every November.

As climate change puts Pala at increased risk, impacts to the psychosocial health of the community are inevitable. Psychosocial health refers to the mental, social, spiritual, and emotional health of a community. While Pala has been committed to addressing these impacts, the stress on the community from heat, drought, severe weather, loss of species and cultural sites, and wildfires cannot be ignored.

Critical climate concerns in Pala

Air temperatures

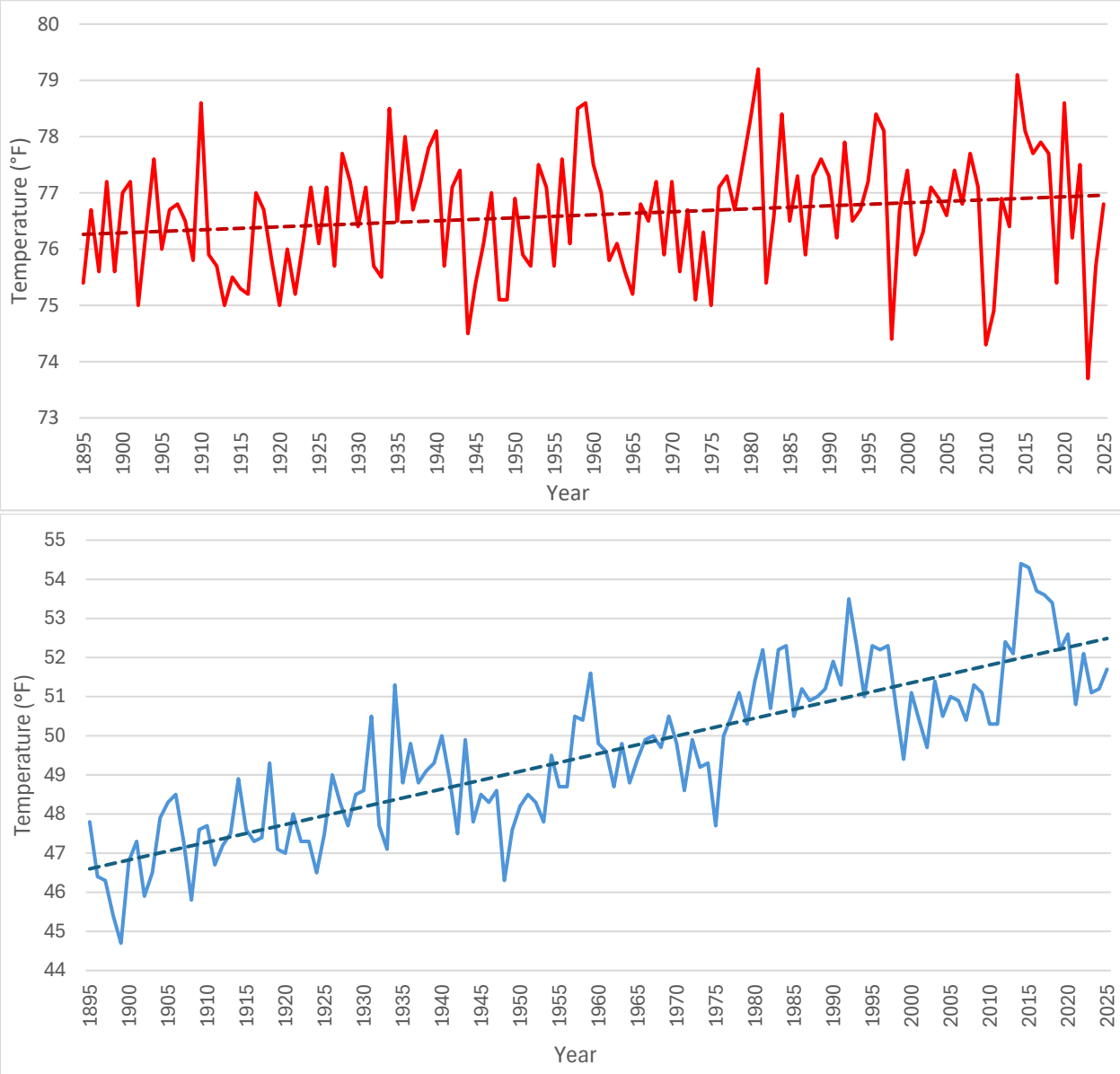
At Pala, both the annual average minimum temperature (nighttime temperature) and annual average maximum temperature (daytime temperature) are rising, with the nighttime temperature rising more quickly. Elevated temperatures affect human health, mental health, cultural and spiritual health, and socio-economic health, as well as the plants and animals that are part of Pala. Elders, children, outdoor workers, and those with existing medical conditions are particularly susceptible to these impacts (Pala, 2019).

Figure 6.7.3 shows that before 1950, the nighttime temperature varied between 44.7°F (7.05°C) and 51.3°F (10.72°C), and the daytime temperature varied between 74.5°F (23.61°C) and 78.6°F (25.89°C). Since 1950, the nighttime temperature has ranged from 47.7°F (8.72°C) to 54.4°F (12.44°C) and the annual average maximum temperature has ranged from 73.7°F (23.17°C) to 79.2°F (26.22°C) (PRISM Climate Group, 2026).

Warming temperatures are considered a high-risk exposure for the Pala Tribe. Heat waves consisting of multiple consecutive days of triple-digit heat have increased and are expected to become more common. As is evident from the increasing minimum

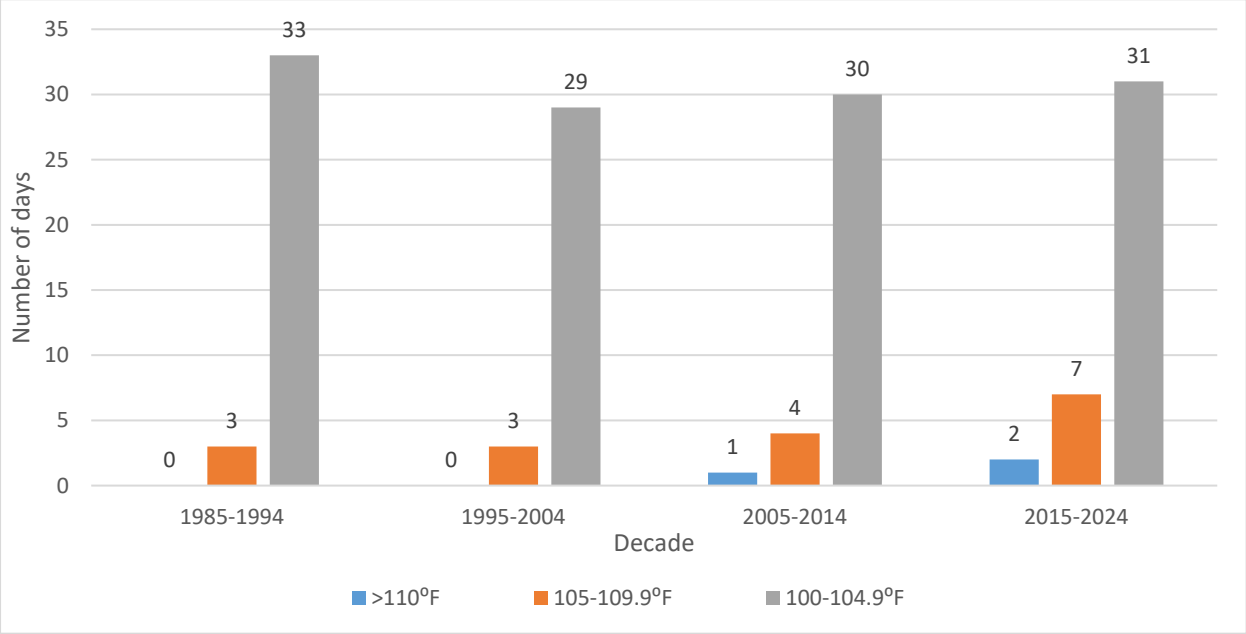
temperatures, the cooling nights that Pala is accustomed to are warming over time. The combination of warmer daytime and nighttime temperatures are impacting both the human and the plant communities (Pala, 2016).

Figure 6.7.3. Daytime (Top) and Nighttime (Bottom) Temperatures at Pala from 1895 to 2025.



The top graph shows annual average maximum (daytime) temperatures at Pala and the bottom graph shows annual average minimum (nighttime) temperatures. Both are shown in degrees Fahrenheit with linear trendlines. Source: PRISM Climate Group (2026)

Figure 6.7.4. Number of Extreme Heat Days Per Decade at Pala from 1985 to 2024.



Source: PRISM Climate Group (2025)

Figure 6.7.4 shows that over the past three decades, there have been an average of 35.75 days per decade with temperatures over 100ºF (37.8ºC) at Pala. The number of days of the most extreme heat, above 105ºF (41ºC) and 110ºF (43.3ºC), are increasing over time.

As temperatures have increased, Pala's Environmental Department staff have observed declining areas of important habitats including chaparral, native grasslands, wetlands, riparian, and upland habitats and increasing areas of non-native grasslands. Pala has observed impacts to production of some crops cultivated on the Reservation, including avocado and citrus fruit. These trees need a certain number of chilling hours in the winter when temperatures are between 32 and 50°F (0 to 10°C); as temperatures increase and chilling hours are reduced, crop yield decreases (Pala, 2019).

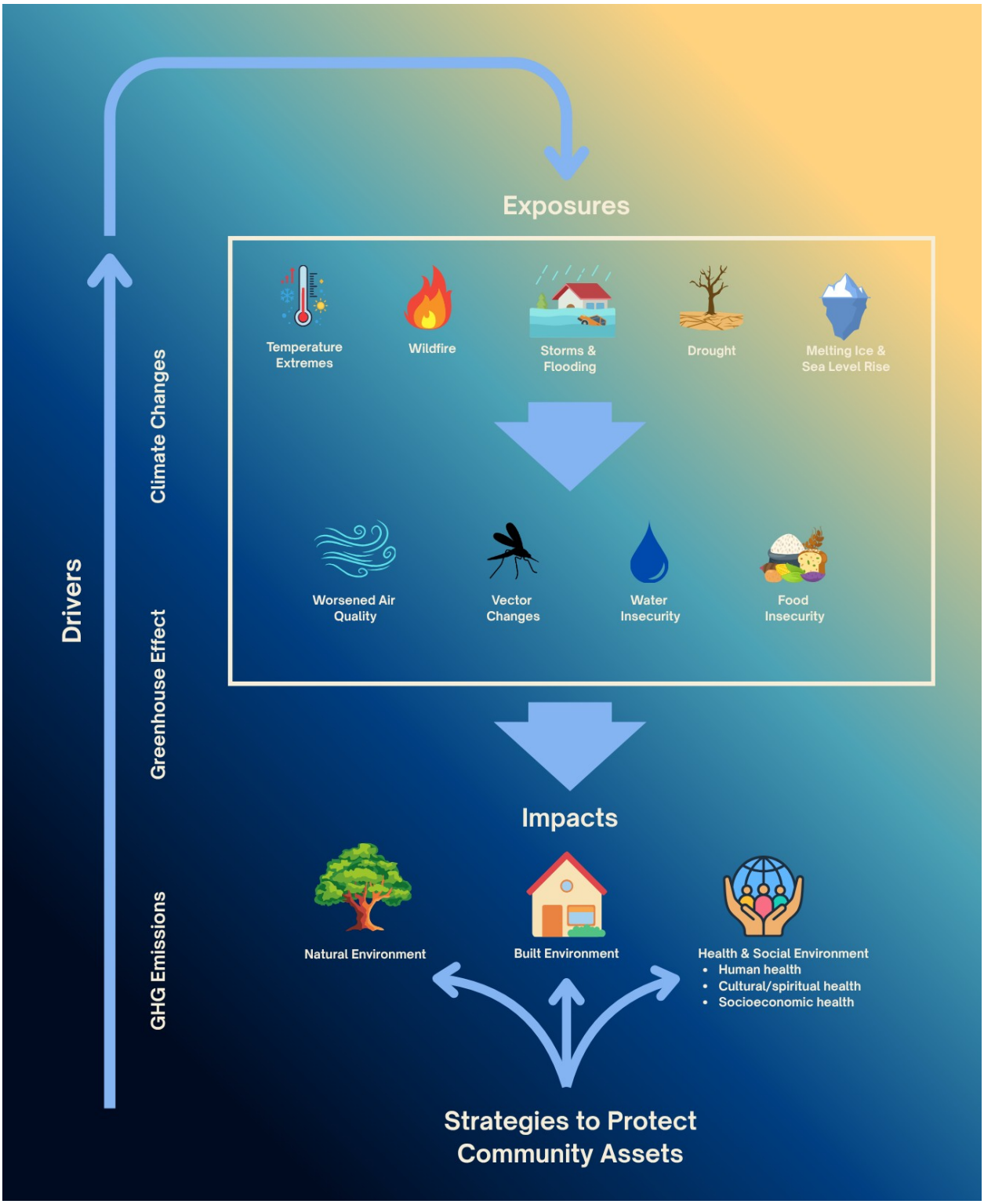
Climate changes are also causing certain native animal populations to decline in Pala's region. Temperature increases are altering habitat suitability for endemic species like

the federally endangered Quino checkerspot butterfly and California gnatcatcher, for which range shifts have been observed (Parmesan, 2015). These temperature shifts can also impact the breeding cycles of aquatic species that are triggered by warming temperatures, like the federally endangered arroyo toad (*Anaxyrus californicus*).

A Tribe's social and economic institutions are an important factor in its overall community health. Extreme heat and its effects on human health can result in a variety of negative socio-economic impacts**.** **Figure 6.7.5** shows how changing exposures impact health, social, natural, and built environments (Pala, 2019). Health impacts and power disruptions triggered by extreme heat can result in lost work days and revenues for Tribal businesses. For Pala, critical economic drivers include gaming, entertainment, hospitality, and other business ventures. Health impacts and power outages due to extreme heat can also result in lost school days and closures of school and afterschool activities that impact Pala's youth.

Elevated temperatures at Pala increase water evaporation and lower water levels in rivers, streams, and aquifers. This presents a challenging scenario as Pala already relies on groundwater for domestic water and irrigation. Increased water demand from development in the region, coupled with declining water supply from the California snowpack and the Colorado River, will place additional burdens on local water resources.

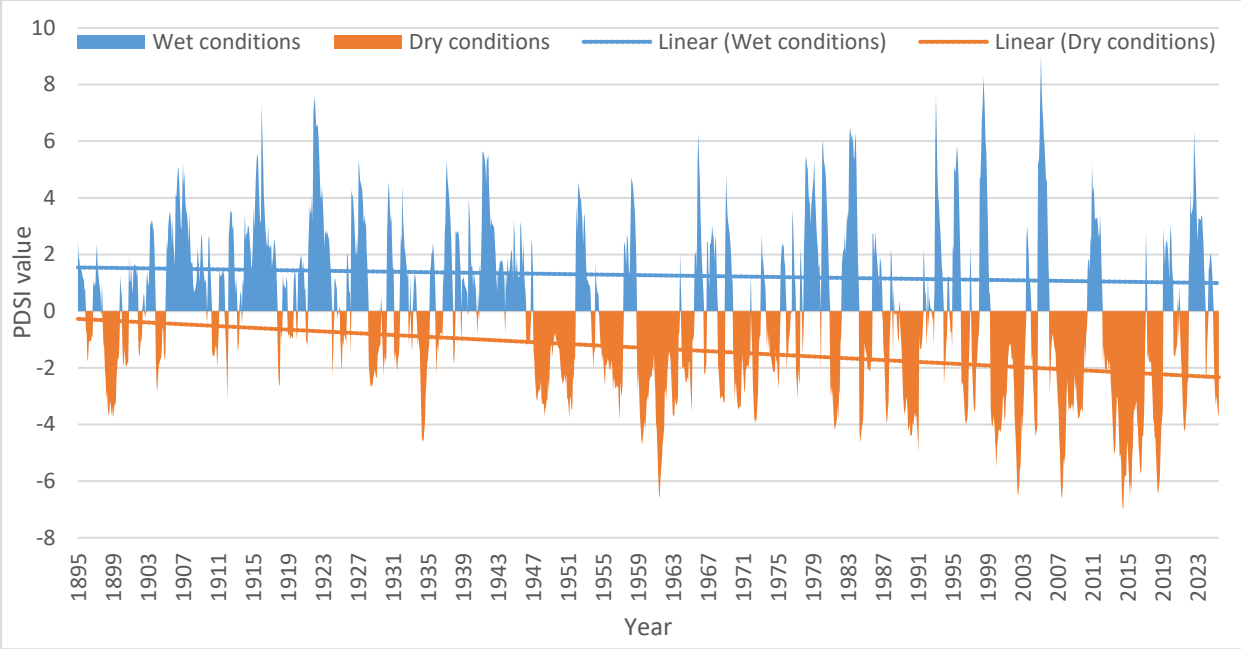
Figure 6.7.5. Interaction of Climate Change Impacts.



Source: Pala Environmental Department

Drought

Figure 6.7.6. Monthly Palmer Drought Severity at Pala, 1895 to 2025.



Source: Abatzoglou et al. (2025)

Figure 6.7.6 shows the monthly Palmer Drought Severity Index (PDSI) at Pala from January 1895 to June 2025. Over this period, drought has become more severe. PDSI is a scale derived from air temperature, precipitation, and the moisture-holding capacity of the soil to represent the relative wetness (10 being the most wet) or dryness (-10 being the most dry) of a place over a specific period of time. Values less than negative four (-4) are considered severe drought while numbers greater than four (4) are considered severe flood. In the past 30 years, Pala has had 12 years during which they experienced severe drought conditions, and five years during which they experienced severe flood conditions.

Drought, combined with climate change-driven extreme heat, season shifts, and insect and pest outbreaks can weaken plants, trees, and forests or shift growth patterns. There is ample evidence of such drought impacts in Southern California. Some vegetation types in Southern California (e.g., chaparral and coastal sage scrub) have experienced

declines in vegetation greenness over the last 17 years (Pala, 2019).

Pala Environmental Department staff note that manzanita and other upland plants are moving into the riverbed as riparian vegetation and wetlands dry up. Reduced riparian vegetation lowers the area's natural capacity to absorb storm water, which exacerbates flooding threats on the Reservation. Gold spotted oak borer beetle is a concern for the oak groves on the reservation, particularly in light of the increased drought, which has taken a toll on native oak species (see **Invasive insect pests** section, below). Pala Environmental Department staff note declining numbers of Englemann oak (*Quercus engelmannii*) and coast live oak (*Quercus agrifolia*) trees, which are considered culturally important (Pala, 2019).

Pala Creek used to flow for many days after a substantial precipitation event, but that is no longer the case since repeated droughts have reduced the groundwater basin. Pala staff report that the San Luis Rey River and Pala Creek no longer have regular flow. Because water levels have been so low in the river and streams, Pala Environmental Department notes that aquatic species such as the arroyo toad and anadromous fish such as Steelhead and Pacific Lamprey are no longer present in significant numbers.

The Pala reservation is home to endangered or threatened plant species including Parry's tetracoccus (*Tetracoccus dioicus*) and Rainbow manzanita (*Arctostaphylos rainbowensis*). Drought, along with increased temperature, stresses these plants and creates conditions for certain non-native, invasive species to thrive. Examples of invasive species present on the Pala Reservation are eucalyptus, arundo, and tamarisk. These species can degrade habitat quality for native wildlife and contribute to increased wildfire frequencies.

The degradation and loss of habitat combined with drought is assumed to be the cause of the disappearance of the southwestern willow flycatcher (*Empidonax trailii extimus*). Southwestern willow flycatchers (**Figure 6.7.7**, below) live in moist microclimatic and vegetative conditions and breed only in dense riparian vegetation near surface water or saturated soil. Southwestern willow flycatchers have not been seen at Pala since 2013 and are assumed to be extirpated (Pala, 2019).

Figure 6.7.7. Southwestern Willow Flycatcher.



Photo credit: USFWS

Source: NPS (2026)

Drought and changes in precipitation contribute to species migration and range shifts. Native bird species at Pala are dependent on native vegetation for habitat, which has declined during severe drought (National Fish, Wildlife and Plants Climate Adaptation Partnership, 2012). At Pala, tree and habitat losses have affected several bird species. In addition to the southwestern willow flycatcher, Pala Environmental Department staff have also observed a reduction of acorn woodpeckers (*Melanerpes formicivorus*), a species tied to oak trees.

Storms and flooding

As precipitation becomes less predictable and more intense, flooding is a high concern for Pala and has impacted the Tribe (Prosper Sustainably, 2018). Drought conditions and lower soil moisture lead to flash floods in inland areas, as well as mudslides and landslides, especially in areas recently affected by wildfire.

Since 1895, Pala has received less annual rainfall over time. When the rains come, these rain events are becoming more intense, causing flooding that rises and falls

quickly (Prosper Sustainably, 2018). The Pala Environmental Department tracks rainfall, water flows, stream levels, storm damage, and flooding at multiple locations on the Reservation. Flooding has become a regular occurrence at Pala. Between 1917 and 1997 there were two major flood events. Since 1997 there have been 23 major floods that covered roads, damaged property, and trapped residents (Pala ED, 2025).

Flooding can weaken and remove vegetation and soil leading to downed trees, erosion, and mudslides. Pala staff have observed that floods have shifted riparian habitats. For example, shifting river sediments and braided water flows during heavy storms have created new San Luis Rey River channels in some areas, while silting and blocking previous flow channels. This leads to a shifting riparian regime that can change between major flood events.

Figure 6.7.8. Flood Damage on Lilac Road in Pala, February 2024.



Source: Pala Environmental Department

Loss of riparian vegetation reduces the ability of the floodplain to naturally absorb and manage high levels of stormwater. Certain invasive species on Pala lands, such as *Arundo donax* and tamarisk easily spread in flood conditions.

Animals that depend on the riparian habitat and may be temporarily or permanently displaced by storms and flooding including endangered species at Pala such as the southwestern willow flycatcher, yellow-billed cuckoo, coastal California gnatcatcher, and the arroyo toad. The yellow-billed cuckoo (*Coccyzus americanus*) historically nested on or near the San Luis Rey River (CWHR, 1999; Mitchell, 2020). According to a 2015 study (HT Harvey and Associates, 2015), habitat at Bubble Up Creek and Pala Creek (south of the San Luis Rey River), was of poor quality and unsuitable for breeding, due in part to the minimal width of the riparian habitat.

Severe storms, flooding, and runoff can contaminate water supplies with bacteria, viruses, and other pathogens and toxins, limiting the availability of safe drinking water. For example, the 2017 flood event at Pala exposed drinking water pipelines and caused a substantial rise in influent into the wastewater treatment plant (Pala, 2017).

Figure 6.7.9. Flooding at a Pala Home.



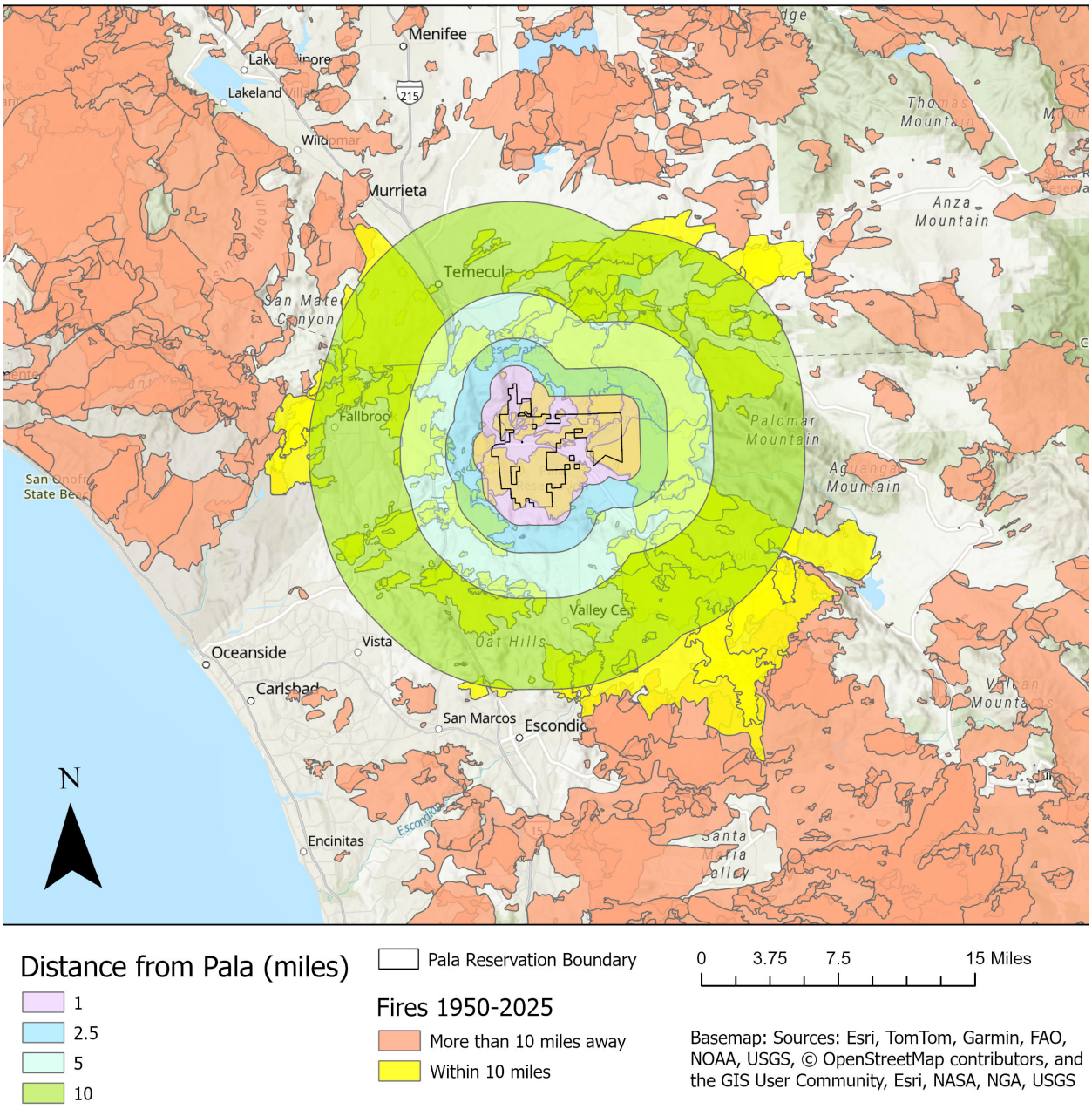
Source: Pala Environmental Department

The changing and intensifying storm and flooding patterns Pala has seen have harmful effects on the natural environment. The effects of changing precipitation over time and the difficulty in predicting future rainfall are compounded by uncertainty in how much the inherent resiliency of plants and animals adapted for dry, variable climates can

accommodate changing conditions (Jennings et al., 2018).

Wildfire

Figure 6.7.10. Wildfire Boundaries Near Pala from 1950 to 2025.



Source: Fire perimeter data from CAL FIRE (2026)

Figure 6.7.10 shows fires in the area of the Pala lands that occurred between 1950 and

2025. The incidence of large forest fires in the western United States has increased since the early 1980s (Wehner et al., 2017). Fire season in California is starting earlier and ending later each year (CAL FIRE, 2020). Between 1910 and 2025, 41 fires burned within Pala's Reservation and 253 fires burned within 10 miles of the Reservation (CAL FIRE, 2026). Recent fires have burned significant portions of Pala's lands. Two of California's largest wildfires have occurred in San Diego County: The Cedar Fire in 2003 and the Poomacha Complex/Witch Fire in 2007. These fires burned 273,246 acres and 240,207 acres, respectively.

Wildfires have caused evacuations and disruptions at Pala. In May 2025, Pala was directly impacted by the 256-acre Henderson Fire, which resulted in mandatory evacuations of some Pala neighborhoods (**Figure 6.7.11**, below). The Poomacha Fire in 2007 resulted in evacuation of 400 Tribal members and closure of the Pala Casino, causing temporary but significant impacts to educational and economic opportunities. Fires at Pala have also disrupted telecommunication lines, hampering the Tribe's ability to do business (Pala, 2016).

Exposure to smoke-related air pollutants, including particulate matter (PM) from wildfires has been associated with a wide range of human health effects, including cardiovascular consequences, early deaths and low infant birth weight, and acute respiratory illness (US EPA, 2019).

At Pala, water security, compounded by drought, is an ongoing concern. Wildfire can further stress water supplies if watersheds or water treatment infrastructure are damaged during a wildfire, or when domestic water supplies are used to combat the fire.

Wildfire can destroy culturally important ecosystems, sacred sites, and points of access to culturally important places to Pala. Numerous cultural sites, functions or traditions are in danger of wildfire encroachment and damage. This can threaten Pala's traditional practices, sovereignty, and community cohesion, which are considered highly important community assets (Prosper Sustainably, 2018).

Wildfire can initially increase the abundance of ticks and increase the risk of Lyme disease (MacDonald et al., 2018). There have been cases of Lyme disease in the Pala region in recent years. Wildfire risk can also increase due to pest infestations and

disease vectors affecting forest health (e.g., bark beetles, fungus, shothole borer). Invasive forest pests and tree diseases increase wildfire risk by stressing and killing trees, which increases the mass of dead and dying vegetation that can fuel wildfire outbreaks. Pala environmental staff have observed an increase in diseased trees and an overall decline in oak trees as a result of invasive forest pests.

Figure 6.7.11. Henderson Fire on the Pala Reservation in May 2025.



Source: Pala Environmental Department

Pala's wildlife depend on healthy, large, and connected habitats to roam, breed, and hunt. Impacts of wildfire include habitat loss, degradation, and fragmentation that result in genetic isolation. Burned areas are subject to increased erosion resulting in the siltation of creeks, streams, and rivers. This can result in channel aggradation (wider, slower channels) and steep slopes destabilized due to the lack of vegetation (Pala, 2019).

Repeated wildfires at intervals too short to allow recovery of natural vegetation facilitate the conversion of natural woody shrublands (e.g., coastal sage scrub) to weedy, flammable annual grasses. For example, the large fire events of 2007 in San Diego resulted in nearly 74,000 acres of overlap with the four-year-old recovering vegetation that burned in the 2003 Cedar Fire. At Pala, the Poomacha fire burned most of the vegetation in the eastern mountainous region, and the area is now dominated by scrub and non-native grasses (Pala, 2016). The US Forest Service documented that shrublands have converted to non-native annual grasslands on a widespread scale across the Cleveland National Forest, which borders the Pala Reservation (Kalansky et al., 2018).

Wildfire and its impact on vegetation conversion, habitat connectivity, food, and freshwater supplies can force animal species to migrate from the area. In San Diego County, repeated fires reduce habitat for shrubland threatened species like the California gnatcatcher (Jennings et al., 2018).

Invasive insect pests

The Pala Tribe has seen an increase in invasive insect pests over time. Three that have been causing signifcant damage among tree species and tree-harvested crops are the Asian Citrus Psyllid (ACP), Invasive Shot Hole Borers (ISHB), and Gold-Spotted Oak Borer (GSOB). While the relationship between climate change and these specific invasive species is not yet fully studied or known, the impacts are related in terms of how they compound ecologically and increase overall stress on Pala lands and culture.

ACP vectors the bacteria responsible for Huanglongbing (HLB) or citrus-greening disease, which is deadly to citrus trees. There are tens of thousands of acres of harvested citrus in San Diego County (Garcia-Figuera, 2021), and at least 1,756 acres

of quarantined commerical citrus in the Valley Center area near Pala (USDA, 2024). Detections of HLB in the Valley Center Area in recent years have resulted in the inclusion of Pala in the Federal quarantine area and the California Department of Food and Agriculture's (CDFA) emergency program area (CDFA, 2025). No citrus can be transported within or beyond the quarantine area, and impacted areas will be treated with a combination of cyfluthrin and imidacloprid insecticides. Citrus is a significant crop for home growers and farmers in Pala. They are concerned not only about the loss of their citrus orchards and products, but also about the overall impact on the Tribe and land as a result of required direct application or indirect drift of insecticides. Pala Tribal members have gone through great efforts to grow organically and, in some cases, invest in organic certification in order to protect their human, environmental, and economic health.

The ISHB is a pest of hundreds of different tree species in San Diego County (County of San Diego, 2016). There are two species of ISHB in California, which are difficult to tell apart and cause the same type of damage. While they can infect citrus, they are more damaging, deadly and productive in other types of trees, including avocado, native oaks, willows, ornamentals, and more (UCANR, 2023). These tiny beetles carve tunnels through host trees to cultivate a fungus called *Fusarium*, which causes a tree disease known as *Fusarium* dieback or FD. Trees which are already stressed, for example due to drought, are more susceptible. FD has been found throughout the Pala Reservation and causes the loss of tree and shrub species that are of significant cultural importance to the Tribe. Along with the loss of Tribal lifeways associated with those species, FD destroys entire habitats, reducing ecosystem integrity and function. In addition, it creates safety and health hazards resulting from dead limbs, standing dead trees, and a build up of wildfire fuels. As with citrus, the Pala Tribe has valuable and sizeable avocado holdings which are at risk of this disease.

"The number one question that Tribal members ask the Environmental Department is, ***'Why are our oak trees dying?'"*** *~Shasta Gaughen*

Native oaks at Pala are impacted by ISHB as well as, to a much larger extent, by the Goldspotted Oak Borer (GSOB, species *Agrilus auroguttatus*). The GSOB is responsible for the death of hundreds of thousands of native oaks in southern California, and the toll is rising (Don't Move Firewood, 2025). This small beetle is native to Arizona and spreads to new areas primarily through the transport of firewood. While there is no effective natural biological control of GSOB in southern California, one of its natural predators is the acorn woodpecker, whose populations, as previously mentioned, are declining around Pala.

GSOB kills trees of three species, coast live oak, black oak, and canyon live oak. These are species of great central importance to the Pala Tribe, and their decline is compounded by extreme drought, heat, and wildfire. The loss of coast live oaks has been most striking to the Tribe because these evergreens make up a large portion of the landscape and turn brown as they die. GSOB attacks primarily larger and thus older trees. Their death causes cascading impacts to the ecosystem and species that depend on them, including many bird species and arroyo toads, and creates large safety and wildfire fuels hazards, increasing existing threats in ways that are often positive feedback loops.

Summary

The people of the Pala Band of Mission Indians continue to work to protect and enhance the natural resources and habitat of their lands. Climate change continues to deeply affect the environment and alter and disrupt the ecosystems within and around Pala. The Pala community is actively working to understand, adapt to, and mitigate the effects of climate change. Their goal is to continue to manage and protect their lands and limit the impact climate change is having on Pala's right to hunt, fish, gather, and continue their cultural practices; activities that are integral to their cultural and psychosocial health, well-being, and livelihood.

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Suggested citation:

Pala Band of Mission Indians (2026). Impacts of Climate Change on the Pala Band of Mission Indians. In: OEHHA 2026 Indicators of Climate Change in California.

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6.8 Impacts of Climate Change on the Wiyot Tribe

Sea level rise and increasing weather variability are contributing to the loss of critical habitats and species in Wiyot territory and threatening the culture and economy of the Wiyot Tribe, including their food sovereignty, culturally important species and places, and cultural artifacts.

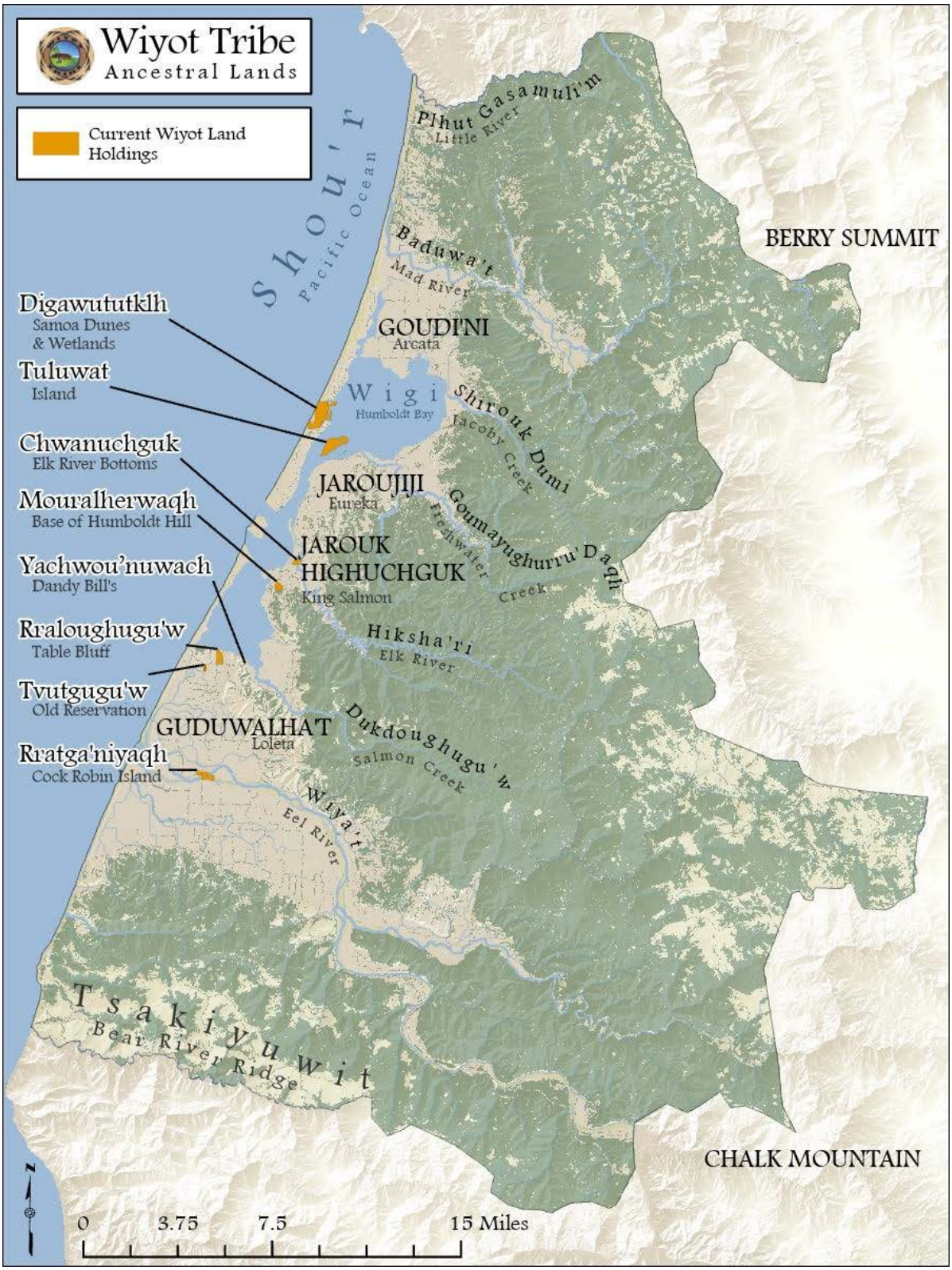
Background

Since time immemorial, the Wiyot people have lived amongst the diverse landscapes of present-day Humboldt County, California. This area includes geographically and ecologically diverse ecosystems such as tidal mudflats, eelgrass beds, salt marshes, estuaries, dunes and wetlands. Forested, prairie and grassland ecosystems also occur in more inland regions. Wiyot traditional homelands extend on much of the Humboldt County coast, from Little River in the North to Bear River Ridge in the South and encompass significant waterways such as Baduwa't (the Mad River), Wigi (Humboldt Bay) and Wiya't (the Eel River) which are shown in **Figure 6.8.1**, below. These vital waterways served not only as travel and trade routes, but permanent Wiyot village sites as well.

Climate of the northern coast is characterized by mild wet winters and cool, fog-heavy summers. On average, Humboldt County experiences 40 inches of rain per year, with about 90% of the precipitation occurring from October through April. Additionally, the Humboldt Bay region is seismically active with the Gorda plate, the North American plate and the Pacific plate meeting in the Pacific Ocean, forming the Triple Junction (Patton et al., 2023).

Through complex and sustained stewardship of these landscapes, the Wiyot people gathered and tended to many species for traditional lifeways, sustenance and basketry material. Traditional stewardship included cultural fire, coppicing, pruning, cultivating edible bulbs and performing the World Renewal Ceremony to bring balance to the land. Culturally significant plant and animal species include acorns, berries, hazelnut, salmon,

Figure 6.8.1. Map of Wiyot Ancestral Territory.



Source: Wiyot Tribe (2025)

Pacific lamprey, sturgeon, crab, shellfish, various surf fish and more. For the Wiyot people, these landscapes represent both a cultural and moral space where community members can tend to and sustain reciprocal relationships with the land and pass down knowledge to future generations.

The Wiyot Tribe has worked diligently to re-acquire traditional homelands. Currently, the land held in trust for the Wiyot Tribe is Table Bluff Reservation (TBR) – which is an 88-acre plot located several miles outside the small town of Loleta, near the South Jetty of Wigi. Through grassroots activism, determination and community programs such as the Wiyot Sacred Sites Fund, the Wiyot Tribe has been successful in purchasing land and other sites of religious and cultural significance for future generations. In 2000, the Wiyot Tribe purchased 1.5 acres of the historic village site of Tuluwat. In May 2004, the Eureka City Council approved a resolution to return an additional 45 acres to the Tribe. In late 2018, the Eureka City Council approved a resolution to relinquish the deed to the remaining 202 acres of Tuluwat, returning it to the Wiyot People. The return of Tuluwat represents the first municipality in the United States to return land without an accompanying sale or lawsuit. In addition to Tuluwat, the Wiyot Tribe acquired 46 acres of Mouralherwaqh in 2022 and 360 acres of Digawutuklh in 2024 (**Figure 6.8.1**).

Climate change and the Wiyot Tribe

The Wiyot people have stewarded and tended to their traditional landscapes since time immemorial. Traditional Ecological Knowledge (TEK) and an intricate, reciprocal relationship with the land have allowed the Wiyot people to adapt to and mitigate changes within the landscape as they arise. However, the severity of climate change impacts to the region are paramount. Due to the diverse landscapes and species of the region, climate change impacts are numerous and include sea level rise, changes in precipitation and changes in air temperatures.

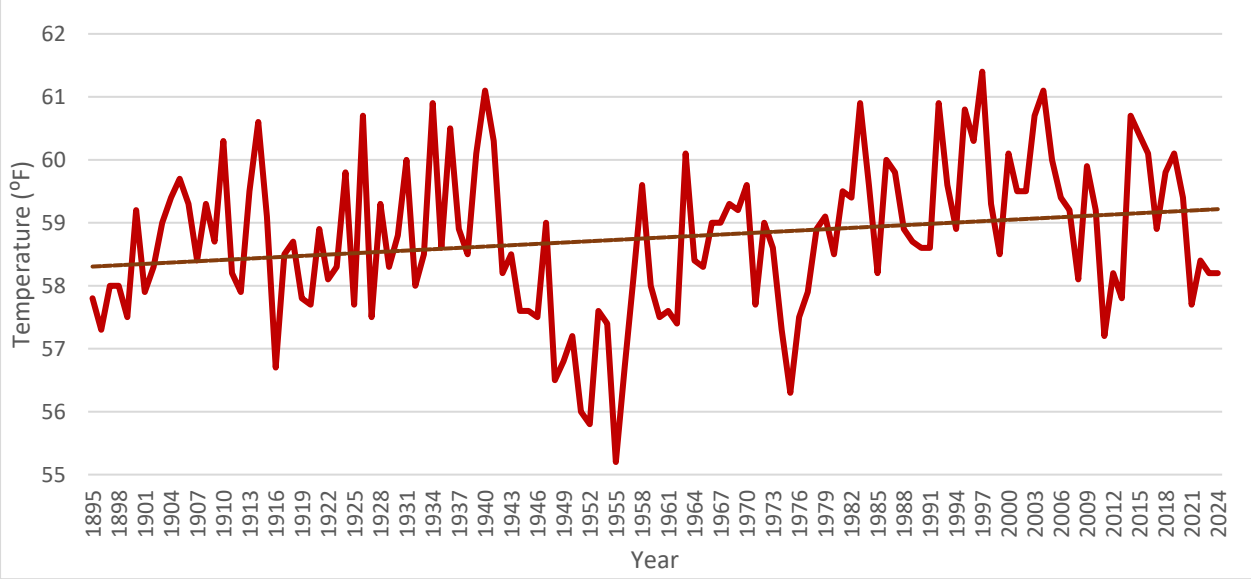
Currently, the Wiyot Tribe has limited capacity to implement robust mitigation measures for climate change impacts. One of the biggest challenges the Wiyot Tribe faces is the loss of traditional homelands. Current Tribal land holdings account for less than 0.2% of their traditional homelands, and the Tribe has few discretionary funds or economic development opportunities to acquire more. Nevertheless, the Wiyot Tribe perseveres

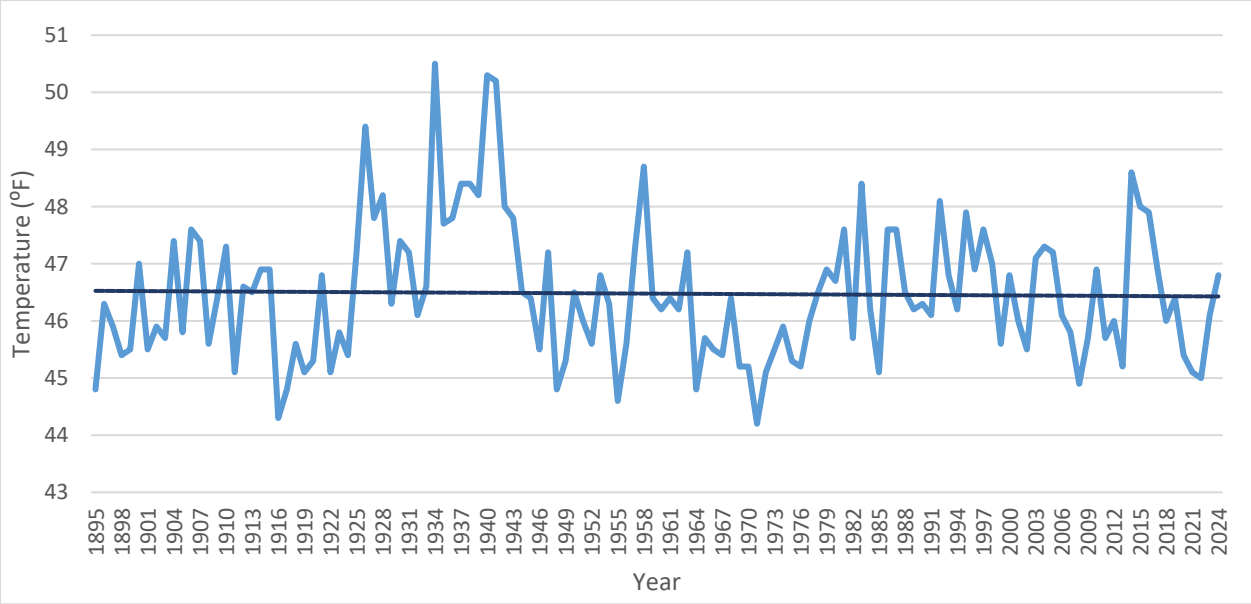
and encourages mitigation measures through grant-funded projects, as well as local partnerships and collaborations. Potential mitigation measures include Shawir Darrudaluduk (Wiyot Natural Resources Department) species monitoring programs, participating in regional planning groups, removal of invasive species, mapping areas of cultural and ethnobotanical significance, establishing a native plant nursery, acquiring more land within Wiyot homelands and advocating for responsible planning and management decisions.

Air temperatures

The Wigi region is characterized by a cool, wet climate with mean temperatures in the 50s (degrees Fahrenheit or ºF, or 10 to 15 degrees Celsius or ºC). The temperature regime of Wiyot territory is relatively stable compared to other areas of California which are experiencing rapid warming, higher extreme heat, and higher variability. However, because Wiyot Tribal members are accustomed to low and consistent temperatures and most of them do not have air conditioning, even relative heat, such as extended temperatures in the high 70s or 80s ºF (24 to 32ºC), can be dangerous for vulnerable Tribal members such as elders.

Figure 6.8.2. Daytime (Top) and Nighttime (Bottom) Air Temperatures at Table Bluff Reservation 1895 to 2024.





The top graph shows annual average maximum, or daytime, temperatures with the linear trend. The bottom graph shows annual average minimum, or nighttime, temperatures with the linear trend. Source: PRISM Climate Group (2025)

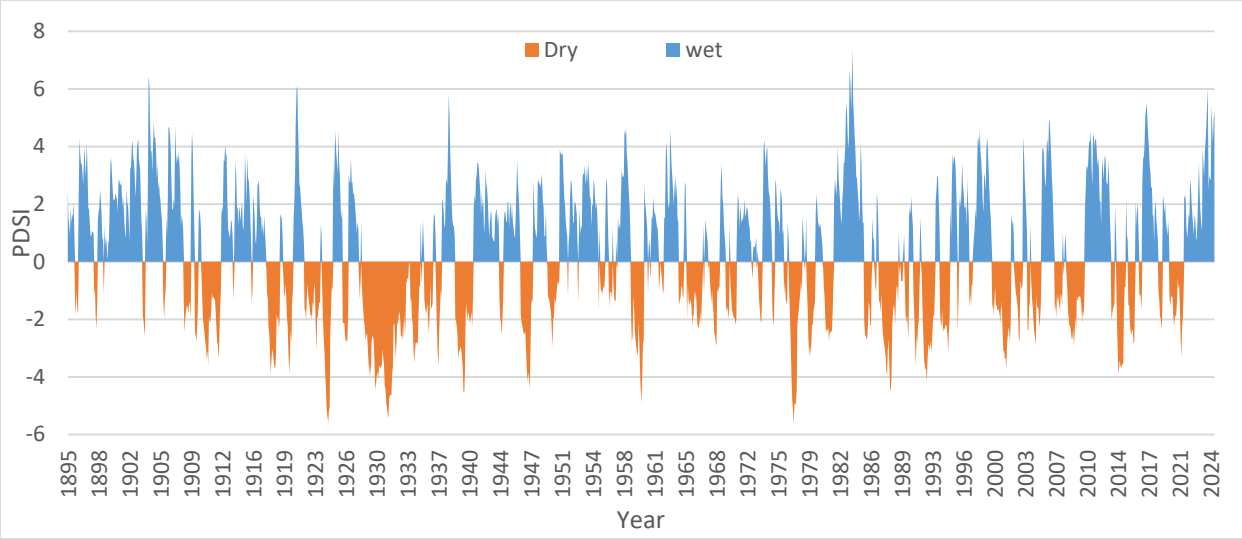
Figure 6.8.2 shows annual average minimum (nighttime) and annual average maximum (daytime) temperatures at Table Bluff Reservation (TBR) from 1895 to 2024, with linear trendlines on both graphs. Nighttime temperatures have decreased over the 130-year period by 0.1ºF (0.06ºC), while daytime temperatures have increased by 0.9ºF (0.5ºC).

Flood and drought

Figure 6.8.3 shows the monthly Palmer Drought Severity Index (PDSI) at Table Bluff Reservation (TBR) from January 1895 to December 2024. PDSI is a scale derived from air temperature, precipitation, and the moisture-holding capacity of the soil to represent the relative dryness (-10 being the most dry) or wetness (10 being the most wet) of a place over a specific period of time. Values less than negative four (-4) are considered severe drought conditions while numbers greater than four (4) are considered very wet.

Similar to temperature, the long-term trend in PDSI at TBR for the 130-year period of record is relatively stable. However, in the past 30 years, TBR has experienced a wetter climate with an increasing trend of severe flood. Seawater encroachment and saturation of coastal soils may be contributing to this trend and are discussed in the **Sea level rise** section (page 209).

Figure 6.8.3. Monthly Palmer Drought Severity Index (PDSI) at Table Bluff Reservation 1895 to 2024.



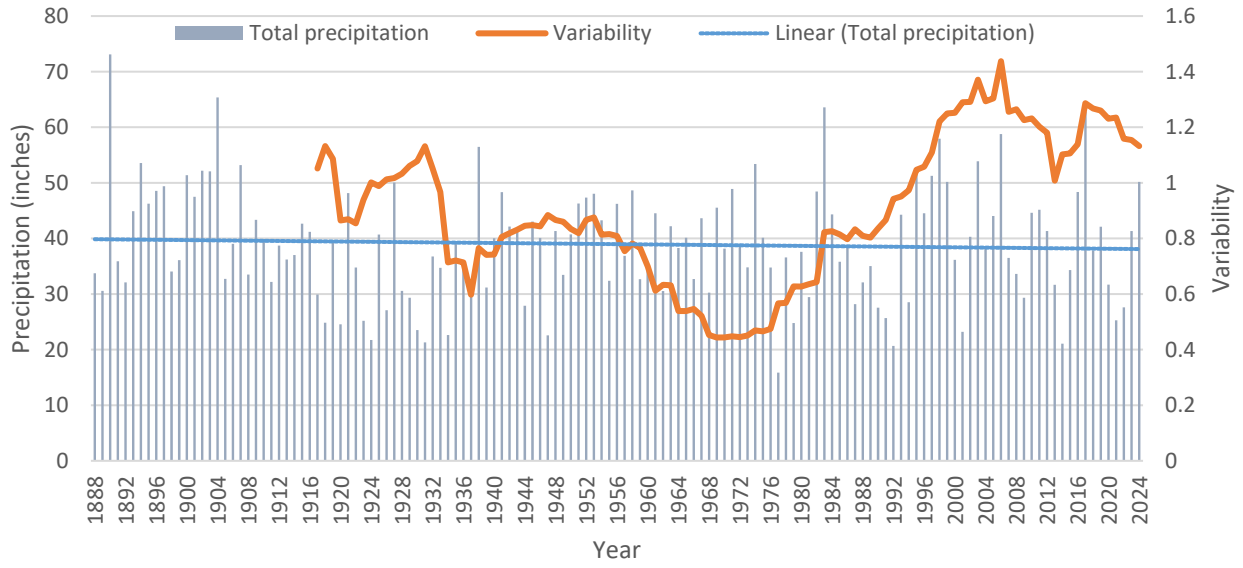
Source: Abatzoglou et al. (2025)

Precipitation

While there has been no observable increase or decrease in total annual precipitation over time (**Figure 6.8.4**, below), there have been changes in the variability of precipitation, including timing and intensity of rainfall around Wigi. Rainfall has been more variable in the last 30 years, corresponding with the period of increasing flood conditions noted in the previous section. The Wiyot have noticed that fall precipitation has become more variable (**Figure 6.8.A-1**, page 228), that there are more, larger atmospheric rivers, and that there is less coastal fog, which is essential for the survival of coastal redwoods, in the inland forests.

Figure 6.8.4 shows total annual precipitation from 1895 to 2024 at the weather station on Woodley Island, which is next to Tuluwat Island in the center of Wigi. There is little to no change in the long-term average annual rainfall over this time period. However, the 30-year variability in rainfall has been at its highest for the last 30 years. Rainfall was most consistent in the 1970s and most variable in the late 1990s to early 2000s.

Figure 6.8.4. Total Annual Precipitation (in Inches) at Woodley Island from 1895 to 2024.



Blue bars represent total water year precipitation on the left y-axis. The orange line represents variability: the ratio of 30-year variance to the variance of all 130 years. When variability is less than one (1), rainfall in the preceding 30 years was more consistent relative to the entire period. When variability is greater than one (1), the preceding 30 years had more variable rainfall compared to the entire period. Source: NCEI (2025)

Fall precipitation arriving at variable times impacts traditional Wiyot lifeways. Wiyot basketweavers and berry pickers must gather plant material and fruit at particular times of year. Gathering camps have traditionally been established around August and September when plants are in the best condition for harvest and traditional uses. This short window is disrupted by early storm activity. Early precipitation can cause less or incomplete ripening of berries, a process which is dependent on there being sunnier days in the period before the cold season arrives.

Losses of material and food due to weather are compounded by the fact that the majority of the Wiyot's historically and culturally important gathering sites were incorporated into National and State Parks. Tribal members are no longer permitted to gather in those areas and may face consequences for trying to access ancestral gathering grounds. This makes it even more important that the sites that Tribal

members can still access are productive.

Increased variability in precipitation has also impacted cultivated resources, such as hay. The Tribe has experienced more losses from both earlier-than-anticipated or excessive precipitation as well as from fire and drought, both of which lead to a loss of income.

Sea level rise

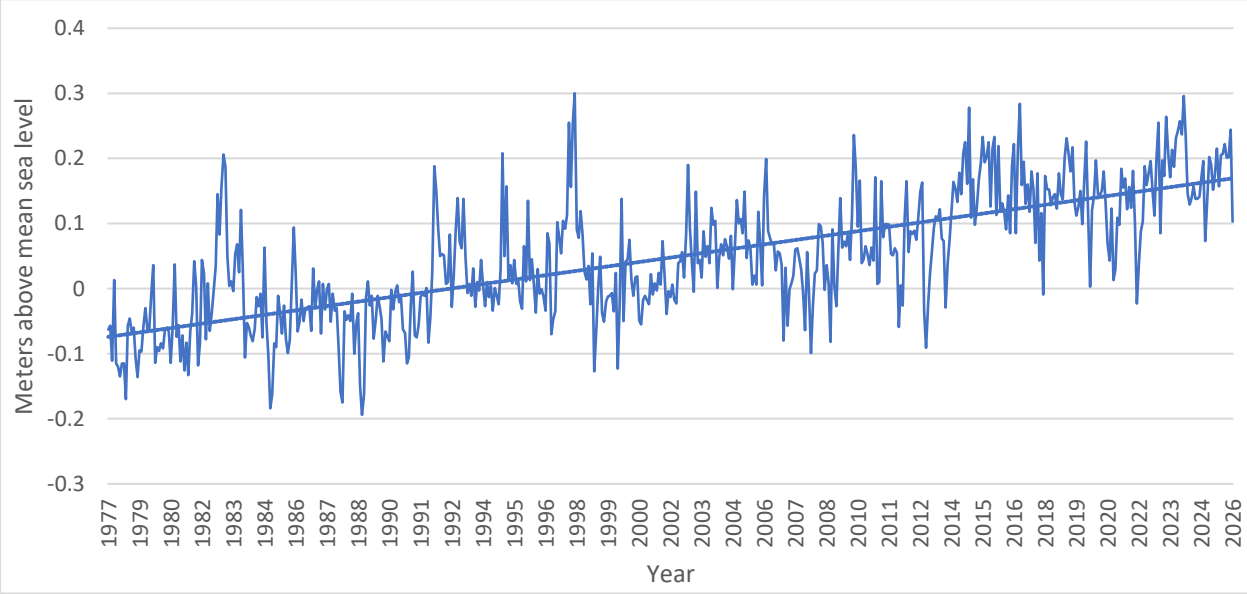
Relative sea level rise is one of the greatest impacts to the developed area around Wigi, including the largely coastal areas that the Wiyot Tribe currently manages and the places where the majority of the population of Humboldt County reside. While sea level change refers to the change in ocean water level relative to land elevation globally, relative sea level change is the way in which seawater level is changing in relation to land in a particular place. Relative sea level change takes into account global sea level change as well as the vertical motion of land and changes in wind and ocean circulation (NOAA, 2025).

Relative sea level rise around Wigi is driven primarily by plate tectonics, with a small contribution from climate warming-driven global sea level rise. Along with changes in precipitation and storm size, relative sea level rise is increasing the frequency and severity of flood events, expanding the tsunami hazard zone, consuming tidal habitats, and causing saltwater encroachment on culturally significant freshwater habitats and sacred sites of the Wiyot Tribe.

Figure 6.8.5 shows relative sea level measurements at the North Spit Station in Wigi, which is maintained by the National Oceanographic and Atmospheric Administration (NOAA). At North Spit, relative sea level has risen at a rate of 5.08 millimeters per year (1.67 feet over 100 years).

Relative sea level is rising 2–3 times faster in the southern portion of Wigi than anywhere else on the California coast. Analysis of temporary tide gages around Wigi suggests that the rate is as high as 6.2 millimeters per year around Hookton Slough in the southern part of Wigi near TBR (Anderson, 2018; Patton et al., 2023). Approximate locations of North Spit and Hookton Slough are in **Figure 6.8.7** (page 212).

Figure 6.8.5. Relative Sea Level Measured Monthly at North Spit Station, September 1977 to March 2026.

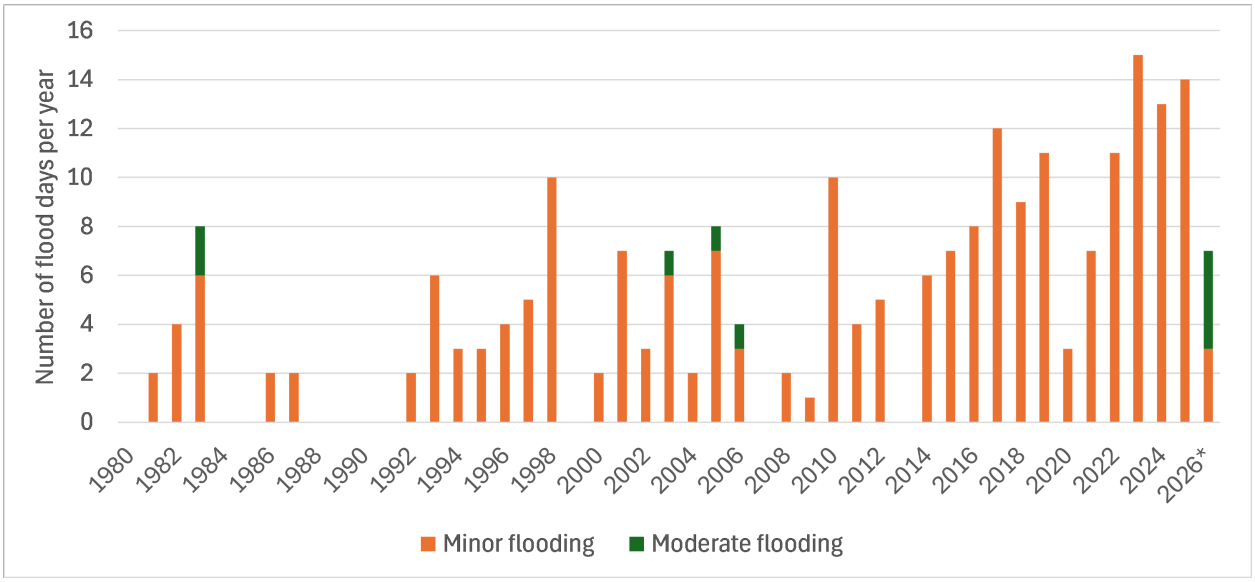


Source: NOAA (2026)

Vertical land motion, or in this case, the subsidence or sinking of the land, is the greatest driver of rising relative sea level around Wigi. The high rate of subsidence around Wigi is caused by elastic deformation of the North American plate as the Gorda plate dips below it along the Cascadia Subduction Zone just off the coast in the Pacific Ocean (Patton et al., 2023). In other words, the coastal land of Wigi is being slowly bent toward the ocean by the force of the plate that is sinking below it to the west (**Figure 6.8.A-2**, page 229).

Relative sea level rise contributes to more severe coastal flooding. The Tribe has experienced an increasing number of high tide flood events over the past 40 years. Annual flood events are shown in **Figure 6.8.6**.

Figure 6.8.6. Annual Flood Fays at North Spit, January 1980 to March 2026.



Data from 2026* is January through March. Source: NOAA (2026)

Flood heights are measured as the height of the water above the average highest tide, or the Mean Higher High Water (MHHW). In other words, the flood level is the height of the water above the highest point that it would reach under average conditions. Flooding is categorized as minor, moderate or major. The thresholds for minor flooding and moderate flooding are 1.92 feet (0.59 meters) and 2.83 feet (0.86 meters) above MHHW, respectively. In 2023, there were 15 flood events, the greatest number recorded in a single year. The highest tide event recorded at this station was in January 2026 when the water reached 3.52 feet (1.07 meters) above MHHW. As of March 2026, there had been more moderate flood days (four) in 2026 than any other year in the record. Major flooding begins at 4.11 feet (1.25 meters) above MHHW and has not been recorded at this station.

The threat of coastal flooding around Wigi has been made worse by development. Most of the region at risk of inundation was already inundated before settlers arrived to Wigi. Settlers created infrastructure such as dikes, levees, and miles of man-made earthen shoreline to drain these coastal areas and raise the land for their farms and homes.

They destroyed coastal wetlands by cutting them off from Wigi, preventing habitats from adaptating gradually and migrating in response to fluctuations in sea level and thus reducing the ecological resiliency of the area overall. King tides already overtop these levees, threatening coastal infrastructure such as the Highway 101 corridor.

Figure 6.8.7. Inundation Map for 1 Meter of Relative Sea Level Rise.



Coastal areas (darker blue) and tidal areas (lighter blue) in Wiyot territory that would be inundated with sea level rise of 1 meter above the average highest tide. Source: NOAA (2025)

Figure 6.8.7 shows the inland flooding extent around Wigi based on elevation when sea level is 1 meter above MHHW. The coastal area (darker blue) which would be inundated is over 83 square kilometers (km), or 20,500 acres. Tuluwat, outlined in purple, and other islands in the bay along with tidal mud flats (lighter blue) make up an additional 24 square km or 6,000 acres likely to be inundated. This map does not take subsidence into account, and thus the inundated area is likely to be larger in the future.

Impacts to Tuluwat Island

Inundation of cultural sites such as Tuluwat is a major concern of the Tribe for the next century. Located in the center of Wigi, Tuluwat is the center of the universe for the Wiyot people. Since time immemorial, the Wiyot people have served as stewards of Tuluwat, performing an annual World Renewal Ceremony to bring balance to the land and its people. Tuluwat is home to sacred village and gathering sites, as well as a historic shell midden. Shell middens, which are commonly found along coastlines, are sites formed through the accumulation of shells from shellfish eaten by the Indigenous people from that specific location or region. This 6-acre, 14-foot deep shell midden covers a smaller village site on the island. The shell midden contains remnants of Wiyot daily life including tools, ceremonial items, meals, and burial sites (EPA, 2018).

In 1860, Tuluwat was seized by Robert Gunther. Gunther diked the island and ran cattle on the land. Additionally, a shipyard repair facility with a dry dock was constructed on the island in 1870. For over a hundred years, the shipyard repair facility utlized various hazardous materials to repair and service boats – such as paints, solvents, petroleum products, and other chemicals (EPA, 2018). Due to the long history of environmentally sensitive operations and improper handling of hazardous materials, Tuluwat was left highly contaminated. In 2001, the Wiyot Tribe received a Targeted Brownfield Assessment (TBA) grant from the US Environmental Protection Agency (EPA) to cleanup and remediate the island. Cleanup and remediation focused on minimizing disturbance – such as protecting the shell midden and burial grounds, while ensuring the island met cleanup levels necessary for ceremonal uses. Today, the Wiyot Tribe continues to protect this site from erosion and corrosion as the water rises.

Tsunami risk

In addition to increased flooding during high tide and storm events, Wigi faces an expansion of inundated areas during tsunamis. The Tohoku Tsunami occurred in March 2011 following a large earthquake in Japan. It reached California during a low tide, and although the inland flooding was not extensive, storm surge caused over $50 million in damage to the state and killed one person, with the majority of damages occurring in Crescent City (Wilson, 2013).

In response to this and other tsunami events and national guidelines, California produced tsunami evacuation area maps between 2020 and 2022, with the next update planned for 2030. The update will take relative sea level rise into account for the first time. The maps are based on a model with a high degree of conservatism, which may have a greater impact on area designations than the contribution from sea level (Patton, 2025).

Impacts to eelgrass and wetland habitats

Sea level rise and increased storm severity, along with ocean warming and acidification, pose a threat to Wigi eelgrass habitat. Eelgrass is a vital habitat for many species, including Dungeness crab, juvenile salmonids, rockfish, and migratory birds (Merkel and Associates, Inc., 2017). As part of their mitigation efforts to help habitats and species migrate inland, the Tribe is working on an eelgrass suitability distribution model. This model will take temperature, salinity, depth, substrate conditions, and other eelgrass habitat parameters into account to help the Wiyot find locations for future eelgrass survival and protection.

"Some places the Tribe already got back will be inundated. People are always trying to give back low-lying land that will be flooded." *~Adam Canter*

Sea level rise and larger storm surges contribute to gradual beach loss and acute scarping, or the erosion of front dunes by waves. These processes are destroying the habitat of bulb species that the Wiyot Tribe depends on, such as various Indian

potatoes (*Brodeia and Dichelostemma congestum*), native lilies (*Fritillaria affinis*), and more. Surviving harvesting locations are further threatened by invasive species such as cord grass, ice plant, and pampas grass.

The Wiyot Tribe bolsters ecological resilience to changing ocean conditions by removing invasive species, planting native species, and encouraging the inland migration of salt marshes and dunes to help attenuate wave energy and protect vulnerable habitats. Mad River Slough is one area lacking this critical natural infrastructure that has been identified as needing additional stewardship. To implement its adaptation plan, the Tribe seeks to protect or acquire more lands of different habitat types along the coastal fringe, where habitats can naturally migrate inland. For example, they have identified freshwater wetlands that would be suitable to convert to salt marsh. A particular challenge for the Tribe in implementation is acquiring more upland habitats, of which they currently have or manage very little. The Tribe has established a Sacred Sites Fund to help them reclaim these lands that are critical for ecological and cultural resilience.

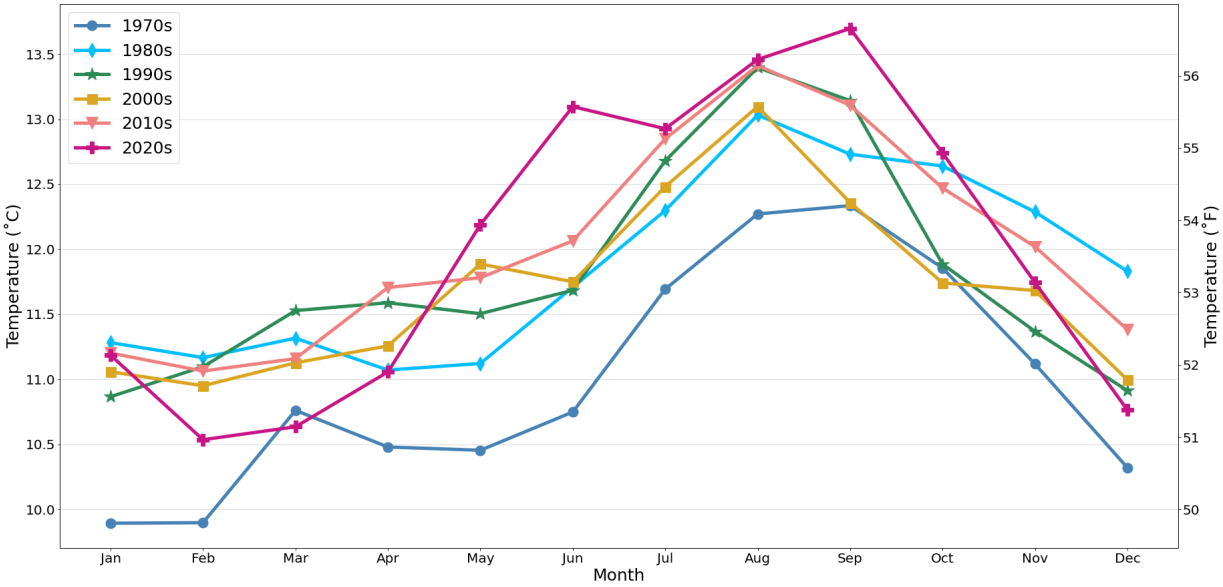
Estuarine system warming, salinization and acidification

As sea level rises, saltwater penetrates higher into marshes and tributaries which are already experiencing stress from drought, heat, and increased salinity. Warming and salinization in the Wigi estuary system are related, but also highly variable and controlled by complex interactions of terrestrial and marine drivers. On land, drought and high air temperatures decrease streamflow and freshwater inputs to Wigi and increase evaporation, which can cause reduced, warmer, and saltier streamflows in tributaries, particularly in the late summer and fall (Merkel and Associates, 2017; Brennan et al., 2022; CDFW, 2025). In the summer, these phenomena often occur at the same time that coastal upwelling brings colder, saltier water to the marine-influenced portions of the Bay (Schlosser and Eicher, 2012). At this dynamic intersection of land and ocean, Wigi's estuaries are impacted by the fluctuating conditions of both.

There is a long-term trend of sea surface warming and salinization in the Pacific Ocean (see the *Coastal Ocean Temperature* chapter). **Figure 6.8.8** shows that sea surface

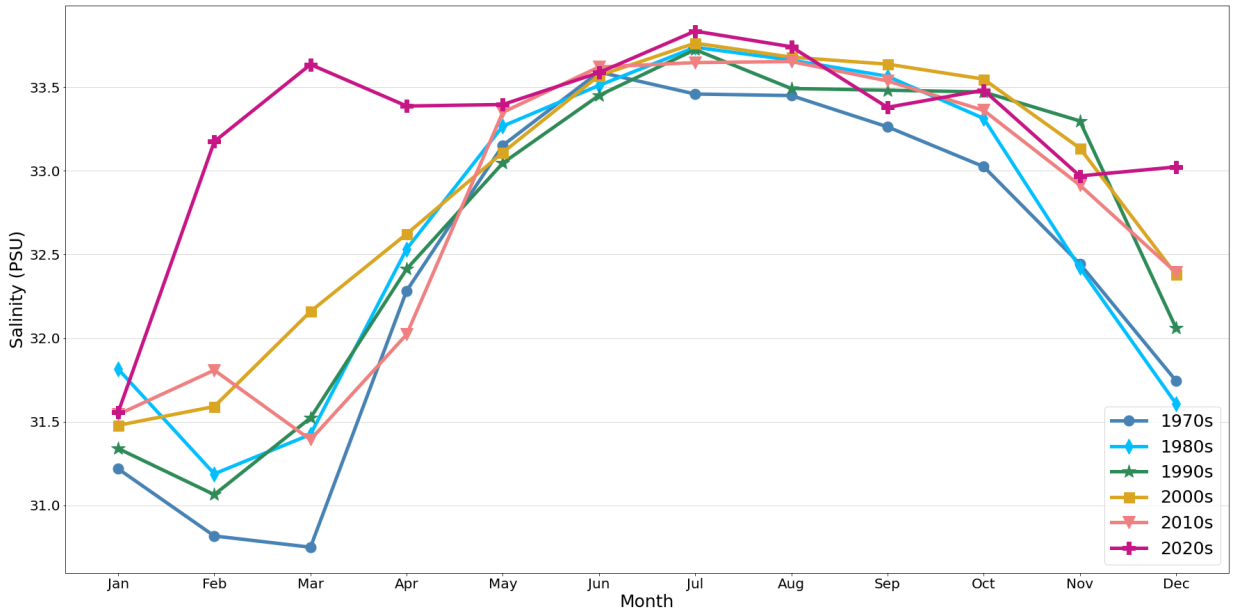
temperature (SST) measured at Trinidad Beach just north of Wigi has been warming over the last 50 years. The greatest increases have been observed in the months of May through September (**Figure 6.8.A-3**, page 230).

Figure 6.8.8. Monthly Mean SST at Trinidad Beach.



Source: Carter et al. (2022)

Figure 6.8.9. Monthly Mean Sea Surface Salinity at Trinidad Beach.



The y-axis shows salinity in the unit of Practical Salinity Unit (PSU). Source: Carter et al. (2022)

Figure 6.8.9 shows an increase in salinity measured at the same station over the same time period. Salinization kills culturally-important bulbs, harms eelgrass, and threatens groundwater quality. Changes in estuarine temperature and salinity can also influence the type, timing, and severity of harmful algal blooms (HABs). See **HABs** section for more detail.

Rising SST increases the likelihood of marine heatwaves, defined by NOAA as when the 30-day mean SST is above 90% of the normal for a particular place and season. Marine heatwaves observed off the coast of Wigi since 2014 are some of the warmest and longest on record (**Figure 6.8.A-4**, page 231). Marine heatwaves have widespread impacts on ocean ecosystems (NOAA, 2024a). In the Northeast Pacific, marine heatwaves may contribute to the rise in whale entanglement in fishing gear through a combination of factors that influence marine mammal migration and feeding patterns as well as fisheries. The California Department of Fish and Wildlife (CDFW), which

manages the commercial Dungeness crab fishery has responded to the potential for whale entanglement by implementing fishing restrictions or early closures for five of the past six years (**Figure 6.8.A-5**, page 232). Marine heatwaves can increase the occurrence and severity of HABs which are discussed in the **HABs** section, below.

Ocean acidification is also a concern for the Wiyot Tribe as it threatens low-lying cultural sites and many estuarine flora and fauna of great importance, including shellfish. While research is ongoing, there is some evidence that Wigi itself demonstrates a buffering effect against the otherwise rising acidity (lowering of pH) of the ocean. There are several hypotheses for this observation, one of which is that eelgrass plays a critical buffering role, underscoring its ecological importance (Barriquand et al., 2023).

Harmful algal blooms (HABs)

The Wiyot are impacted by both marine and freshwater HABs in their territory, which are caused primarily by certain types of diatoms and dinoflagellates, and cyanobacteria, respectively. While there are many factors that influence the growth of HABs, there are signs that climate change may be exacerbating the impacts of HABs in marine and freshwater environments (see the *Marine Harmful Algal Blooms* chapter and the *Cyanobacterial Harmful Algal Blooms (Freshwater and Estuarine)* chapter). For more information on HABs, see OEHHA's HABs webpage.

Freshwater HABs

The Tribe is involved in monitoring efforts for HABs on the lower Wiya't (Eel River). The California North Coast Regional Water Quality Control Board confirmed the presence of freshwater HABs on the South Fork of the Eel River every year from 2016 to 2023 as well as in 2025 (NCRWQCB, 2022; NCRWQCB, 2024). During the same time period, multiple algal blooms were reported for Baduwa't (Mad River), the mainstem Wiya't, and other regional fresh waterbodies, although not all of the reported blooms were confirmed to be HABs via laboratory testing (SWRCB, 2025). Blooms in these rivers are most common in the late summer and fall.

Marine HABs

Domoic acid is a naturally occurring marine biotoxin that may be produced during "blooms" of some species of algae (*Pseudo-nitzschia* spp.). Scientists are still investigating when, how, and why this happens. While no specific trend is evident, marine HABs, including those that produce domoic acid, are influenced by warming ocean temperatures.

Pseudo-nitzschia spp. blooms off the coast of Wigi have had a particularly negative impact on the Dungeness crab and razor clam fisheries, both species that the Wiyot rely on for subsistence. The body mass of these and other invertebrates can accumulate domoic acid, which is toxic for human consumption above a certain threshold. Dungeness crab is fished commercially and recreationally in Humboldt County, and razor clams are fished recreationally. The Tribe has suffered cultural and economic losses as a result of missed catch and consumption opportunities of these and other species impacted by HABs. Razor clam consumption advisories or closures have been in place in Humboldt County over the majority of the past decade due to domoic acid (**Figure 6.8.A-6**, page 233). While there are more varied reasons for closures and restrictions in the Dungeness commercial and recreational fisheries (**Figure 6.8.A-5**, page 232), fishery-dependent communities around Wigi were shown to be particularly economically and socially vulnerable to the 2015 to 2016 domoic acid closure events (Moore et al., 2019).

Impacts on plants and animals

Culturally significant plant and animal species include acorns, berries, hazelnut, malhuk (salmon), gou'daw (Pacific lamprey), sturgeon, crab, shellfish, various surf fish, abalone, and more. Flora and fauna populations have been impacted by ongoing direct human activities, including logging, grazing, agriculture, development, over-harvesting, dewatering and damming as well as by climate change.

Impacts on spruce

Wiyot territory is home to the largest southern-most Sitka spruce population, some of which is under the Tribe's management for fuels reduction and overall ecosystem health

improvement. The spruce population is in decline, and this issue is partly attributable to the invasive green spruce aphid (*Elatobium abietinum*). The aphids are strengthened by warmer winter temperatures, more water-logged soils, and weakened tree defenses.

Impacts on anadromous fish

Climate change harms anadromous fish species within Wiyot territory, including California Coastal Chinook salmon, Northern California Coho salmon, Northern California Summer and Winter steelhead, gou'daw (Pacific lamprey), and ba'm (green sturgeon).

Before colonization, the Wiya't (Eel River) supported large runs of gou'daw, who were mistaken by Europeans as eels. According to the Pacific Lamprey Conservation Initiative, which has included input from the Wiyot Tribe, Pacific lamprey are "imperiled" in the Wiya't and North Coast region and their population is very rapidly declining in the short term. The greatest threats of climate change to lamprey are through reduction in water quality, dewatering (including increasing withdrawals for agriculture) and inadequate flows. While it is difficult to monitor and estimate lamprey populations, "*they are believed to have declined considerably since the 1970's and by 50-70% since 1990, based on anecdotal reports from local residents and the impressions of tribal fishermen*" (PLCI, 2024).

Wiya't was also home to the some of the largest salmon runs in California. In Wiyot oral history, there were so many salmon before colonization that one could cross the river by walking on their backs. It is likely that nearly a million salmon returned to the river in a good year (Yoshiyama and Moyle, 2010). Post-colonization damming, logging, agriculture, and over-harvesting reduced salmon populations by as much as 99%, significantly reducing their ability to respond or adapt to climate change-related events.

Salmon and steelhead populations are considered more vulnerable to climate change impacts than lamprey and sturgeon as their migrations and life stages are highly sensitive to changes in freshwater temperature, flow, and quality. They are impacted by declining habitat access and quality both upstream, as freshwater quality and quantity declines, and downstream, as critical salmonid estuarine habitats, such as eelgrass

beds, declines (NOAA, 2024b; NOAA, 2024c). They face increasing challenges at all stages of their life cycle. Threats from climate change include but are not limited to: increased ocean, estuarine and freshwater temperatures; decreased instream flows; lack of habitat of suitable complexity, size or depth; decreased dissolved oxygen; impeded fish passages (around dams) during high winter flows; increased predation by more heat tolerant native and invasive species; increased vulnerability to diseases; and eutrophication (NOAA, 2024d).

The Wiya't, its tributaries, and the Baduwa't support ecologically distinct populations of California Coastal Chinook salmon (*Oncorhynchus tshawytscha*), which are currently listed as threatened under the Federal Endangered Species Act (ESA). Chinook counts have been below average for the past six years and the population shows no long-term trend for recovery, remaining at high risk of climate vulnerability. Coho in the South Fork Wiya't are a critical population listed as threatened under both the Federal and California ESA, although their populations are declining and likely to become endangered in the foreseeable future. Summer steelhead are also listed as endangered under the California ESA and their habitat indicators are getting worse over time (NOAA, 2024d).

Wildfire and wildfire smoke impacts

Contrasting western views of "wilderness" as a pristine and untouched landscape, California was carefully shaped and stewarded by Indigenous peoples through the use of fire. Indigenous fire is the intentional application of fire on the land for cultural purposes – such as increased quantity and quality of basketry material, increased abundance of edible bulbs, seeds, and mushrooms, pest control, removal of dead material, and much more (Anderson, 2005). Unlike western fire suppression regimes, Indigenous application of fire entails important considerations such as frequency, seasonality, and the extent of the fire. More specifically, frequency ensures that Indigenous fire is controlled and low intensity.

Since time immemorial, the Wiyot people have regularly burned to steward their homelands. For example, coastal prairie ecosystems found along Baduwa't, Wigi, and Wiya't were established and maintained through frequent fires. Wiyot fires ensured the

coastal prairie ecosystems were bountiful with grasses, ferns, and various small plants which created nutrient dense regions for animals to graze and congregate. These fires prevented forest encroachment, which can lead to loss of plant and animal biodiversity, as well as increased erosion and hydrology issues. Unfortunately, fire suppression in the American west is inextricably linked with colonization and the history of federal Indian Policy that removed Indigenous peoples from the land (Kimmerer and Lake, 2001). Today, wildfires pose a significant threat throughout the state of California. Climate change and years of fire suppression have created an environment in which wildfires burn out of control and extremely hot – leading to destruction for both the land and the people.

Although a majority of Wiyot traditional homelands are situated within moderate fire-hazard severity zones, Humboldt County contains many high or very high Fire Hazard Severity Zones, or FHSZ (CAL FIRE, 2025). FHSZ are used to predict the physical damage a fire is likely to cause based on factors that influence fire such as fire history, terrain, weather, and existing and potential fuel sources. Wildfire frequency in the region is expected to intensify, with Humboldt County projected to have one of the highest increases in burn areas in California (Cal Poly Humboldt, 2025). The Wiyot community may not experience frequent wildfires in their traditional homelands; however, increased local wildfires will expose community members to poor or dangerous air quality. More specifically, atmospheric conditions will drive smoke, ash, and soot into the region. Wildfire smoke is composed of particulate matter (PM) and gases which can vary between burn sites and types of fuel burned, such as natural fuel sources (vegetation) versus synthetic fuel sources (plastics). Inhalation of wildfire smoke can cause immediate health symptoms such as difficulty breathing, coughing, wheezing, and irritation of the throat, nose, and eyes. Studies regarding prolonged or chronic exposure to wildfire smoke are ongoing. However, preliminary data suggests significant decreases in lung function and increases of inflammatory markers throughout the entire body (Lein et al., 2023). In addition to smoke, wildfires produce ash and soot. Ash is the powder created from the combustion of vegetation or synthetic materials, and soot is the powder made from the incomplete combustion of carbon materials. Both ash and soot can accumulate and persist within the environment, leading to long term negative

heath consequences for community members and the environment.

Lastly, increased wildfire frequency throughout California has led the northwest coast of Humboldt County to be referred to as climate refugia. Climate refugia are generally defined as areas relatively buffered from contemporary climate change which can safeguard plants, wildlife, and ecosystems (Morelli et al., 2020). The northwest coast is not immune to climate change; however, climate change impacts different parts of the world in different ways. For Wiyot traditional homelands, the proximity to the Pacific Ocean and the Redwood Belt helps moderate and sustain a cooler, wetter climate. When compared to other regions of California, the local climate is relatively "stable" – making it a destination for individuals fleeing wildfires and other climate change impacts. Catastrophic fires, such as the 2018 Camp Fire, created an influx of people into to the region who were escaping the aftermath of the fire. Furthermore, as temperatures increase throughout California, many state residents flock to the region for relief from dangerous temperatures. People flocking to the region and putting increased demand on the poor infrastructure and limited resources within Wiyot traditional homelands pose a significant risk to the Wiyot community.

Impacts on Tribal health

Climate change continues to negatively affect the livelihoods, health and cultural practices of the Wiyot people. Climate change not only affects the landscapes but significantly impacts overall tribal health and wellbeing by exacerbating health disparities. Some health related impacts include wildfire smoke inhalation and increased risk of vector-borne diseases. As mentioned previously, increased local wildfires will expose community members to poor or dangerous air quality. Inhalation of wildfire smoke can cause immediate health symptoms such as difficulty breathing, coughing, wheezing, and irritation of the throat, nose, and eyes (Lein et al., 2023). Furthermore, Wiyot community members have noticed an increase of disease-carrying ticks within the region. Changes in temperature allows ticks to become more active in the spring and fall seasons. Humboldt County, as well as Santa Cruz, and Sonoma, have the higher average rate of Lyme disease (from 2013 through 2019) when compared to other regions of California (CDPH, 2021).

The Wiyot Tribe conducted climate change surveys among community members over a several month period in 2020 and 2021. The survey, conducted by Shawir Darrudaluduk, consisted of basic participatory information, as well as a series of questions. Community responses to the questions highlighted climate change disruptions to cultural practices, gathering traditional foods, and overall mental health well-being. More specifically, responses noted deep concerns for sacred village sites, gathering sites for food and basketry material, ceremonial sites, land back, and the overall loss of cultural stories, memories, and knowledge.

Summary

The Wiyot Tribe continues to be stewards of their traditional homelands around Wigi (Humboldt Bay) and of the watersheds and upland regions surrounding and connected to it. The Tribe is seeing rising and more destructive tides; loss of estuaries, wetlands and the plants that live there; changing precipitation patterns; losses of freshwater flows and critical fish species; increased losses of flora and fauna to invasive species and pathogens; and increasing impacts from regional wildfire and drought. The health of the Wiyot Tribe is impacted by the loss of lifeways associated with these plants, animals, waterways and landscapes, as well as by increases in vector-borne diseases and smoke inhalation. The Wiyot bolster ecological resiliency in their region by protecting, restoring and assisting in the migration of critical habitats as climatic conditions continue to change.

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Suggested citation:

Wiyot Tribe (2026). Impacts of Climate Change on the Wiyot Tribe. In: OEHHA 2026 Indicators of Climate Change in California.

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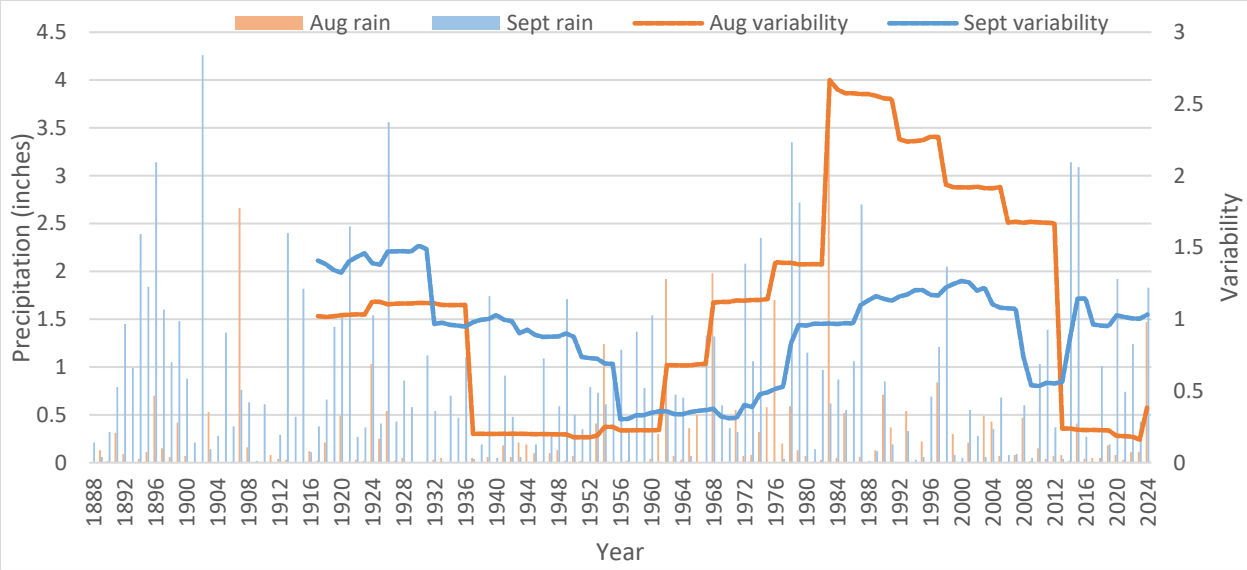
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Appendix

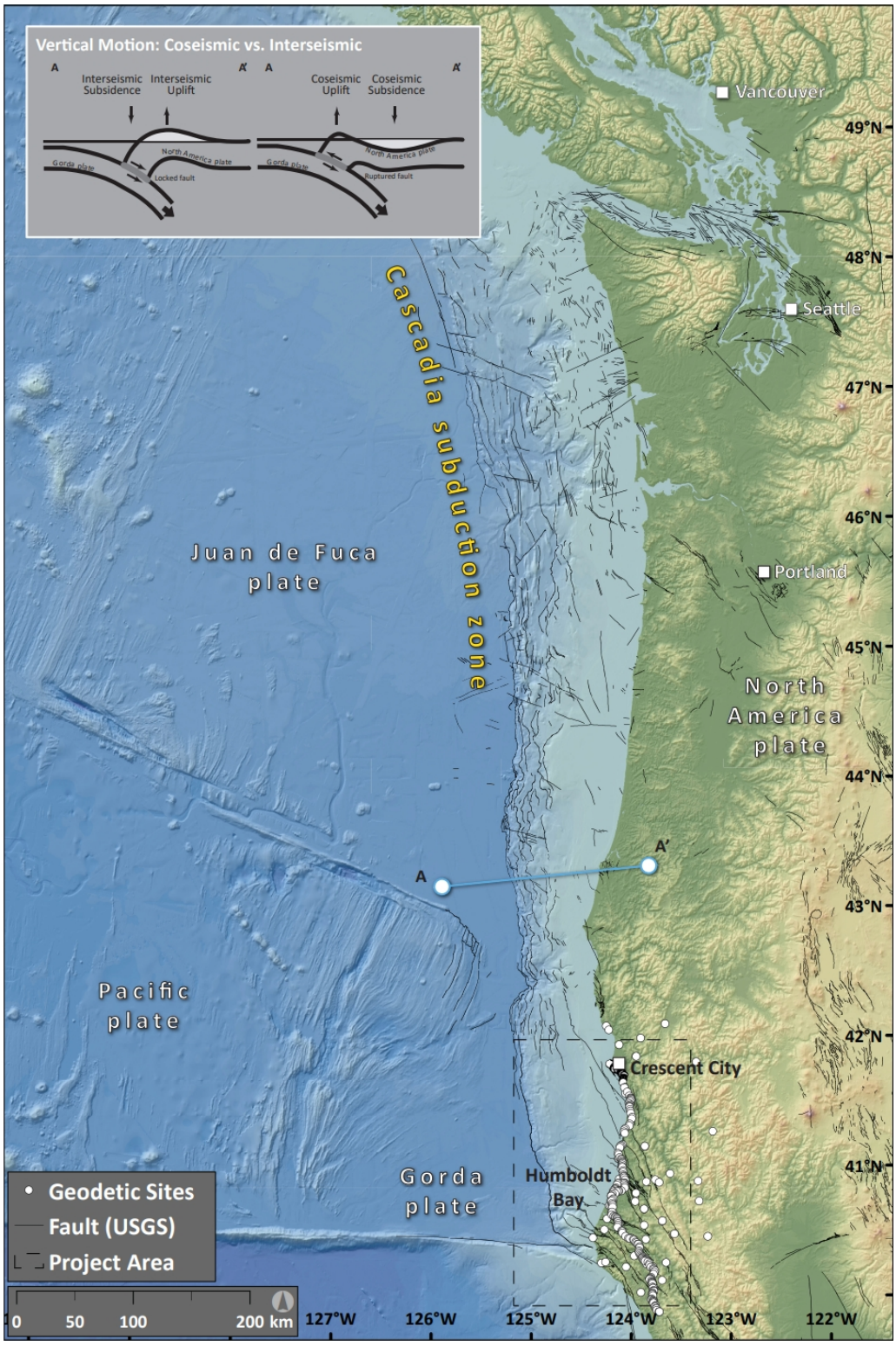
Figure 6.8.A-1. Variability in August and September Precipitation at Woodley Island 1895 to 2024.



The vertical bars represent total August (in orange) and September (in blue) precipitation each year. Variability is calculated using the same method as in **Figure 6.8.4** (page 208). Source: NCEI (2025)

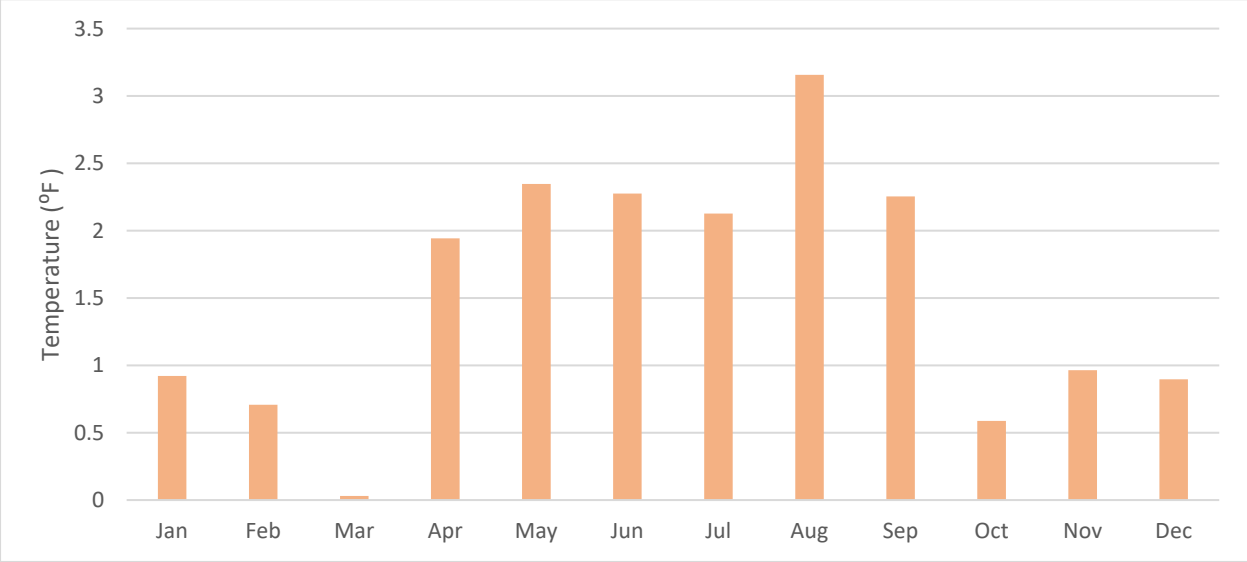
Figure 6.8.A-1 shows that August rainfall at Woodley Island was most variable between 1982 and 2013, peaking at it's highest variability around 1983. August rainfall has been more consistent in the past decade. Total September rainfall has been less variable than August overall. It was most variable at the end of the 20th century, and again around 2015 when there were two years of very high September rainfall after a period of low rainfall.

Figure 6.8.A-2. Cascadia Subduction Zone Map.



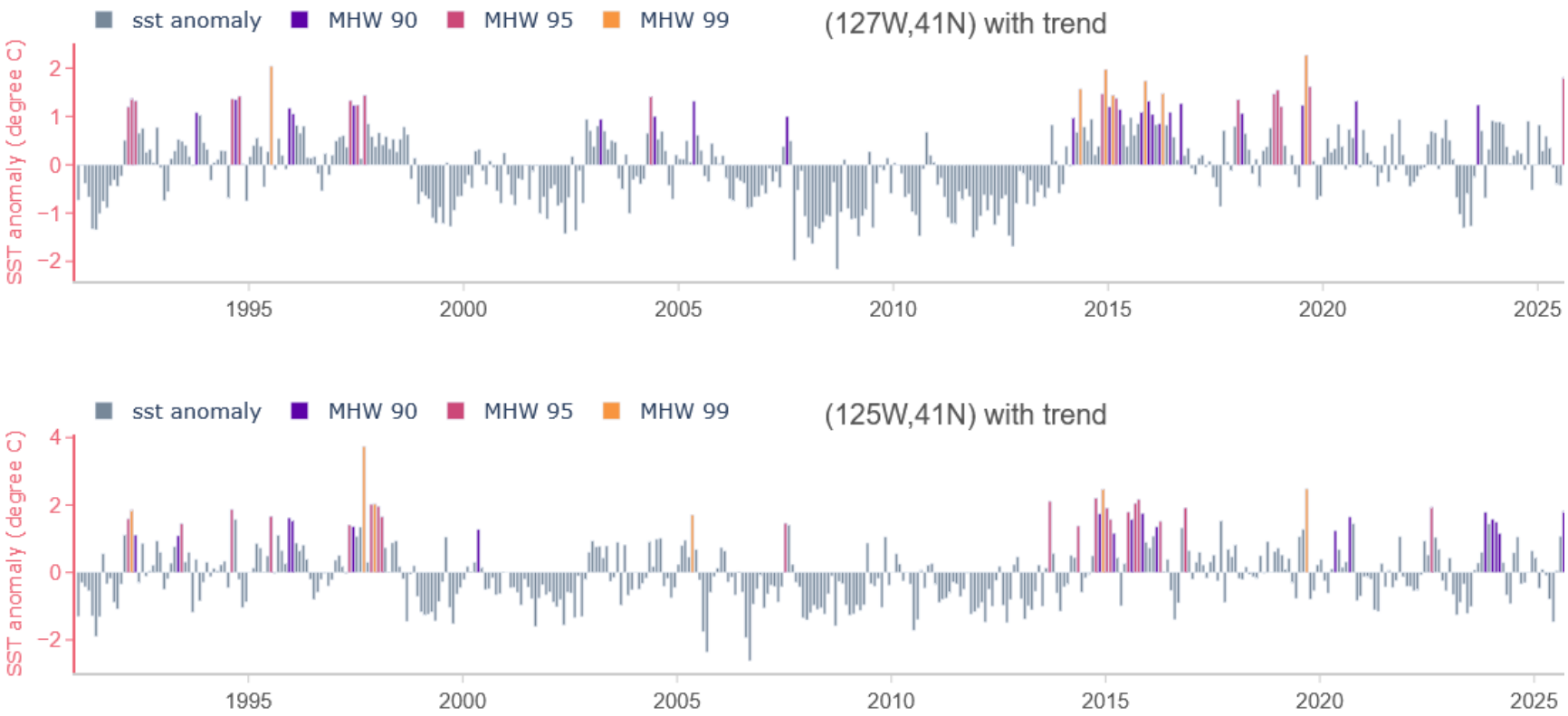
A plate tectonics diagram superimposed on a map of the Cascadia Subduction Zone region along the California coast. Source: Patton et al. (2023)

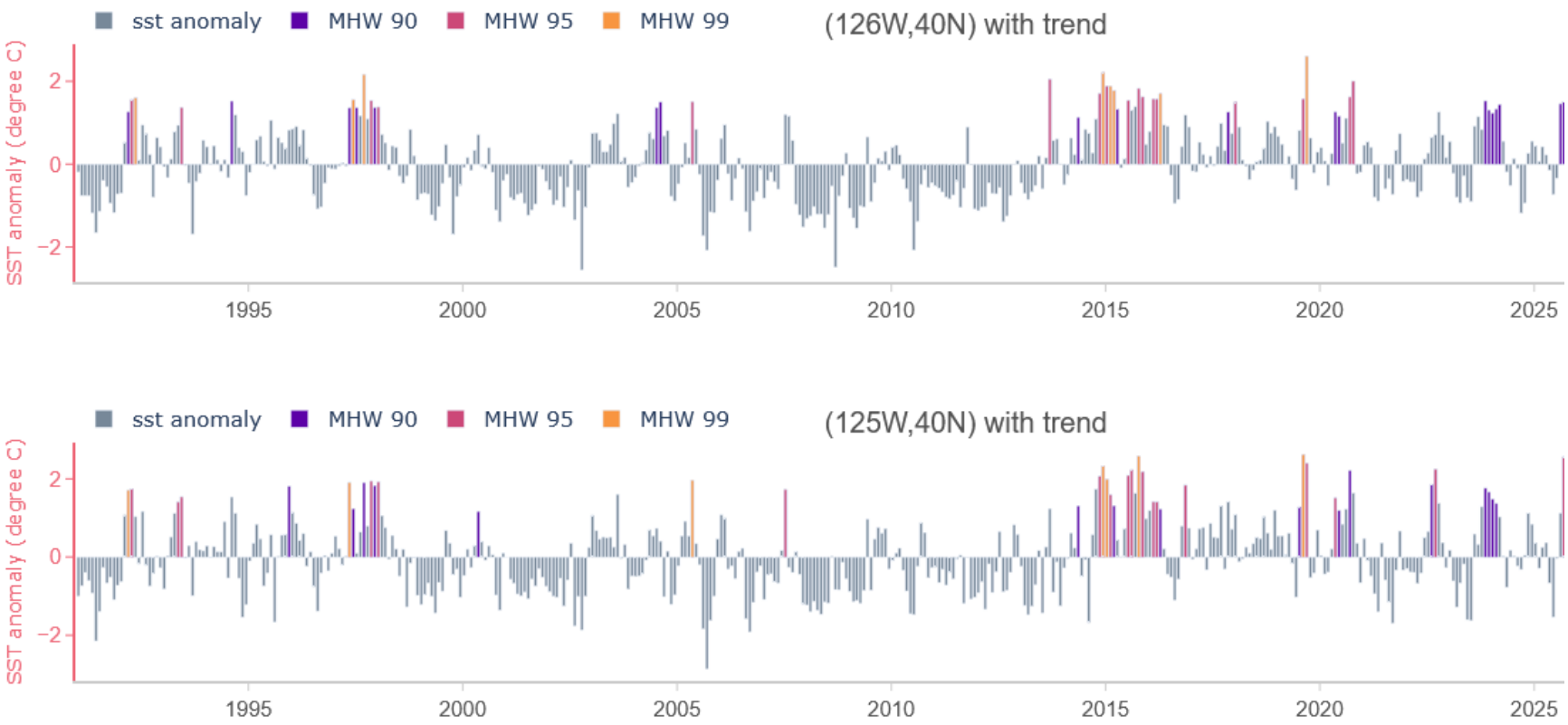
Figure 6.8.A-3. Increase in Monthly Average Sea Surface Temperature from 1975 to 2024 at Trinidad Beach.



Average increases in sea surface temperature from 1975 to 2024 at Trinidad State Beach, approximatley 10 miles (16.1 km) north of Wigi. The greatest increases have occurred in April through September, with a maximum of +3.16ºF (+1.76ºC) change in August. Source: Carter et al. (2022)

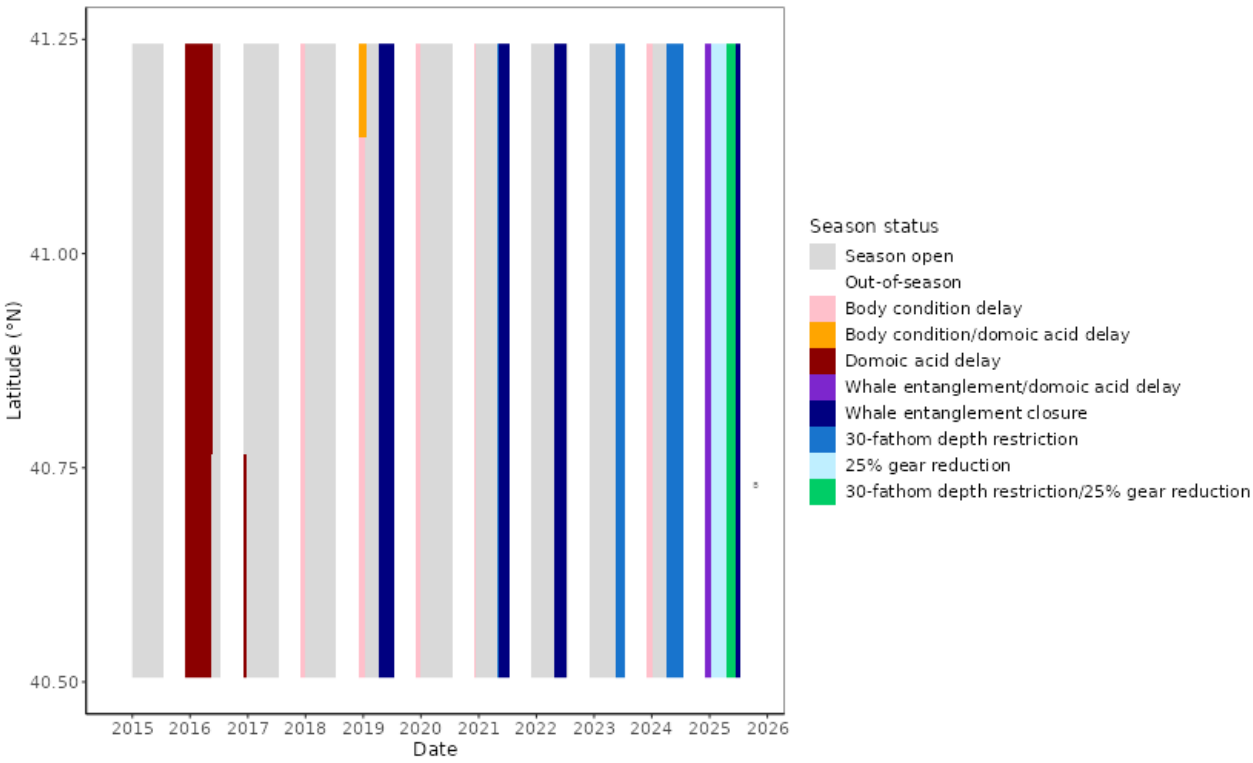
Figure 6.8.A-4. Sea Surface Temperature (SST) Anomaly and Marine Heatwaves (MHW) off the Coast of Wigi.





Temperature anomalies, or departures from normal average temperature, are graphed in degrees Celsius (ºC) for four locations in the Pacific Ocean nearest Wigi from NOAA's Optimum Interpolation Sea Surface Temperature (OISST Version 2) dataset. MHW 90 (purple bars) is defined as average temperatures for a 30-day period that exceed 90% of the normal range of temperatures for a location or region in the relevant season. MHW 95 (pink bars) and MHW 99 (orange bars) are 30-day periods which exceed 95% and 99%, respectively, of normal temperatures. The global trend of climate change-induced sea surface warming has not been removed from these time series. See NOAA's Physical Sciences Laboratory website in source for more information. Source: NOAA OI SST V2 High Resolution Dataset data provided by the NOAA PSL, Boulder, Colorado, USA, from their website at https://psl.noaa.gov/data/gridded/data.noaa.oisst.v2.highres.html

Figure 6.8.A-5. Commercial Dungeness Crab Fishery Management Actions.



Source: Free, Moore and Trainer (2022)

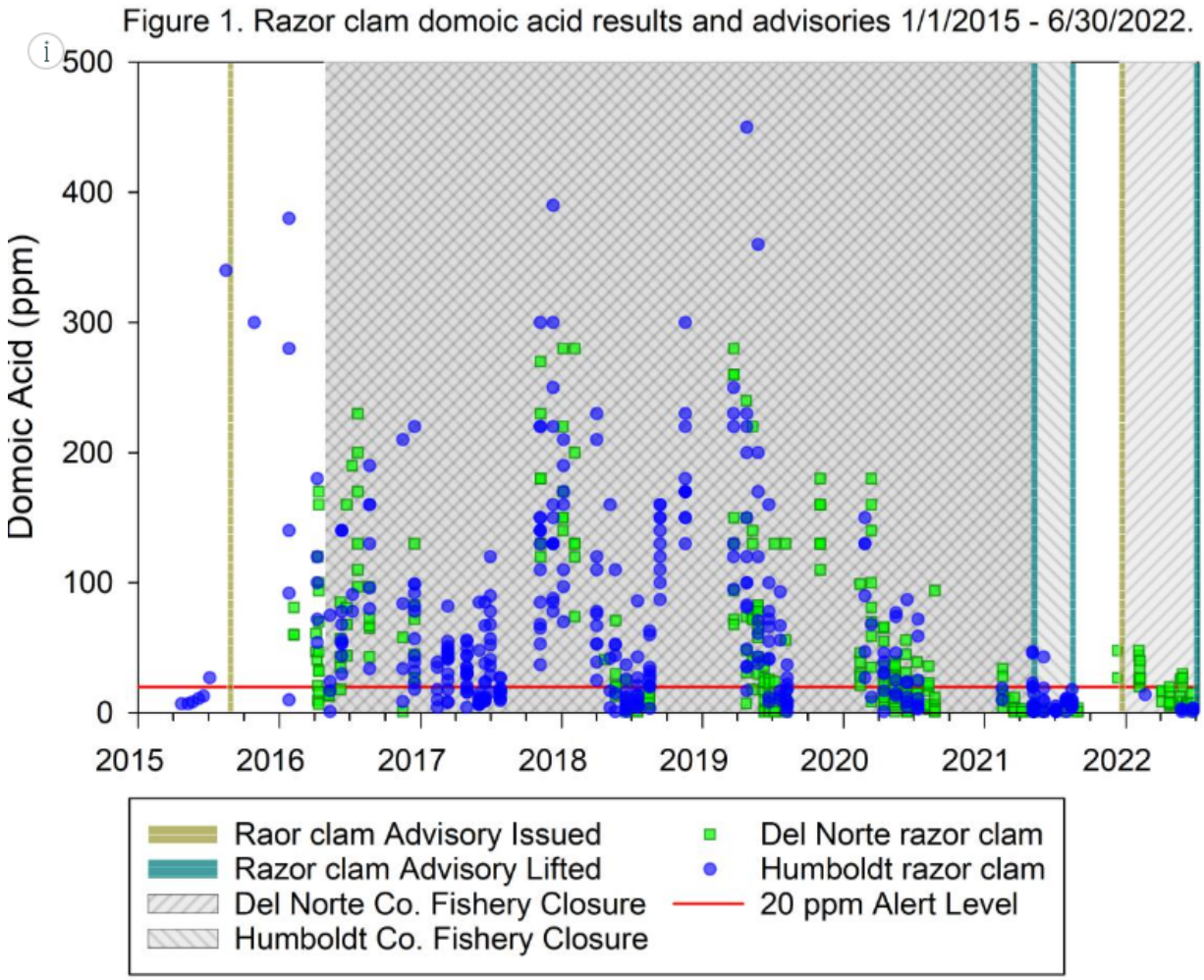
Season status

The figure above illustrates the following management actions during the season:

- **Season open:** The season is open without restrictions.
- **Out-of-season:** Outside the Dungeness crab season, which goes from Nov 15-Jun 30 in Central California, Dec 1-Jul 15 in Northern California, Dec 1-Aug 14 in Oregon, and Dec 1-Sep 15 in Washington.
- **Body condition delay:** The season is delayed because body condition (meat quality) does not meet market standards. These are also known as meat quality delays.
- **Body condition/domoic acid delay:** The season is delayed due to both poor body condition (meat quality) and high domoic acid toxicity.
- **Domoic acid delay:** The season is delayed or the area is closed due to high domoic acid toxicity.

- **Evisceration order:** The fishery is allowed to operate in this area with a requirement that the toxic viscera are removed.
- **Evisceration order (+depth/gear restrictions):** The fishery is allowed to operate in this area with a requirement that the toxic viscera are removed. In addition, some depth or gear restrictions are in place.
- **Whale entanglement closure:** The fishery is closed to avoid marine life entanglements (generally whales).
- **XX-fathom depth restriction:** The fishery can only operate in waters shallower than XX-fathoms to avoid marine life entanglements (generally whales).
- **XX% gear reduction:** Vessels can only use XX% of their traps to avoid marine life entanglements (generally whales).
- **XX-fathom depth restriction/XX% gear reduction:** The fishery can only operate in waters shallower than XX-fathoms and vessels can only use XX% of their traps to avoid marine life entanglements (generally whales).

Figure 6.8.A-6. Domoic Acid Concentration in Razor Clam Results and Recreational Fishery Advisories.



For an area with no current advisory, CDPH issues an advisory upon first detection of domoic acid in the clam meat that is greater than or equal to 20 parts per million (ppm), which is the alert level. The advisories for razor clams remain in place until two (2) sets of samples, collected seven (7) days apart, are below the alert level. Source: CDPH (2023)

Appendix

The following reports were published in the 4th edition of the *Indicators of Climate Change in California* in 2022. They are included as an appendix here for reference.

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North Fork Rancheria of Mono Indians of California (2022). Impacts of Climate Change on the North Fork Rancheria of Mono Indians of California. In: OEHHA 2022 Indicators of Climate Change in California.

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IMPACTS OF CLIMATE CHANGE ON THE AMAH MUTSUN TRIBAL BAND

Drought, wildfire, and sea level rise, as well as loss of native plants and animals, are threatening the physical, cultural, and spiritual health of the Tribe, its habitats, and ecosystems.

Background

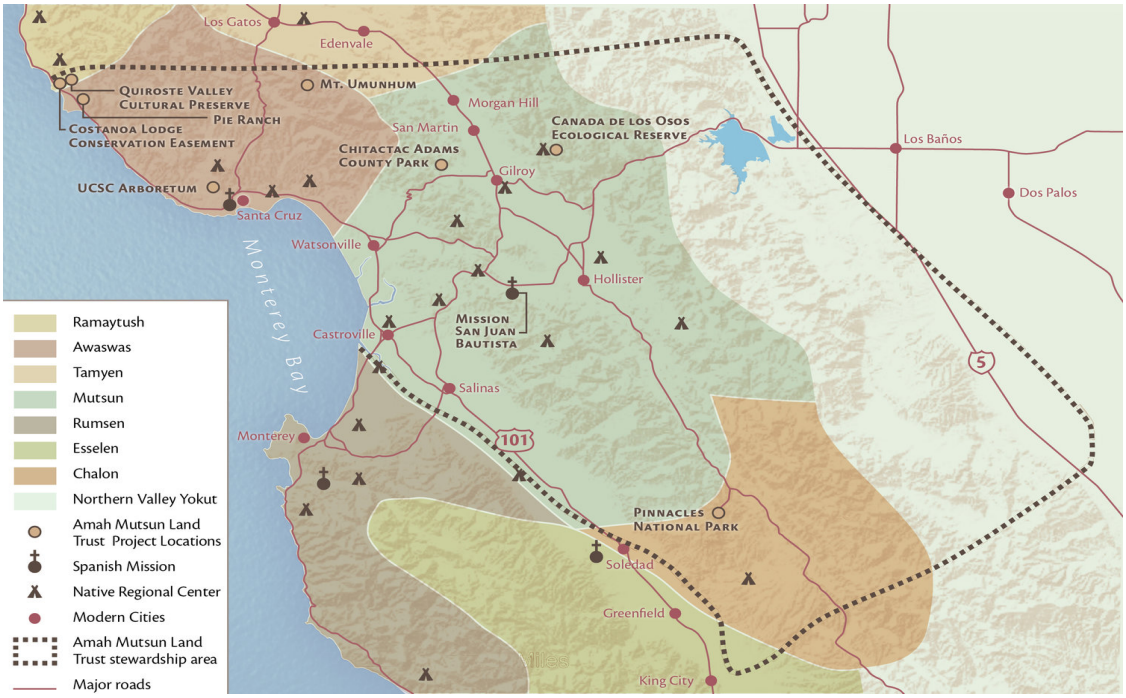
The Amah Mutsun Tribal Band (AMTB) is a continuous and historic Tribe composed of the descendants of the Indigenous peoples whose villages and territories were taken over by Missions San Juan Bautista (Mutsun) and Santa Cruz (Awaswas) during the late 18th, 19th, and early 20th centuries (AMTB, 2021). The Indigenous people were baptized as legal wards of the Franciscans and forced into labor building the missions, farms, and ranches of the colonizers (Madley, 2017). The AMTB represents the surviving descendant families of these groups. The AMTB is recognized by the State of California as a Tribal Government but lacks federal recognition. Consequently, the AMTB holds no tribal lands, nor receives financial assistance from either the Federal or State governments.

Prior to European contact, the Amah Mutsun community was made up of approximately 20 to 30 contiguous villages stretched across the Pajaro River Basin and surrounding region. These villages were united by shared cultural practices and traditions. Most significantly, Amah villages were distinct from tribes outside their valley because of their unique language. While the Costanoan/Ohlone language family was made up of eight separate languages, including Mutsun, each language was different. Mutsun was one of the first American Indian languages extensively studied in North America (AMTB, 2021).

The Amah Mutsun Tribe was drawn to the abundant resources in the triangle of land formed by the Monterey Bay and the Pajaro and San Benito Rivers by the abundant resources. These lands later attracted other settlers who drastically changed the lives of the Amah Mutsun. While the traditional territory of the Amah Mutsun encompasses all or portions of the current Counties of San Benito, Monterey, Santa Cruz, Santa Clara, and San Mateo, the high cost of living in the San Francisco and Monterey Bay areas, combined with a lack of treaty or tribal trust land, has resulted in over 80 percent of Tribal members living outside of their ancestral territory. Many members live in Fresno, Madera, Hanford, Las Vegas, and Lake County, and other areas outside of California (AMTB, 2021).

Through three periods of brutal European colonization (Spanish, Mexican Republic, and United States) (Madley, 2017), the Tribe's traditional ecological knowledge and physical connection to their ancestral lands were disrupted.

Figure 1. Amah Mutsun (Awaswas and Mutsun) historic lands and neighboring tribes



Source: AMTB, 2021

The AMTB continue to maintain a sacred obligation to continue in the footsteps of their ancestors, stewarding the lands and waters of their traditional homeland. In 2013, the AMTB created the Amah Mutsun Land Trust (AMLT) to help achieve this vision.

AMLT is a Native-led, non-profit organization. Through the AMLT, the AMTB is restoring Indigenous stewardship to the Mutsun and Awaswas-speaking peoples' ancestral lands and waters, which stretch from Año Nuevo Point to the Monterey Bay, and inland to include the Pajaro and San Benito watersheds (see Figure 1 above). AMLT focuses on education, stewardship, research, and cultural revitalization, in addition to land acquisition. AMLT brings an Indigenous perspective to resource management that models constructive relationships between people and place, where active engagement with the land contributes to more diverse, resilient, and meaningful landscapes. AMLT engages a Native Stewardship Corps (NSC), made up of AMTB members plus an array of state, county, University and tribal partners, to bring Indigenous stewardship to lands that are already in conservation. Because the Tribe is currently unrecognized by the federal government, the NSC functions much as an environmental department would.

Cultural and spiritual health

Historically, the Amah Mutsun ensured a sustained yield of plant and animal foods by careful management of the lands. Controlled burning of extensive areas of land was carried out each fall to promote the growth of seed-bearing annuals.

When the Tribe speaks of “cultural resources,” they look all around at the mountains, the meadows, the waterways and wetlands, the air, and scenic vistas – as well as those buried beneath them, and those who inhabit them. Those are the Amah Mutsun cultural resources – all holds value to the Amah Mutsun Tribe (AMTB, 2021).

When non-indigenous people think of California Indian culture and cultural resources, they often look at tangible objects such as basketry, housing, clothing, food, and dance regalia such as feathers, whistles, skins, clapper sticks, etc. These are all important manifestations of Amah Mutsun culture, but to understand the culture of the Amah Mutsun Tribe, one must also understand two important axioms.

Axiom I: There is no natural hierarchy in the Amah Mutsun culture that categorizes plants, animals, minerals, or humans as being above any of the others. It is the Tribe’s belief that the Creator made all beings – therefore we are all equal. Men, women, and children were all created equally and are respected equally. The Amah Mutsun are a matriarchal society. Women can bring life – possessing the strength to bear the burden of two souls within them. Men possess physical strength to provide and protect – creating balance in the family and community. The Amah Mutsun believe human beings were gifted with a higher level of intelligence and reasoning for the express purpose of protecting and caring for all other life.

Axiom II: The Creator, using infinite wisdom, placed the Amah Mutsun in the lands of “*Popeloutchum*”, the homeland, as the protectors and stewards of the lands, waters, plants, and other creatures of this place. The Creator blessed the Amah Mutsun with these magnificent lands with a mild climate, bountiful foods from the land and sea, and a landscape that is considered among the most beautiful in the world.

As Amah Mutsun ancestors worked to fulfill their obligation to protect the plants and animals of the land, they also studied their non-human relatives for thousands of years. The Bear Clans, Bird Clans, etc. were given the responsibility to learn all they could about those creatures. The knowledge they collected was shared with their Tribe and their descendants.

The Amah Mutsun, never felt that they owned the land – rather that they belong *to it.* When the Amah Mutsun talk about “our land” – or “*makke pire*”, they are referring to the land to which *they belong*…rather than the land which they “own.”

Because the Amah Mutsun have a responsibility to care for our finned and winged brothers, they must protect and conserve the rivers (water quality) and the sky (air quality). The Tribe must help ensure that their populations can move and interact (habitat corridors) to maintain healthy and resilient populations (AMTB, 2021).

Impacts

The impacts and future threats resulting from climate change in Amah Mutsun Territory are drastic and rapidly compounding, both on land and in the sea. On land, the

increasing destructive wildfires are followed by higher rates of erosion and landslides. Culturally important plant and bird species are being impacted by drought, wildfire, and increasingly variable rainfall. Tribal members living in the inland areas report drier, hotter summers, less annual rainfall, low water tables, lakes and creeks drying up, poor air quality, and more intense, more frequent wildfires. These changes, along with development and urban sprawl, impact housing and intensify destructive land-use practices. In the sea, the coast has become more vulnerable to coastal erosion resulting from high energy storms and swell events with the collapse of kelp forests that had acted as buffers. This erosion, along with sea level rise, are threatening cultural sites along the shoreline. Loss of ocean biodiversity, drastic reductions of certain species and overpopulation of others, and marine harmful algal blooms (HABS) also threaten Tribal resources.

Land

The most recent and high-profile impacts of climate change are evidenced by the August 2020 CZU Complex fires, started by lightning in an area that historically had a very low number of lightning strikes. The CZU Complex burned for over a month, torching 86,509 acres in Santa Cruz and Santa Clara counties, destroying 1,490 structures, and damaging 140 (CALFIRE, 2020). These fires led to the evacuation and displacement of the NSC, loss of a month's work, loss of necessary field equipment, and an overall unstable, uncertain, disrupted work and life flow. Heavy rain four months after the fires led to another evacuation because of potential landslides, putting the NSC in yet another high-risk situation.

Droughts brought about by climate change are making oak woodlands more susceptible to death from pathogens and pests. Wildfire in areas with these dead and dying trees will tend to form crown fires that spread from treetop to treetop. Once removed by wildfire the woodlands may be replaced by shrubland and other vegetation types that are unable to support native plant, animal, and bird species.

Catastrophic fires impact watersheds, water and air quality, rangelands, wildlife, culturally significant sites, infrastructure, croplands, and of course, the Amah Mutsun's way of life. These fires are intense due in part to unmanaged fuel loads. The CZU Complex is also a prime example of how the compounding impacts of fire suppression, poor land management, and climate change can result in widespread, destructive wildfires. The Tribe believes that fire can be managed more effectively if Indigenous stewardship and cultural knowledge around Indigenous peoples' use of fire are more widely accepted and implemented by land managers.

Recent eco-archaeological research in the area provides evidence that Amah Mutsun people had regularly practiced cultural burning as a landscape management strategy prior to European colonization. Informed by traditional ecological knowledge, cultural burning by Indigenous people protects ecological and cultural resources and builds wildfire resilience. Cultural burns are properly timed, low-intensity fires that move slowly

through a segmented management unit of land and promote the abundance and health of many culturally significant native plants.

Figure 2. Amah Mutsun controlled burn



Source: AMTB, 2021

The Amah Mutsun have great respect for fire as a land stewardship tool. As Chairman Valentin Lopez explains:

> "*We see fire as a gift from Creator. Like all gifts, it is important to respect and recognize it in that way. Fire is sacred and used as a prayer. A spiritual fire is placed in the middle during ceremonial dances and carries our prayers up to Creator. Fire is used as a light, and as a land management tool. Our ancestors divided the land into management units, they then burned segments when needed, on a rotating cycle, until the cycle was complete. This allowed for consumption and reduction of fuel loads and control of encroaching brush, aiding the ecosystem. Coastal prairie grasslands have diminished due to outlawing the practice of Indigenous burns. Fire has a critical role in maintaining the coastal grassland prairie. The coastal prairie*

grassland was one of the most viable landscapes and rich in biodiversity in North America before Europeans arrived."

"Cultural burns help control pests, reduce buildup of heavy fuels, and aid native plants that require fire to germinate. We have a responsibility of taking care of plants, birds, and feeding the animals by taking care of native seeds. The first year of the burn cycle aids in seed and seed bed preparation. The second year after the burn, plants strengthen reproduction, and shoots are soft and nutritional for grazing wildlife. The third year, there is increased fruit productivity. The fourth year yields strong plant fibers which are utilized for crafts and housing materials. A special ceremony is held when cultural burning in oak woodlands. Smoke helps purify the trees. Smoke chokes out pests in trees, and therefore aids in the production of acorns. Insects are choked out and fall down, and then are consumed in fire. Therefore, fire and smoke aid with insect infestation in trees and killing of pests such as ticks in grasses."

Wildland fire knows no boundary and taking care of Mother Earth requires a coordinated effort, and as Honorable Chairman Valentin Lopez says, *"Indigenous stewardship must lead the way."* Indigenous stewardship practices like cultural burning are gaining traction among land managers as effective methods of building resilience in natural systems.

To restore ecological health and resilience to the Amah Mutsun by bringing back small-scale fire as a tool to mitigate the impacts and threats of destructive wildfires, the AMLT works with:

- California State Parks and University of California (UC) campuses at Berkeley and Santa Cruz to understand the historic extent of fire as a Native landscape management tool.
- California State Parks and CALFIRE to remove thick stands of Douglas fir to create fuel breaks and restore grasslands.
- California State Parks and UC researchers in Quiroste Valley, an area east of Año Nuevo State Park to research and re-introduce traditional resource and environmental management, including cultural burning, as practiced in the valley before the arrival of Europeans. The uplands above the meadow and riparian valley contain dense Douglas fir, and coyote brush stands with little to no understory. These stands have encroached upon the open coastal prairie grassland. Due to the dense canopy cover, little sunlight reaches the forest floor, allowing little to no grasses and forbs. This reduces biodiversity and threatens the coastal prairie, which was once much more widespread.
- Inter-Tribal Fire Network to better relationships with federal and state land management agencies and with other tribes throughout California.
- A grant from the California State Coastal Conservancy, which has provided funding (cap-and-trade funds from California Climate Investments) to aid in the

development of a Cultural Burns program, where the Tribe can strive to best steward ancestral lands.

- A cooperative Habitat Restoration Project with Pinnacles National Park using an integrated approach to habitat restoration and research by incorporating traditional Native American land management practices with contemporary techniques to restore and protect the natural and cultural processes.
- The Karuk and Yurok Tribes, which host Prescribed Fire Training Exchanges (TREXs). These trainings emphasize the stewardship of cultural resources and build key working relationships and coordination with many land management organizations. Tribal members are currently becoming National Wildfire Coordinating Group Firefighters, Type 2 certified, and are gaining experience with prescribed fire.

Bird species important to the Tribe have also been impacted by climate change. The condor is a culturally important species to the Amah Mutsun and the Tribe has worked with Pinnacles National Park reintroducing the birds and providing an understanding of the cultural meanings of the California condor (AMTB, 2021). These newly released birds were again threatened when the CZU Complex burned in nesting areas with fledgling birds, unready to fly to escape (NPR, 2020).

Along with exacerbating wildfire risks, climate change has also impacted the availability of certain native plant species of ethnobotanical importance to the tribe. These are species traditionally used for building, basketry, and food. Members of the NSC have reported that many culturally important coastal prairie and woodland plants are becoming rarer and more difficult to restore, while invasive plants like Jubata grass, poison hemlock, and thistles are incredibly difficult to eradicate in grasslands.

Figure 3. Amah Mutsun Tribal members and Land Trust propagate plants



Source: AMTB, 2021

Part of AMLT's land restoration work includes:

- Working with UC Santa Cruz arboretum to propagate ethnobotanically important plants.
- A coastal grasslands propagation project at Quiroste Valley. This California Proposition 68 funded project intends to directly plant 30,000 native plants at Quiroste Valley.
- An additional 90,000 native plants at a neighboring location, which will provide additional seed to be sown directly into the Valley in subsequent seasons. Despite ongoing impacts of COVID-19 and the August 2020 CZU fire complex in the Santa Cruz Mountains impacting water supplies, the program has remained on track to meet the ambitious goal of returning culturally important grassland plants.
- Tending a permanent source of grassland seed for gathering and restoration. This is even becoming more important since AMLT can propagate and plant drought-tolerant native grasses, like Purple Needlegrass, the state grass of California.

Sea

The Amah Mutsun have lived and interacted closely with the coast since time immemorial. Their ancestors stewarded the sea through resource management practices that maintained abundant, healthy coastal waters. The rich and biodiverse kelp forests provide habitat for fish, marine mammals, and invertebrates. The sandy and rocky shorelines are filled with a myriad of seaweeds and animals. This depth of knowledge lives with the Amah Mutsun Tribal Band elders. It is further documented in ethnographic records and evidenced in archaeological sites along the coast.

Today, the Amah Mutsun witness a wide range of impacts on local coastal waters. Sea level rise is eroding ancient cultural sites from the shoreline. The loss of kelp forests due to the rapid spread of purple sea urchins because of the mass wasting of sea stars, their main predator, is leading to significant losses in biodiversity. Ocean temperatures affect the availability of food for sea lion pups and pregnant sea lion mothers. Warmer waters can reduce the abundance of phytoplankton and other organisms that make up the base of the marine food chain along the California coast. Changes to the availability of these organisms affect higher levels of the food chain, including sea lions (OEHHA, 2018). Unusually warm ocean temperatures can also amplify harmful algal blooms that periodically occur along the California coast. Certain algae species produce toxins such as domoic acid that enter the marine food web and ultimately harm sea lions (OEHHA, 2018). Harmful algal blooms are especially abundant and widespread within Amah Mutsun territory and can render many culturally important resources toxic and inedible. Rising ocean temperatures and increased carbon levels make it difficult for many native species to survive, especially considering the competition of encroaching invasive species that crowd them out. By monitoring these resources throughout the year, the Tribe can better understand the issues affecting them and contribute to protecting and managing them.

Figure 4. Amah Mutsun youth and UC Berkeley researchers getting ready for a day at the beach.



Photo courtesy of Rob Brodman

At the direction of Tribal leadership, the Amah Mutsun are now looking to build the capacity of AMTB members as ocean stewards by developing and implementing a new AMLT marine stewardship program. Work includes:

- Participating in the Tribal Marine Stewards Network (TMSN) pilot project, along with four other tribes/tribal organizations, who received funding from the Ocean Protection Council in 2020.
- Developing a coastal monitoring program that will return traditional resource stewardship to the coast within Mutsun and Awaswas territories. This program builds upon previous work that combined archaeological and ethnographic information to restore and revitalize resource stewardship on the land, such as fire to manage coastal grasslands.
- Partnership with the California Indian Environmental Alliance, Tolowa Dee-ni' Nation, Resighini Rancheria, Kashia Band of Pomo Indians, and Ecotrust to form a Tribal Marine Stewards Network. The Tribal Marine Stewards Network pilot project received generous funding from the Ocean Protection Council in 2021. The Amah Mutsun Tribal Band's participation is further supported by a grant made through the Sustaining California's Ocean Program of the Resources Legacy Fund.

- Monitoring other significant natural and cultural resources, especially kelp forests, rocky intertidal zones, and seagrass beds, which provide habitat for a diverse range of species and are essential for maintaining productive marine ecosystems.

Each of these projects will build the capacity of AMLT Native Stewards as stewards of the marine environment by creating opportunities for Tribal members to learn and practice new skills. These projects will also contribute new data that will be shared with the State and aid in the management of California's Marine Protected Areas. The community outreach project will be focused on revitalizing and building upon the AMTB tribal communities' traditional ecological knowledge about coastal and marine resources and how to steward them.

Other impacts

The creeks, streams, and rivers within AMTB historic lands have also been impacted by climate change in a myriad of ways. Rising temperatures and drought have decreased water flows and led to warmer waters in culturally important fish habitat and unfavorable spawning conditions.

Salmon populations are impacted by nutrient availability, drought, temperature, and freshwater/saltwater interfaces, all of which are affected by climate change. To gain more insight into managing habitat conditions to favor salmon populations, AMLT collaborates with:

- Researchers at Michigan State University to study ancient and modern salmon and steelhead genetics within their traditional territories.
- Researchers at UCLA to develop an environmental DNA monitoring program for species of ecological and cultural importance, many of which are influenced by climate change. As part of this research AMLT is actively working on a dam removal project in their territory geared towards salmon restoration.

Summary

Climate change is causing a loss of native plants and animals, causing droughts, wildfires, landslides, sea level rise, and increasing marine harmful algal blooms. These impacts are threatening the physical, cultural, and spiritual health of the Amah Mutsun Tribe.

Neither the lack of a permanent land base, nor the lack of federal recognition has prevented the Amah Mutsun Tribal Band from fulfilling their continuing obligation to protect the plants and animals on their Tribal homelands. The AMTB are reaffirming their role as environmental stewards of Mutsun and Awaswas territories by using innovative research, partnerships, and tribal community education to relearn traditional ecological knowledge and apply it to the most pressing issues in natural resource management and conservation. AMLT continues to successfully apply this approach to terrestrial ecosystems, using archaeology and modern ecological science to affirm the

utility of ancient traditional resource management practices to restore balance and resilience to the diverse ecosystems in AMTB territory.

The Tribe relies on historical ecological data preserved in coastal archaeological sites. These sites contain information regarding past stewardship practices and traditional ecological knowledge of coastal resources. The archaeological record is a non-renewable resource with specific windows of opportunity for the Tribe to engage. Unfortunately, due to climate change-related sea-level rise, these windows are rapidly closing as artifacts are exposed and destroyed, as they are washed out to sea or collected by treasure hunters for sale. Many of these sites are being impacted by rising seas and high energy storms, both directly linked to climate change. Without adequate monitoring and protection of these sites, this vital historical dataset for the Amah Mutsun Tribal Band could be lost forever, impacting the conservation science. Indigenous knowledge and evidence from the archaeological record hold information regarding human relationships with marine ecosystems over thousands of years.

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Suggested citation:

Amah Mutsun Tribal Band, 2022. Impacts of Climate Change on the Amah Mutsun Tribal Band. Prepared by Mike Grone, PhD, Amah Mutsun Land Trust. In: OEHHA 2022 Indicators of Climate Change in California

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Impacts of Climate Change on the North Fork Rancheria of Mono Indians of California

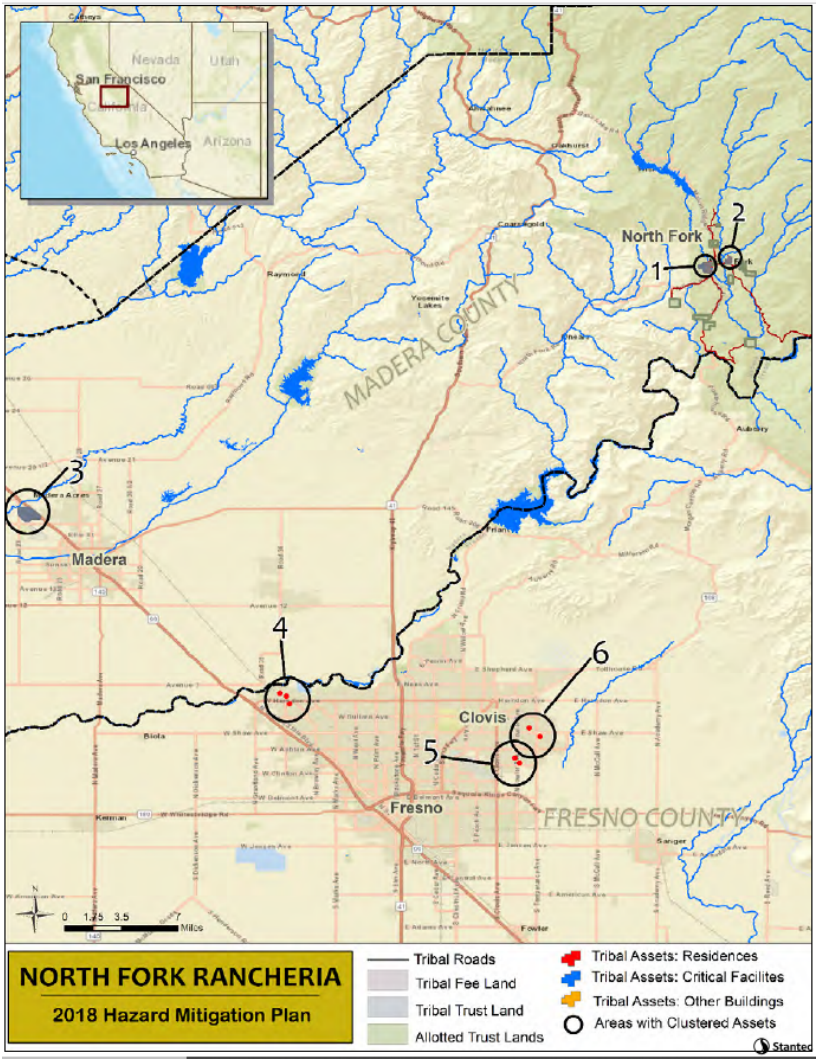
Elevated day and nighttime temperatures, drought, wildfire, and flooding due to increasingly variable precipitation patterns are threatening the physical, cultural, and spiritual health of the Tribe, its habitats and ecosystems, and its built environment.

Background

The North Fork Rancheria of Mono Indians of California (NFR) is a federally recognized Tribe currently located in Madera County, California. The North Fork Rancheria lies in the foothills of the Sierra Nevada Mountains, along the Sierra Vista National Scenic Byway. The Rancheria lies less than 40 miles from Fresno, California. The Western Mono have resided in the San Joaquin Valley for thousands of years (NFRMIC, 2018). However, after non-native encroachment of historical lands, the Tribe's ancestors concentrated around the town of North Fork, from which the Tribe's name was derived (Tatum, 2006). Intermarriage with other local tribes occurred and sharing of the land and its resources was important for all the tribes. Western Mono language is part of the Uto-Aztecan language family and is most similar to the Paiute-Shoshone languages.

The Tribe has 2,310 citizens nationwide, with the majority residing in Fresno and Madera Counties, making them one of California's largest native tribes (NFRMIC, 2018).

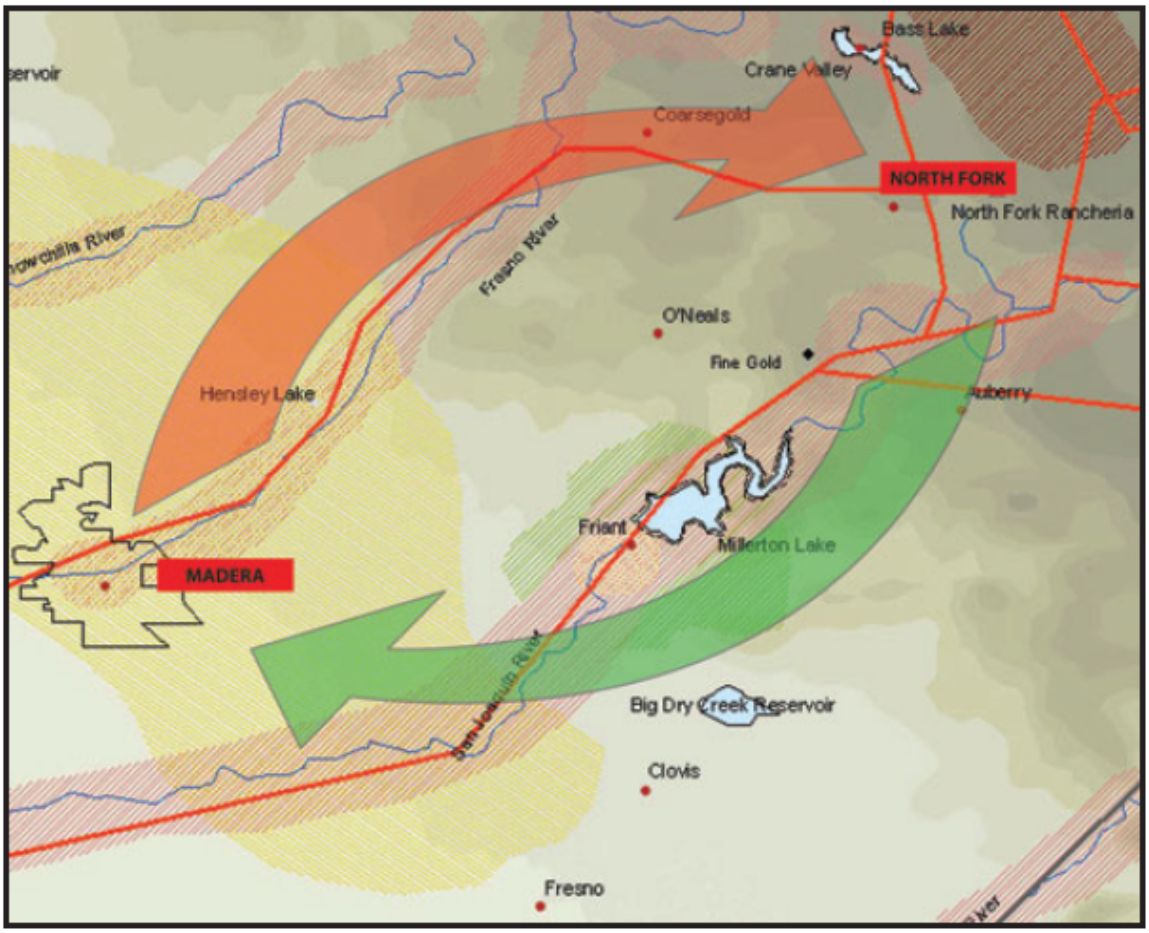
Figure 1. Current North Fork Rancheria Lands and assets



Source: NFRMIC, 2018

The first reservation lands were allotted in 1851 but failed treaty ratifications resulted in the closure of the reservation in 1860 (NFRMIC, 2006). Traditionally, the North Fork Mono travelled between the foothills of the Sierra Nevada and the San Joaquin Valley (Figure 2).

Figure 2. The North Fork Tribe migrated from the foothills down to the Valley for hunting and fishing and worked with other tribes along the way.



Source: Tatum, 2006

The Tribe also traded throughout the Eastern side of the Sierras and have trail systems that go to Bishop, Yosemite, Mono Lake and through the Pacheco pass. Travel was vital for traditional hunting and gathering, ceremonies, and for trade with other tribes creating a complex interdependent system of social, political, and economic ties between groups (NFRMIC, 2006). Historically, the weather in the foothills was more hospitable for permanent residence due to the severe heat, drought, and flooding in the Valley. In the Valley, the Mono hunted for large game like elk and antelope, fished for salmon, and gathered roots of the sedge plant found along the riverbanks on the Valley floor (Tatum, 2006). In contrast, in the foothills the Tribe had access to acorns from Black Oak trees, a staple for the North Fork Mono as their acorns made better flour than

those from oak trees found closer to the Valley. Federal recognition as an Indian Tribe was restored in 1983 under a court-approved settlement, and the Tribe subsequently elected a governing body and adopted a Tribal Constitution in 1996. Today, tribal leadership consists of five elected members of the Tribe's citizenry who serve four-year terms elected on a two-year staggered basis. The 80-acre Rancheria is held in trust for descendants of one Mono family; therefore, the Tribe is considered 'landless' and has had to purchase land for its people.

Cultural and Spiritual Health

The wellness of the tribal people is tied to the lands from which the Tribe is from. The water, plants, soil, air, minerals, and other resources provide a connection to the landscape that is not easy to convey in written form. An example would be when a weaver gathers material for a baby basket, they must know where to go for materials, that material must grow in the right conditions, have plenty of water, and once cleaned and ready to use the weaver can be overcome with a feeling of reflection and relaxation as they weave the basket for a child.

Climate Change and Its Impacts

Unless otherwise stated, the *North Fork Rancheria Tribal Multi-Hazard Mitigation Plan* (NFRMIC, 2018) is the basis for the information below.

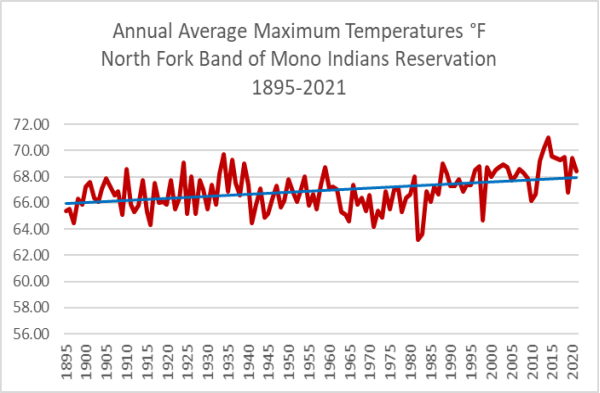
Elevated Temperatures

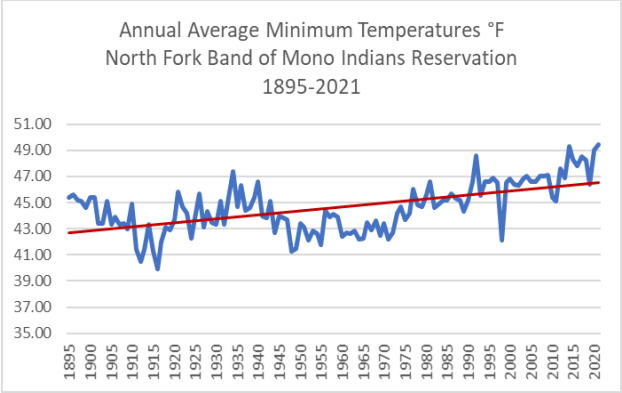
The North Fork have experienced warming temperatures across both the winter and summer months. In general, the area experiences both cold winters with temperatures below freezing as well as hot summers where temperatures exceed 100°F. However, accelerated warming over the last decade has contributed to warmer winters and hotter summers, which has impacted both the health of tribal citizens and the plant and animal resources on which they rely.

What does this indicator show?

At North Fork, both the nighttime temperatures and daytime temperatures have risen steadily since 1895. Looking first to daytime temperatures (Figure 3) we can see that temperatures have remained within 8°F but that the average temperature currently sits at around 68°F. However, in more recent years the temperature has varied more extremely with sharp increases and decreases from 1995 to 2021 (PRISM, 2022). Looking next to nighttime temperatures (Figure 4), we can see that temperatures cover a range of about 10°F, with temperatures remaining consistently above 45°F since 2001. Currently, the annual average minimum temperature is around 48°F. Overall, nighttime temperatures have increased at a much faster rate when compared to daytime temperatures over the last century, at 5°F compared to 2°F.

Figures 3 and 4. Annual Average Minimum and Maximum temperatures at North Fork Rancheria 1895-2020





Source: PRISM, 2022

Why is this indicator important?

Changing temperatures have cascading effects on other climatic variables, like precipitation, drought, and wildfires, further impacting the Tribe. Particularly important to the Tribe has been the decrease in acorn availability. The Tribe on the western side of the Sierra Mountains has depended heavily on acorn as a staple food for thousands of years. However, warming temperatures have decreased acorn availability especially during the drought between 2014 and 2016. During seasons when acorns are plentiful, the health of wildlife in the area benefits as well (McDonald, 2020).

As the climate has changed, the North Fork Rancheria has had to contend with a wide range of pests, disease, and non-native species (NFRMIC, 2018). Warming temperatures and extreme heat events contribute to drought stress on trees. The Tribe has observed instances of tree mortality over the last six to seven years, due to the combined effects of drought and bark beetles (McDonald, 2020). As water competition increases, trees become weakened, thus contributing to susceptibility to bark beetles (Preisler *et al.*, 2017). The Tribe is concerned that Sudden Oak Death will become a problem in the area as the climate continues to change.

Warmer temperatures also negatively impact the health of Tribal Citizens. Ground ozone needs heat and sunlight to form, so hot temperatures have worsened air quality by exacerbating ground ozone levels. Data from CalEnviroScreen, California's Environmental Justice Screening Tool, shows that ozone levels in North Fork are ranked in the 67th percentile compared to other areas across the state, meaning that North Fork has higher ozone levels than most of the communities in California (OEHHA, 2021). Vulnerable populations, especially children, the elderly, and the disabled are at the greatest risk of exposure to extreme heat. Those without air conditioning may be at higher risk (NFRMIC, 2018)

<u>Drought</u>

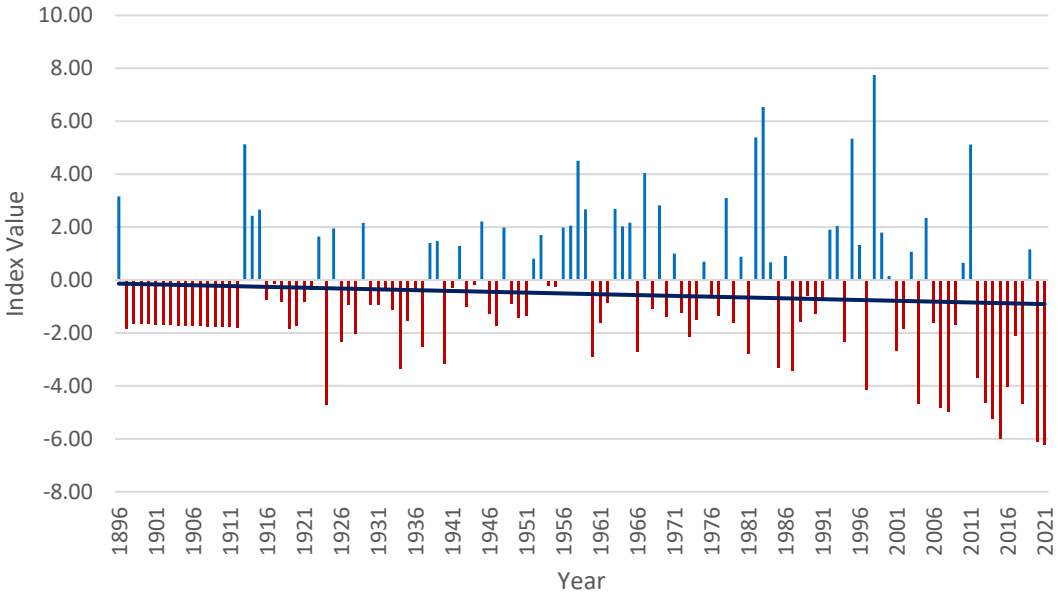
North Fork experiences clear wet and dry seasons, with the dry season lasting from mid-spring to late fall. Historically, the North Fork people have experienced multiple

instances of the destructive effects of drought including failed crops and changes to land-use patterns. Local hazard identification efforts have determined that drought conditions are to be expected across 10 to 50 percent of the North Fork area, with critical severity in terms of property damage, facility shut down, and injuries expected in the next year-ten years (Madera County, 2016).

What does this indicator show?

Using the Palmer Drought Severity Index (PDSI), a value of 0 indicates normal conditions while negative numbers represent drought conditions and positive numbers correspond to wet spells. Looking specifically the North Fork Rancheria, PDSI values show that the Tribe has experienced many instances of extreme drought since 2000 (Figure 5). Over those 21 years, there were nine years of extreme drought (PDSI values below -4) and three years of moderate to severe drought (values between -2 and -3). While the Tribe did experience moderate drought in the 100 years prior, those droughts were milder. The Tribe is seeing a trend of increasingly severe droughts.

Figure 5. Palmer Drought Severity Index (PDSI) for the North Fork Rancheria, 1896-2021



Source: Abatzoglou *et al.*, 2022

Why is this indicator important?

The increase in frequency and severity of drought conditions for the North Fork have important implications for surrounding wildlife and traditional cultural practices. Drought has reduced the availability of materials needed for basket-making, disrupting cultural traditions, and impacting the ability to pass on practices to younger generations (BPT, 2020; McDonald, 2020).

Drought conditions in the area have had significant impacts on tree mortality in the Sierra National Forest, causing large-scale die offs that are fueling other effects such as disease, pests, and wildfire events (Madera County, 2016). As mentioned in the *Elevated Temperatures* section, drought conditions and resulting water competition have made trees susceptible to bark beetle populations, contributing to the mortality observed. Fallen trees in the area have reduced the availability of mushrooms, an important food resource to the Tribe, which grow when forest soil is exposed to air. Along with a reduction in mushroom availability, tribal members also note that access to prime resource areas has been impacted by the abundance of fallen trees, which are blocking paths and access routes (McDonald, 2020).

Drought also impacts other native plants such as the sourberry, used both medicinally and for basketry, which require an ecosystem that is disappearing. Manzanita and Black Oak acorns, other species heavily utilized by Tribal Citizens, have also been negatively impacted by drought. Lack of water reduces the availability of berries and dries out the branches of plants, making them difficult to use for basketry. This can trigger negatively re-enforcing feedback loops where surrounding plants and animals relying on threatened species are unable to survive themselves. Deer herds in the area have been in decline for decades due to forest conditions and forest health. Deer are indicators of forest health; resources that the Tribe uses are also utilized by the deer. Dry conditions additionally facilitate the occurrence of wildfire events further impacting the health of populations and lands.

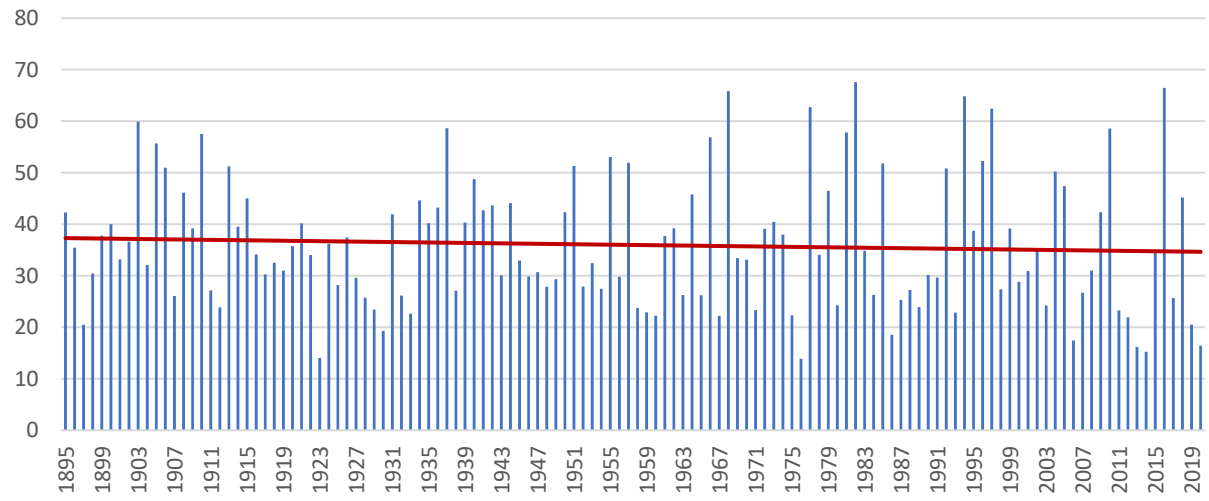
Precipitation

In addition to changing temperatures and instances of drought, the North Fork Rancheria has also experienced changes in precipitation patterns. Extreme precipitation events are expected to continue to impact the Tribe and the ensuing flooding can result in damages to property, roadways, and plant and animal species.

What does this indicator show?

Precipitation in North Fork has become more variable over time (Figure 6). Since 2010, the Tribe has seen large-scale differences from year to year, differences which are expected to continue as the climate continues to warm overall. Additionally, not specifically highlighted in annual rainfall summaries are instances of intense rainfall, which can lead to flooding, as well as periods of prolonged dryness (i.e., drought).

Figure 6 Annual precipitation by water year, North Fork Band of Mono Indians Reservation, 1895-2021



Source: PRISM, 2022

Why is this indicator important?

Changing precipitation patterns have the potential to significantly increase flooding at North Fork. Further, warming temperatures lead to precipitation falling as rain rather than snow, which in turn impacts the volume and timing of snowmelt in the Sierra Nevada mountains, and the sudden onset of early springtime warm temperatures and subsequent snowmelt have the potential to increase flooding (NFRMIC, 2018). Past flooding events have led to mandatory evacuations and have closed roadways – impacting the health and safety of tribal members.

Decreases in precipitation have contributed to lower-than-normal creek flows (BPT, 2020). Tribal members are dependent on water systems, and a reduction in creek flows has limited tribal access to additional clean water. According to CalEnviroScreen, North Fork is ranked in the 97th percentile compared to other areas across the state for drinking water contamination (OEHHA, 2021). This means only 3 percent of communities in the state evaluated by CalEnviroScreen have worse drinking water contamination issues. Aquatic ecosystems have also been affected by changes in precipitation patterns. Reduced creek flows have triggered large scale fish die-offs. This is concerning not only for the health of the aquatic ecosystem, but also for the diet of tribal populations. Central California roach, hardhead, Sacramento pikeminnow, Sacramento hitch, Sacramento perch, and Sacramento tule perch are all culturally important species to the North Fork Mono and the Tribe has seen reductions in numbers due to the diminished quality of aquatic ecosystems (SWRCB, 2014).

Flooding has impacted the gathering of materials for the Tribe. Basketry material such as sedge can be inaccessible during periods of high water and can also be impacted by large flood events, as increased flows can dislodge the root systems. The roots of the

sedge are used for the basket material. Sedge is typically found in sandy areas, which tend to be prone to wash out in high flows.

Wildfire

Wildfires are expected to increase in frequency and severity as the climate warms. Across the entire state, fire season has started earlier in the year and has expanded across more areas. For the Tribe, more frequent and intense fires have enormous consequences on both physical and cultural health and well-being.

What does this indicator show?

Wildfires have had a significant impact of the North Fork Rancheria. Of the five largest fires (in terms of area), three have occurred in the last 20 years (Figure 7, Table 1). These fires, along with many smaller fires, have burned significant portions of North Fork lands and lands surrounding the Rancheria.

Fires Impacting the North Fork Rancheria of Mono Indians (1950-2020)

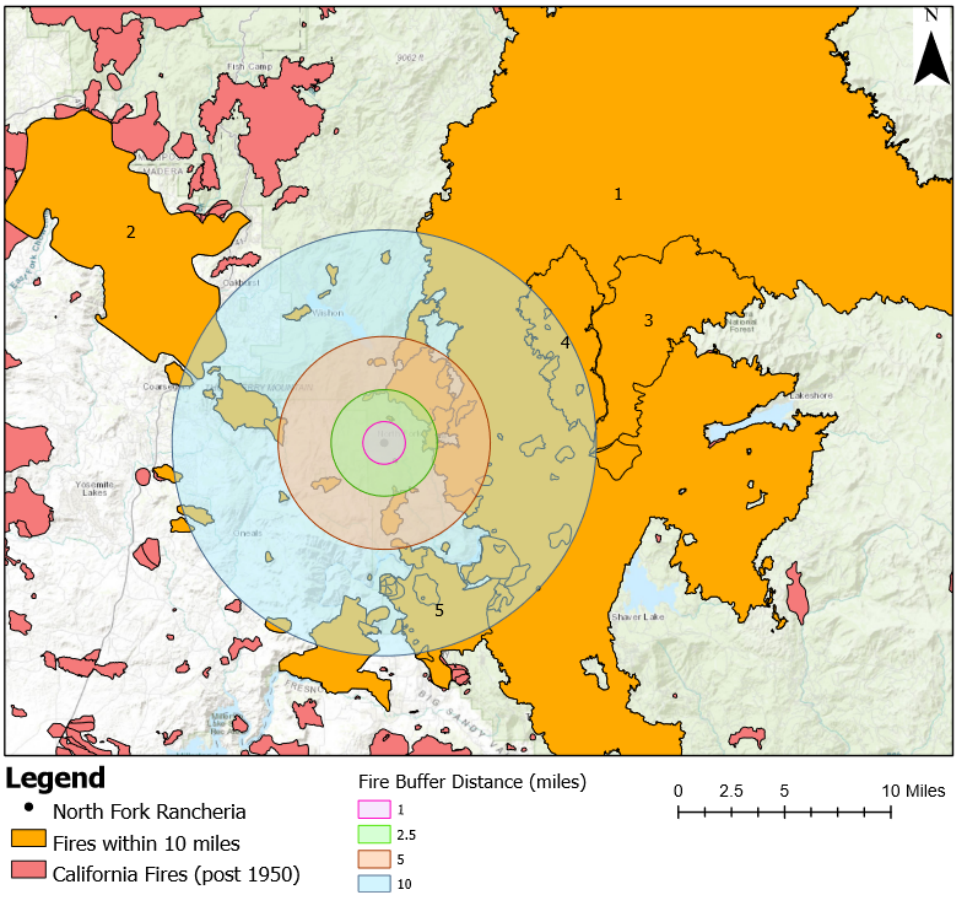


Figure 7. Wildfires that have impacted the North Fork Rancheria between 1950-2021 with fires within a 10 miles radius highlighted in orange. The numbers on the map denote the top five fires by area burned; see Table 1 for more information.

Source: CAL FIRE, 2021a

Table 1. Top 20 fires impacting the North Fork Rancheria of Mono Indians between 1961 and 2021, with the top 5 largest fires highlighted in blue.

RANK	YEAR	FIRE NAME	AREA (ACRES)
1	2020	CREEK	379,882
2	1961	HARLOW	43,331
3	2013	ASPEN	22,938
4	2014	FRENCH	13,832
5	1989	POWDERHOUSE	11,800
6	1982	TEMPERANCE FLAT	7,802
7	2015	WILLOW	5,701
8	2001	NORTH FORK	4,131
9	1968	THORNBERRY #2	3,131
10	1992	ITALIAN	2,157
11	1987	CHAWANAKEE	1,487
12	2017	MISSION	988
13	2015	CORRINE	922
14	1973	HORSESHOE	835
15	1985	MAMMOTH	764
16	1995	POWERHOUSE #2/#3	624
17	1970	LONG RIDGE	598
18	1961	MCALISTER FIRE	590
19	2005	QUARTZ	547
20	2003	NORTHFORK	472

Source: CAL FIRE, 2021b

In 2020 the Creek Fire – ranked the fifth largest wildfire in the state (CAL FIRE 2021a) -- devastated North Fork aboriginal territory. Of concern is the repeated burning of certain areas, as seen with the Creek Fire in 2020, the Aspen Fire in 2013 and French Fire in

2014 (Fires #1, #3 and #4 in Figure 7, Table 1). While it is uncommon for previously burned areas to re-burn, climatic changes are altering fire patterns that could influence the length of time between re-burns (Buma *et al.*, 2020). In total, there have been 73 fires within 10 miles of the North Fork Rancheria between 1950 and 2021. The loss of resources is severe, and it will take generations for the oak, pine, fir, and cedar to regrow.

Why is this indicator important?

Surrounding wildfires have contributed to both poor air and water quality in the North Fork Rancheria. Air pollution from wildfire smoke can lead to negative health outcomes like asthma, cardiovascular disease, and premature mortality. Soil erosion and sediment runoff from areas that have lost vegetation due to fires can degrade local surface water quality. This deposition of sediment, along with soot, can impact aquatic life in local waterways (BPT, 2020). Culturally important sites like the Mono Hot Springs have also been impacted. The alkaline runoff from wildfire soot increases the pH of water and the smoke from the wildfires lowers the temperatures (De Graff et al., 2018). On the North Fork Rancheria, fires have the potential to impact anywhere from 50-100 percent of the Tribe. Wildfires are likely to cause severe property damages, facility shutdowns, and injuries and illness (Madera County, 2016). Heavy rain, especially on wildfire-scarred land where the ground is unstable due to vegetation loss, can catalyze landslide events and severely threaten the health and safety of the surrounding community (NFRMIC, 2018).

The combined effects of multiple environmental stressors have been shown to directly impact wildfire events. Warming temperatures and drought conditions have exacerbated potential for wildfire (CAL FIRE, 2017). Drought and decreased snowpack have weakened trees, making them susceptible to disease and pest infestations; tree mortality in the Sierra National Forest has increased fuel loads, and thus the risk of wildfires (Madera County, 2016).

Another important consequence of increased frequency and intensity of fires across the state is the reduction in the number of days the Tribe can conduct cultural burning and fire ceremonies (BPT, 2020). For the North Fork Mono, regular burning encourages new growth of many species such as deer grass, sourberry and chapparal which are materials needed for basket-weaving. Since these plants are adapted to fire, after burning, the root stock remains intact and can resprout after spring rains. Due to long periods or dryness without regular prescribed burning, forests have become overgrown, causing conditions that could give rise to more extreme and dangerous fires. Additionally, vegetation management by Pacific Gas and Electric to remove brush and protect power lines has resulted in a loss of resources for the Tribe.

Summary

Warming temperatures, drought, wildfires, increasingly variable rainfall – and ensuing floods and erosion – have impacted the people of the North Fork Band of Mono Indians and their environment. In addition to exposures to temperatures much warmer than they are acclimated to, these changes have altered and disrupted the ecosystems within and

around North Fork, impacting many species of cultural importance to the Tribe. The community is actively working to understand, adapt to, and mitigate the effects of climate change. With the Tribe's goal of being consistent, transparent, and honorable, the North Fork Band of Mono Indians continue to manage and protect their lands and limit the impact of climate change on the North Fork Tribe's right to hunt, fish, gather, and continue their cultural practices –activities that are integral to their cultural and psychosocial health, well-being, and livelihood.

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Suggested citation: North Fork Rancheria of Mono Indians of California (2022). Impacts of Climate Change on the North Fork Rancheria of Mono Indians of California. In: OEHHA 2022 Indicators of Climate Change in California

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IMPACTS OF CLIMATE CHANGE ON THE SANTA YNEZ BAND OF CHUMASH INDIANS

Sea level rise, flooding, erosion, drought, air quality and changes in flora and fauna are threatening the physical, cultural, and spiritual health of the Tribe, its habitats and ecosystems, and its built environment.

Background

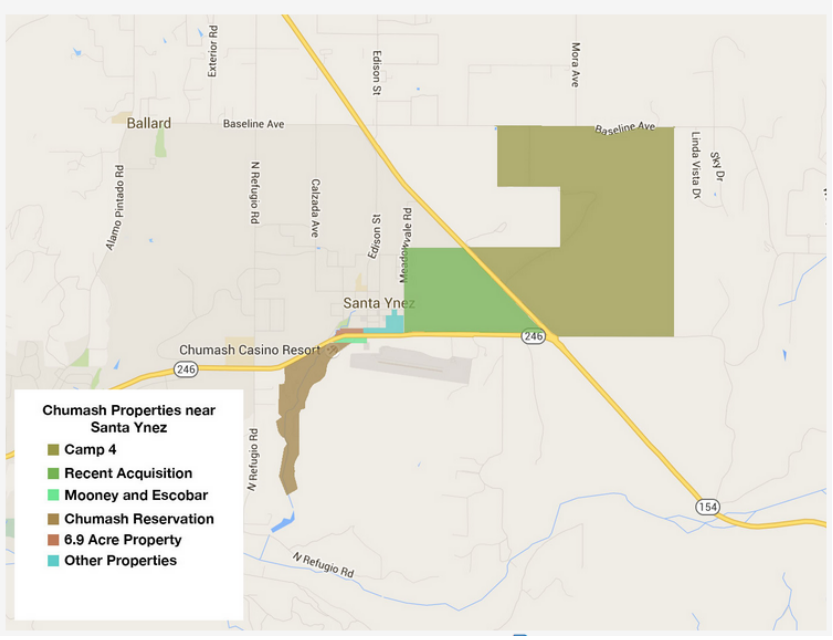
The Santa Ynez Band of Chumash Indians is a sovereign nation located in Santa Barbara County. They are currently the only federally recognized band of Chumash Indians. Santa Ynez is leading a coordinated effort of 11 of the 14 (SYBCI, 2020b) bands of Chumash Indians to document the impacts of climate change on the traditional Chumash territory (SYBCI, 2020a).

The culture of the Santa Ynez Band of Chumash Indians is deep within the souls of every tribal member and rests within our hearts. Throughout time, and in spite of challenges, the Tribe has maintained a connection to its ancestors and to a core identity of being Chumash. The Chumash have survived because of their strength as a Tribe and their spiritual connection to Chumash heritage and lands"

~Nakia Zavalla, Santa Ynez Chumash Cultural Director

For over 15,000 years the Chumash lived in a territory that encompassed approximately 7,000 square miles and ranged from the Channel Islands and Malibu to Paso Robles, then inland to the western edge of the San Joaquin Valley (Thornton, 2000). The Chumash population of approximately 25,000 people was decimated by disease and genocide, first by the Spanish starting in 1769, then by the

Figure 1. Chumash properties near Santa Ynez



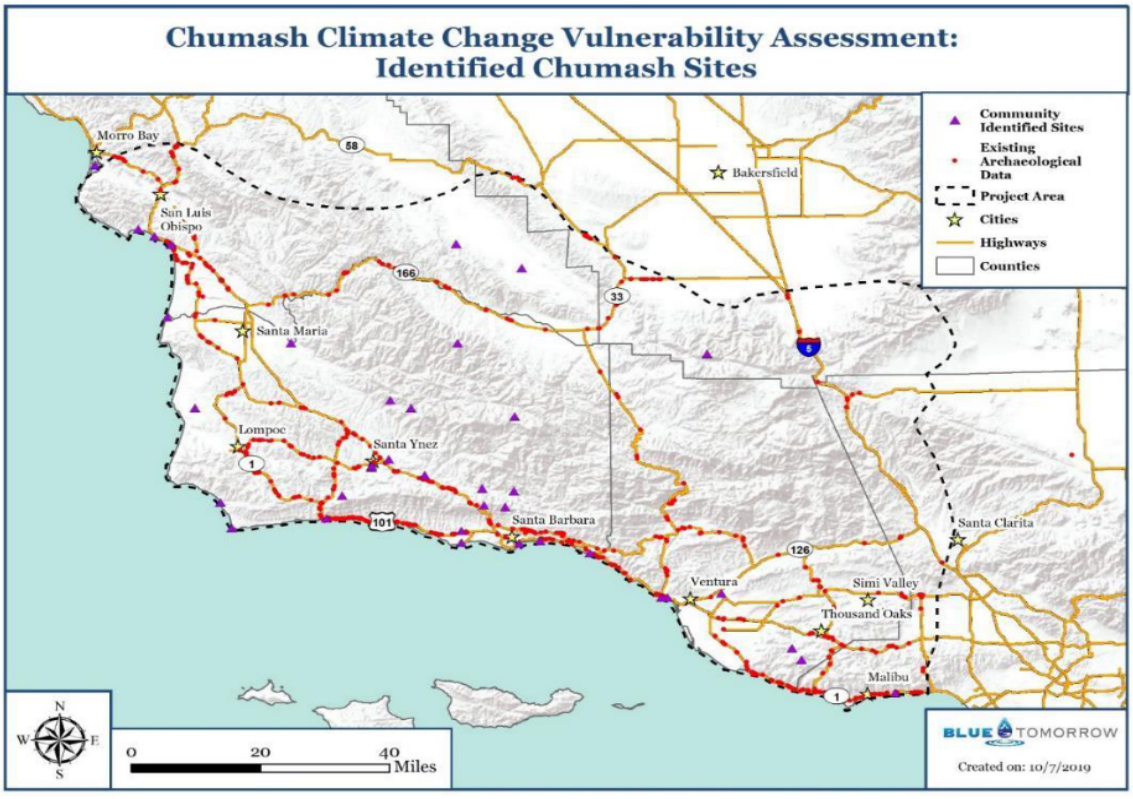
Source: County of Santa Barbara, 2021

Mission system and immigrant Americans colonizing the West (McWilliams, 1983). Today there are approximately 3,000 Chumash.

The Santa Ynez area is primarily rural, with vegetable and flower fields, cattle and horse ranches, vineyards, and wineries. As shown in Figure 1, access to the Santa Ynez reservation is via State Route 246, which connects on the west to Highway 101 and on the east to Highway 154. A creek bed separates the reservation into the Upper Reservation (west) and Lower Reservation (east). The original reservation covered 99 acres. In 2010, the tribe purchased 1,427 acres of land known as the Camp 4 property. The Camp 4 addition brought the size of the reservation to 1,526 acres (SYBCI, 2019). This addition also improved the overall lands of the Santa Ynez Chumash as the original reservation was intentionally placed along a floodplain (McCormick, 1996).

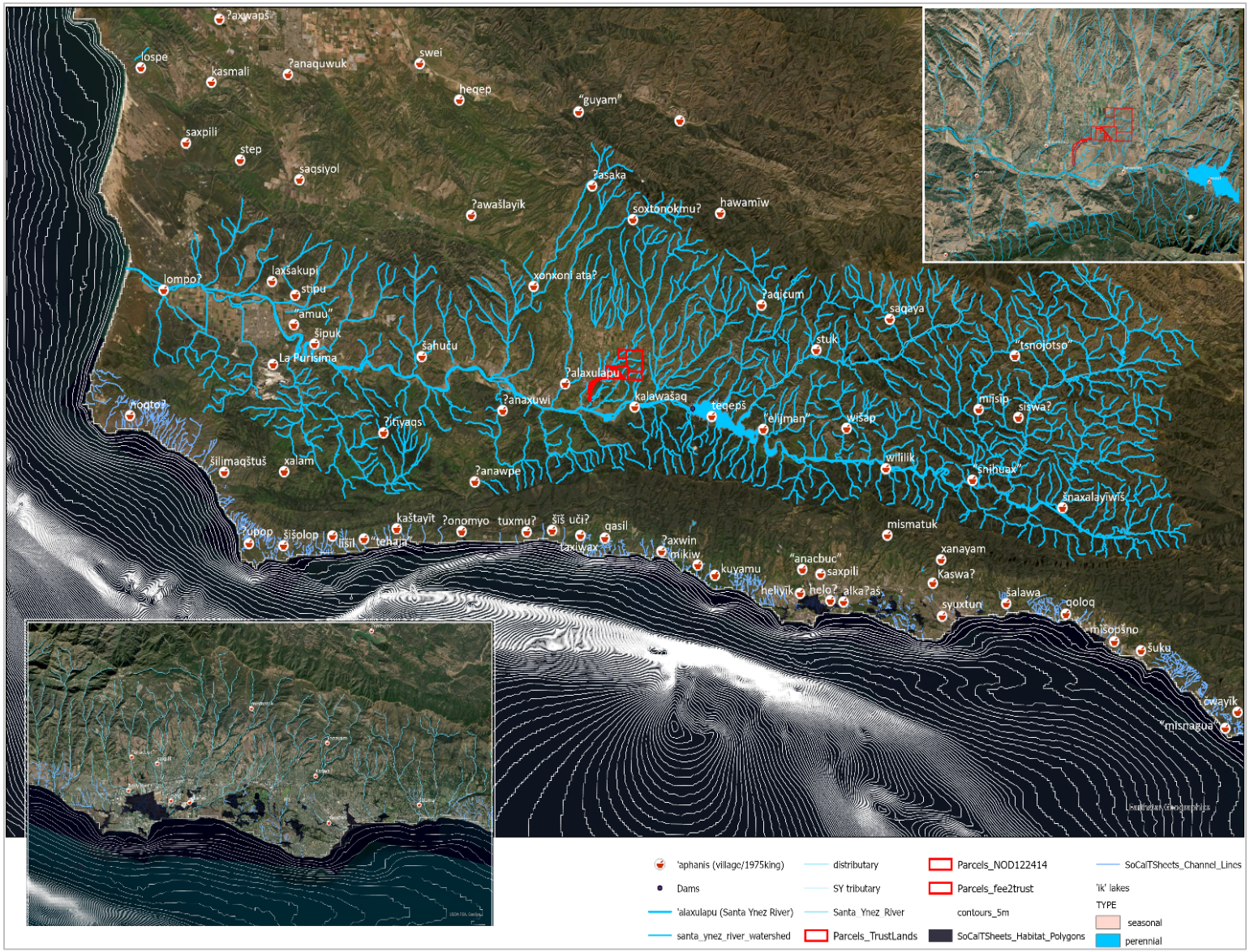
In assessing the impacts of climate change, the Chumash considered the approximate range of traditional Chumash tribal lands as those lands still hold important Chumash cultural sites (see map, Figure 2). Non-federally recognized Chumash bands and sacred and important Chumash cultural sites are located throughout this area (SYBCI, 2020a).

Figure 2. Chumash area considered in assessing the Tribe's vulnerability to climate change ("Project Area," dotted line), and sites of cultural significance to the Tribe



Source: SYBCI, 2020a

Figure 3. Watershed areas and creeks listed in Samala



Source: SYCEO, 2021a

Samala is the primary language traditionally spoken by the Santa Ynez Chumash people. Recent years have seen a renaissance of Chumash pride and identity, including efforts to continue to teach Samala and other Chumash languages (SYBCI, 2020a). For example, the watershed map in Figure 3 identifies creeks using their Samala names within the Chumash tribal area.

Climate change and the Santa Ynez Tribe

According to the Santa Ynez Chumash Environmental Office (SYCEO) Tribal Hazard Mitigation Plan, by 2100 the average temperatures are predicted to rise by over 7 degrees Fahrenheit (˚F), resulting in over six times as many extreme heat days. Average precipitation, currently about 16 inches per year (SB County, 2021), will increase by approximately 4 inches and hectares burned in wildfire will increase by over 20%.

Increasing temperatures, changing precipitation patterns, sea-level rise, wildfires, drought, and debris flows can all cause impacts to the Chumash by disturbing plants and animals, potentially leading to their local extinction. These disturbances in turn may impact traditional hunting and gathering practices, the timing of spiritual practices, and the loss of local food sources, traditional medicinal plants, and traditional materials used for jewelry, sculptures, ceremonial pieces, basketry, nets, and lodgings (SYBCI, 2020a).

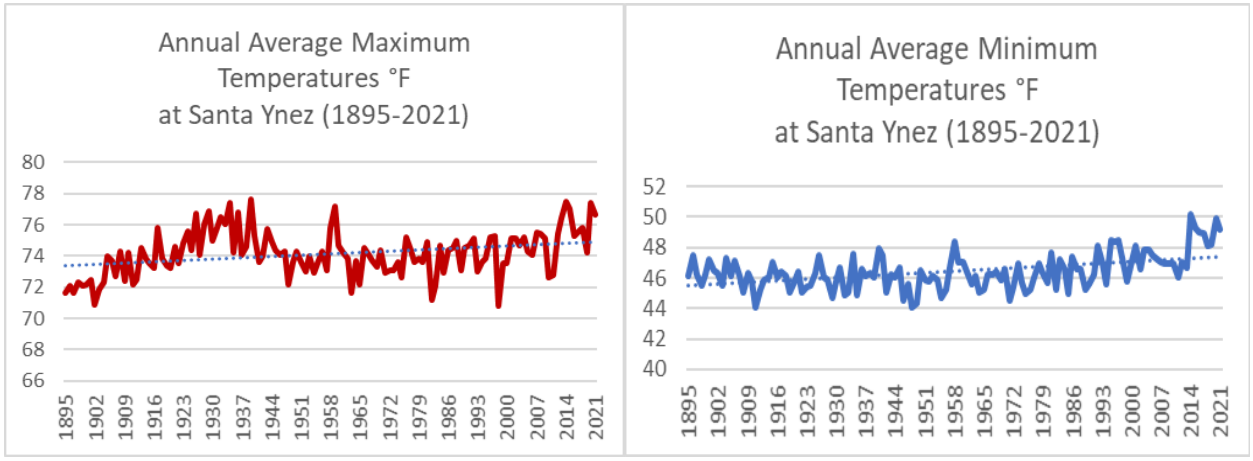
In a survey conducted by the SYCEO as part of a Climate Change Vulnerability Assessment, 90% of respondents stated that climate change and the resulting sea level rise, flooding, erosion, wildfires, reduction and extirpation of plants and animals, has already had an effect on access to cultural sites (Figure 2) and resources, including the availability of plant and animal resources (SYBCI, 2020a).

Elevated Temperatures

What does this Indicator show?

At Santa Ynez, both the nighttime temperatures and daytime temperatures are rising, with the nighttime temperatures rising more quickly. As shown in Figure 4, before 1950 the annual average minimum temperature varied between 41.5°F and 46.1°F and the annual average maximum temperature varied between 72.5°F and 77.5°F. Since 1950 the annual average minimum temperature has been between 42.2°F and 48.5°F and the annual average maximum temperatures has ranged from 71.6°F to 77.6°F (PRISM, 2022).

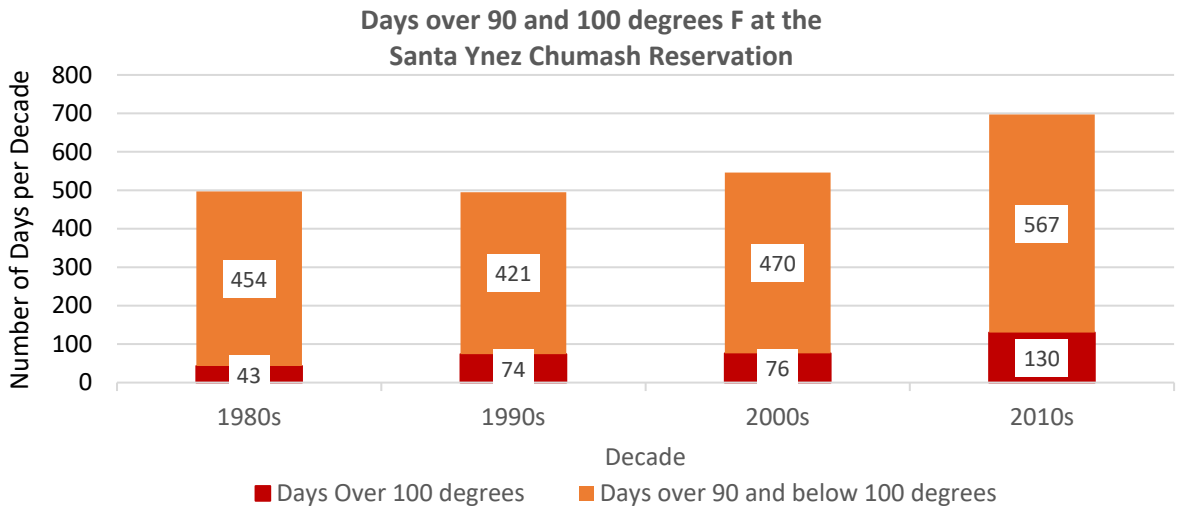
Figure 4. Annual average temperatures at Santa Ynez 1895-2021



Source: PRISM 2022

The number of extreme heat days has increased as well. As shown in Figure 5 the number of days with temperatures over 100°F has more than tripled since the 1980s (PRISM, 2022). In 2020 and 2021 the Tribe experienced 111 days over 90°F and 17 days with temperatures over 100°F.

Figure 5.



Source: PRISM, 2022

Why is this indicator important?

Elevated temperatures affect human health, mental health, cultural and spiritual health, and socio-economic health, as well as the plants and animals that are part of the Santa Ynez Chumash environment. Elders, children, outdoor workers, and those with existing medical conditions are particularly susceptible to these impacts.

With the increasing nighttime temperatures, people do not have the chance to cool down. In addition, in traditionally temperate areas such as Santa Ynez, people are not

physiologically acclimated to higher temperatures. The Tribe currently does not have enough cooling centers to help members in need during times of extreme heat.

Many indigenous cultural practices rely on natural or seasonal cycles associated with changes in weather patterns, plants, and animals. Increased temperatures, extreme heat, and heat waves affect the traditional timing of Chumash cultural practices due to climate's effect on the landscape. Warmer temperatures and changes to precipitation patterns may cause plants to fail to grow in one area and be able to grow in another. Some species may be able to expand their range, while others may experience a decrease in range. The Tribe has already seen traditional plants migrating to different areas and the off-season blooming and fruiting of many species (SYBCI, 2020a).

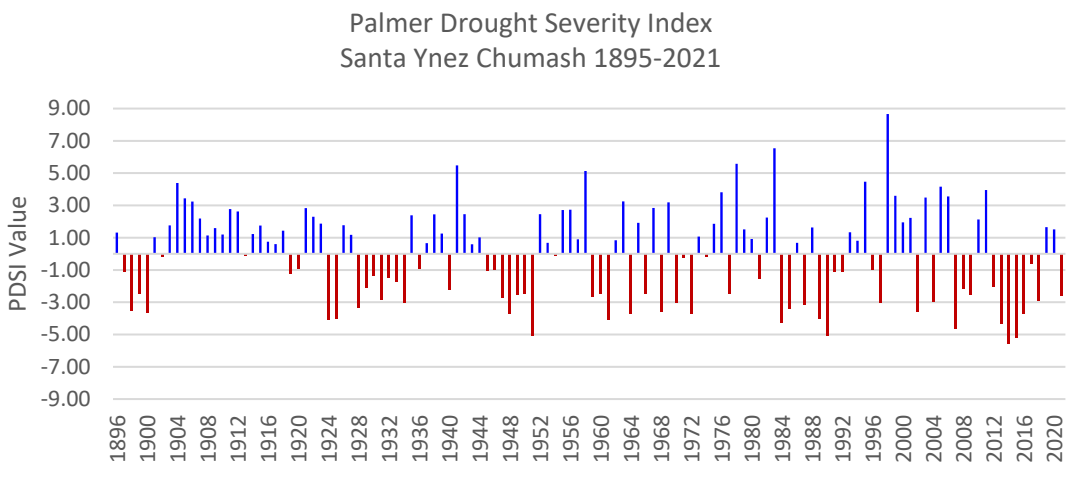
Drought

What does this indicator show?

Because of its geography, Santa Barbara County does not always experience drought at the same time as the rest of California. The county has been free of drought at times of state-declared drought emergencies, but also has experienced drought when there is no state-declared drought. For example, after the state lifted its declaration for the drought of 2014 – 2017, Santa Barbara County's local drought declaration remained in place. As a result, examining impacts at a local level reveals a more accurate picture of drought impacts (SYBCI, 2020a).

The Palmer Drought Severity Index (PDSI) combines both temperature and precipitation data to provide data on relative dryness (drought) on a scale from +10 (wet) to -10 (dry). The lower the number the drier the conditions. As is shown below in Figure 6, the Santa Ynez Chumash Tribe is having more, and more intense, dry years. Prior to 1950, dry years (with PDSI values below zero) occurred 26 times, three of which were classified as extreme drought (PDSI at or below -4). From 1951 to 2021 Santa Ynez experienced 35 dry years, including 7 years of extreme drought.

Figure 6. Drought at Santa Ynez



Source: Abatzoglou et al., 2022

Why is this indicator important?

The Tribe has observed that ground water levels on the Santa Ynez reservation have dropped during drought, and that plants are migrating to higher elevations or are not propagating due to a combination of drought and extreme heat.

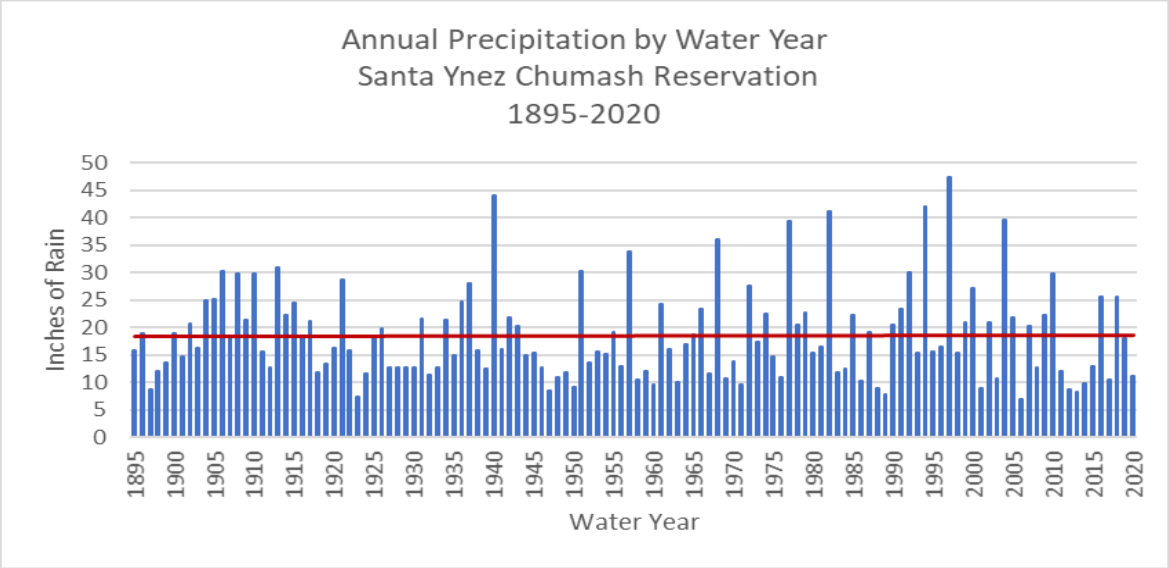
During interviews with the Chumash community, 74 plant species were identified that have traditionally been or currently are gathered. Approximately 76% of respondents (22 individuals) said that they have noticed changes in the availability of plant and animal resources in recent years, with 20 respondents experiencing a decrease in availability. For those respondents who experienced a decrease in plant and animal resource availability, the commonly reported reasons for the decline included: loss of access, overharvest, drought, lack of instream water availability, and development (SYBCI, 2020c).

Precipitation and Flooding

What does this indicator show?

As shown in Figure 7, while the total amount of rain over time has remained steady, the fluctuation in wet and dry years has grown greater over time. Looking at water years, which start in October and run through September the following year, between 1895 and 1958 the Santa Ynez Chumash experienced one year with rainfall over 35 inches. From 1959 to 2020 the Santa Ynez Chumash experienced six years with rainfall of over 35 inches per year. This high intensity rain is matched with high runoff and the Chumash have seen that groundwater is not being recharged as a result (PBMI and SYBCI, 2021).

Figure 7. Annual Precipitation at the Santa Ynez Chumash reservation

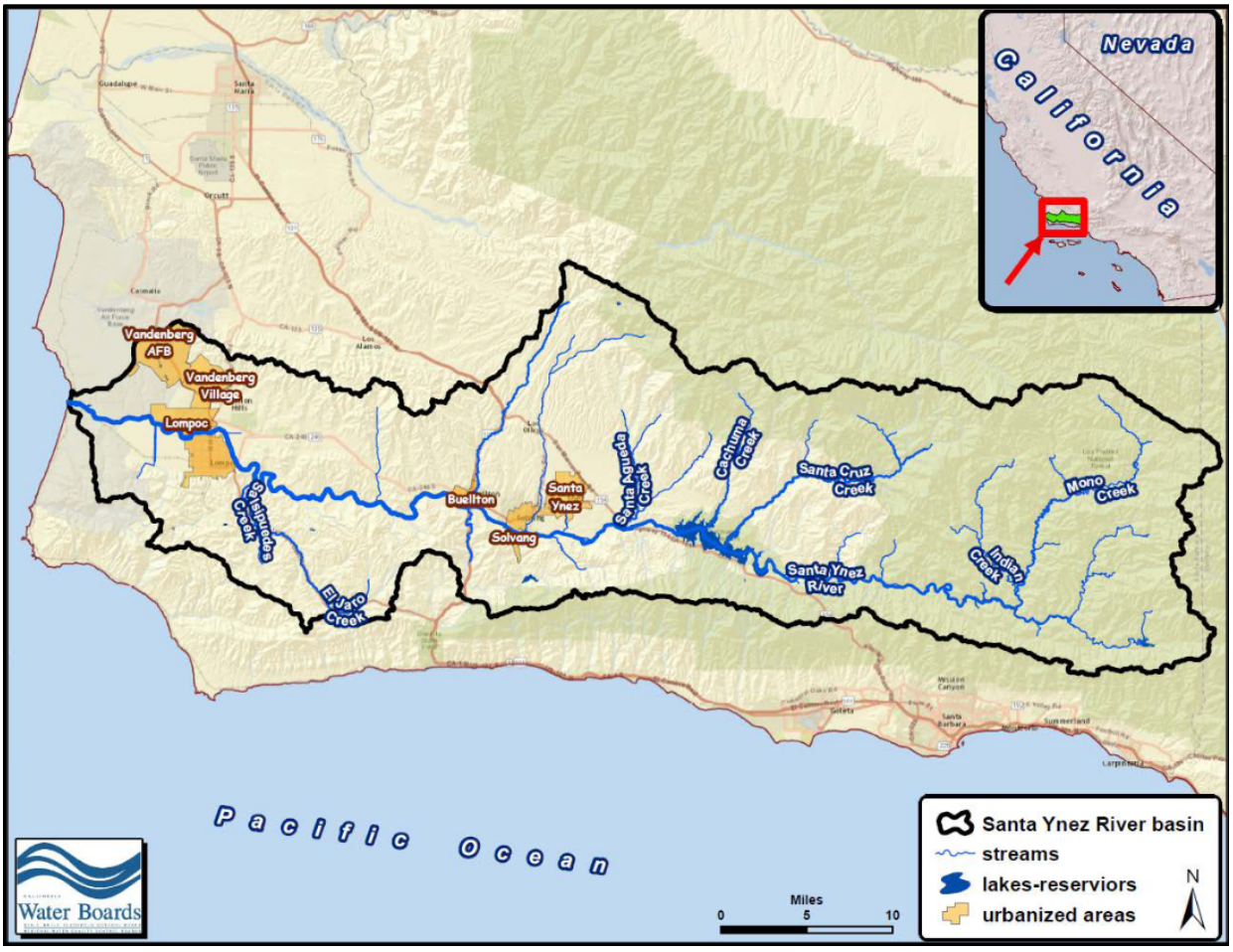


Source: PRISM 2022

Why is this indicator important?

The Santa Ynez Reservation lies within the Santa Ynez River Watershed (See Figure 8, Watershed subbasins). The Santa Ynez River borders the southerly edge of the Santa Ynez Valley, along the northern slopes of the Santa Ynez Mountains. One of the largest rivers on the Central Coast of California, the Santa Ynez River is 92 miles long, flowing east to west across the valley, through Solvang, Buellton, and Lompoc. The watershed encompasses 897 square miles. It drains from the Santa Ynez River's headwaters in the Santa Ynez Mountains west through the Santa Ynez Valley before emptying directly into the Pacific Ocean north of Surf Beach. Elevations range from 4 feet at the head of the estuary to 6,820 feet in the Santa Ynez Mountain headwaters.

Figure 8. Santa Ynez River watershed subbasins

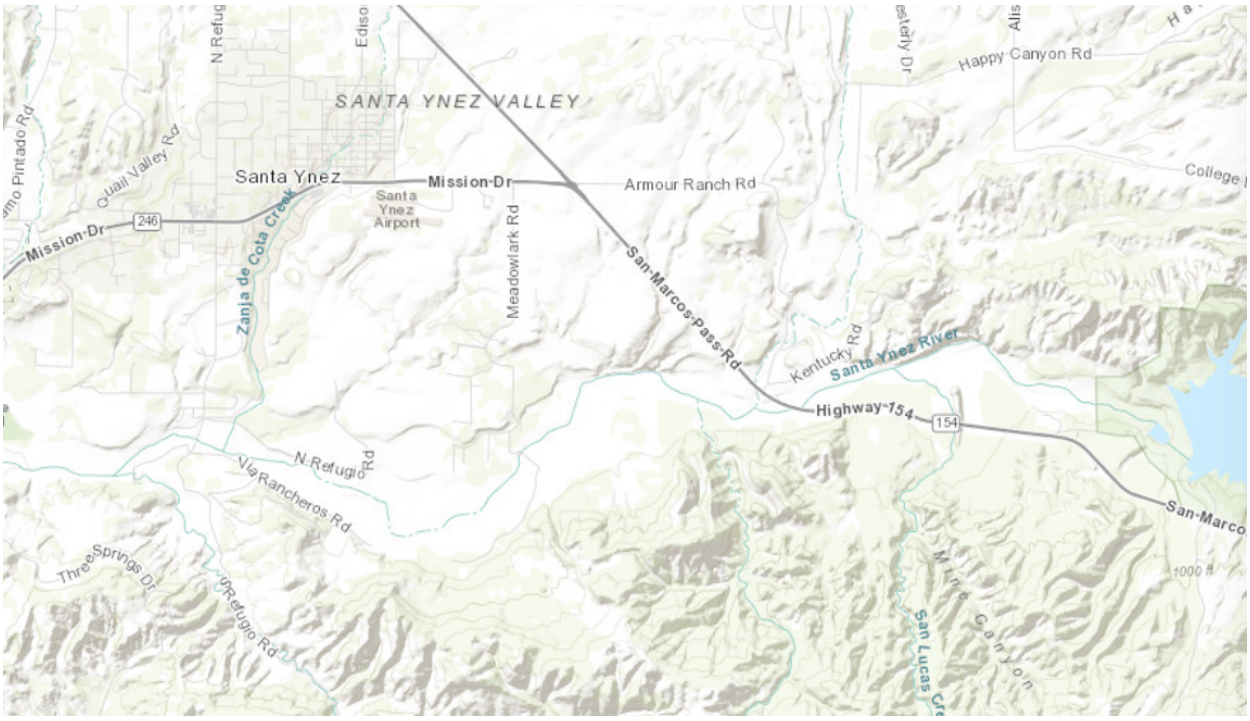


Source: Waterboards, 2016

The USGS designates the Santa Ynez River as a fourth-order river (medium sized) with 2,077 miles of total tributary stream length: 1,663 intermittent miles, 350 perennial miles, and 63 miles of man-made channels. Drainages exiting the hills and draining to the Santa Ynez River cross the valley northeast to southwest. The most significant

surface water for the Santa Ynez Tribe is the Zanja de Cota Creek (see Figure 9) which bisects the original Santa Ynez Chumash reservation lands.

Figure 9. Zanja de Cota Creek



Source: USGS, 2021

With increasingly variable precipitation, extreme rainfall events are projected to pose a risk of flooding. (Coastal Resilience, 2020). Santa Barbara County experienced 14 significant floods between 1862 and the 1998. Eight of these floods were declared state and federal disasters. The Santa Ynez Reservation has seen major flooding along Zanja de Cota Creek and the Santa Ynez River. In recent years, major flooding along the creek occurred in 1980, 1995 and 1997.

The 2019 Santa Ynez Band of Chumash Multi-Hazard Mitigation Plan (SYBCI, 2019) provides an account of flooding on the reservation along Zanja de Cota Creek and the Santa Ynez River. As is summarized below in the first 130 years of modern flood records the Santa Ynez Chumash endured four major floods; in the last 30 years the Santa Ynez Chumash have experienced five major floods.

Summary of major flood events

- 1862—Great Flood
- 1907—Flood flows on the Santa Ynez River engulfed the entire Lompoc Valley
- 1969—California declared Santa Barbara County a disaster area on January 25; major flooding along the Zanja de Cota; Santa Ynez River experienced the highest flows in almost 3,000 years; 16 inches of rain fell at Juncal Dam (Goleta)

in a 24-hour period; in the Upper Santa Ynez watershed, the flood was equivalent to a 100-year storm
- 1980—Major flooding along the Zanja de Cota; mudslides in some areas
- 1992–1993—Santa Ynez Valley received approximately 180 percent of normal rainfall
- 1995—Major flooding along the Zanja de Cota; part of widespread flooding throughout the County
- 1997–1998—Flooding along the Zanja de Cota; several record-breaking rainfalls with 50-year storm event intensities in February 1998
- 2011 (March) Santa Ynez River flooding
- 2018 Montecito debris flow. This debris flow impacted local Chumash cultural resources and caused damage to the reservation.

Sea level rise

What does this Indicator show?

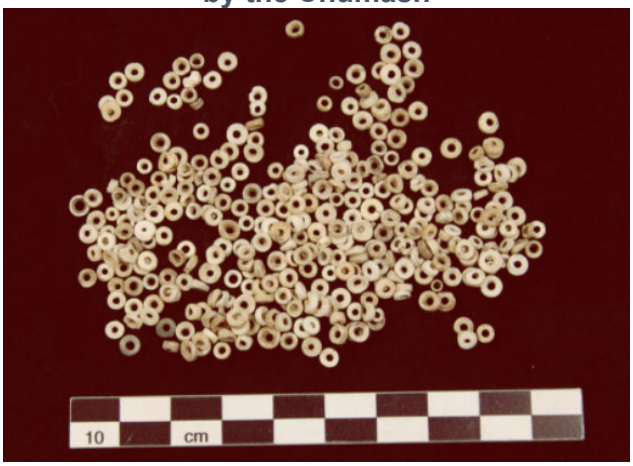
The Nation Oceanic and Atmospheric Administration (NOAA) reports that the mean sea level in Santa Barbara County has increased an average of 1.08 millimeter per year between 1973 and 2020 (NOAA, 2021).

Why is this indicator important?

Sea level rise and the resulting erosion are already impacting important Chumash cultural sites along the coast (PBMI and SYBMI, 2021). Like many cultures, the Santa Ynez Chumash youth are taught by parents or elders in the group. As sea levels rise, sites previously used for gathering are no longer accessible. In addition, the Tribe has seen damage to cultural sites due to erosion along the coast. Without access to these traditional sites, knowledge can be disrupted, and the weight of that loss is felt by generations of tribal members (PBMI and SYBMI, 2021).

Olivella shells (Figure 10), are gathered by the Tribe for use in shell money, jewelry, and regalia, are becoming more scarce and traditional areas for gathering are often no longer accessible (PBMI and SYBMI, 2021).

Figure 10. Olivella shells carved by the Chumash



Source: Science News, 2021

While sea water intrusion is not expected to impact the Santa Ynez reservation directly, its impact on other aquifers will likely increase dependency on the other groundwater basins between the Santa Ynez Mountains and the Pacific Ocean (Coastal Resilience, 2020).

Impacts on Plants and Animals

What does this indicator show?

The Santa Ynez Chumash have already seen a reduction or extirpation of species such as steelhead, red-legged frogs, kelp, sea grass and Olivella. Both Chia Sage (*Salvia columbariae*) and Chuchupate (*Ligusticum porter*) are no longer found in the area and grow only at higher elevations where temperatures are cooler, and more water is available.

Plant communities and animal habitats are anticipated to be further affected by changes to primary (temperature, precipitation, sea-level rise) and secondary (drought, wildfire, flooding, flooding, cliff erosion, debris flows, and wildfire) climate change impacts (SYBCI, 2020a).

Why is this indicator important?

The Chumash have always harvested from both the land and the sea. Changes in ocean temperature and ocean acidification have impacted species important to the tribe (PBMI and SYBMI, 2021). In 2013 sea stars, the main predator of purple urchin, were decimated by the sea star wasting disease virus; while the causes of the incident have not been established, it is hypothesized that elevated ocean water temperatures may have been an exacerbating factor (Miner et al., 2018). With sea stars gone, the urchin population grew unchecked.

2014 brought a marine heat wave, which was followed in 2015 by an El Niño causing the ocean waters to warm further. These warm waters contained fewer nutrients than the normally cold coastal California waters, which caused kelp to grow more slowly. Urchin and abalone both mainly eat kelp. The explosion in the urchin population and the reduction in kelp due to warming waters impacted two species important to the Chumash: kelp and abalone (UCD, 2021).

Many species which are important to the Santa Ynez Chumash are currently threatened by climate change such as: Belding's Savannah Sparrow, tidewater goby, steelhead, snowy plover, willow flycatcher, white-tailed kite, monarch butterfly, Coastal Range newt, Western Pond Turtle, and brown pelican. Waqaqʾ (red-legged frogs, Figure 11), in particular, used to thrive on the reservation, are no longer present.

Figure 11. Waqaq' (California red-legged frog)



Source: Los Padres Forest Watch

The Zanja de Cota Creek that flows through the reservation used to be the site of steelhead fishing derbies (Figure 12). Due to the drop in water in the creeks, and an increase in pesticide runoff, there are no steelhead remaining in the creeks.

Figure 12. Historic photo - steelhead caught along Zanja de Cota Creek (1912)



Source: Lompoc Historic Society

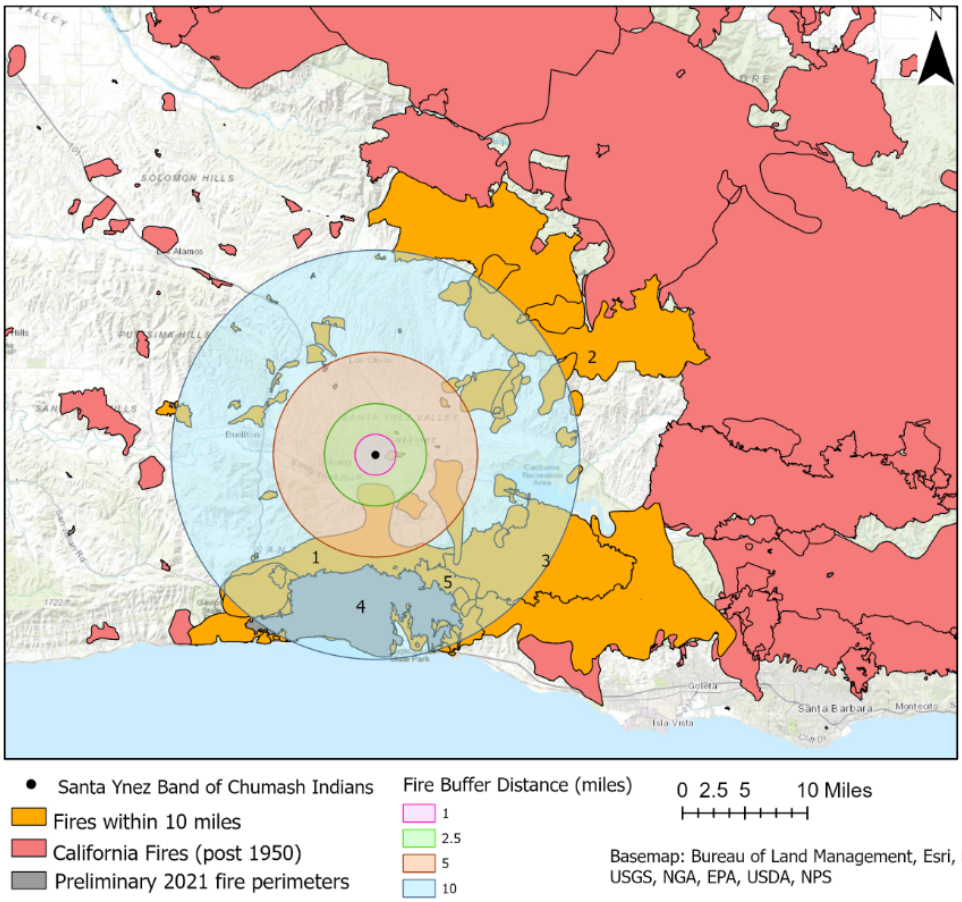
Wildfire

What does the indicator show?

The incidence of large forest fires in the western United States has increased since the early 1980s (Wehner et al., 2018). Fire season in California is starting earlier and ending later each year (CAL FIRE, 2020). A study of microscopic charcoal from the Santa Barbara Channel indicates that over the past 560 years large wildfires (greater than 500 acres) occurred in the Santa Barbara County area an average of every 20 to 30 years (Mensing et al., 1999). Prior to the 1950s, the greater Santa Barbara area averaged one large fire per decade; however, the number of large fires within and adjacent to the County has increased substantially. There were 93 large fires within Santa Barbara County between 1955 and 2021 that burned over 1,475,042 acres. This equates to 1.4 significant fires every year (SB Fire Safe Council, 2021, CAL FIRE 2021). Figure 13 shows the fires that came from within one to ten miles of the Santa Ynez Chumash reservation between 1950 and 2021.

Figure 13.

Fires Impacting the Santa Ynez Band of Chumash Indians (1950-2021)



Source: CAL FIRE, 2021. Map generated using fire perimeter data from CAL FIRE

Why is this indicator important?

Wildfire is considered a high-risk exposure for the Santa Ynez Chumash tribe. Climate factors including Santa Barbara's Sundowner winds (Ryan et al., 1992), increasing temperatures, and severe drought conditions are increasing the wildfire risk at Santa Ynez.

Firefighting equipment can expose and destroy cultural sites. Burned areas that are then subjected to heavy rain will be subject to flooding, landslides and rockfalls. Cleanup of burned areas can expose cultural artifacts and destroy sites important to the Tribe. SYCEO has begun studying impacts in burn scar areas, including loss of trees and species that are returning to these areas. Some burn scar areas are not supporting the growth and reproduction of tree seedlings, likely due to warmer temperatures or insufficient moisture related to climate change, in addition to the wildfires.

Poor air quality, caused by wildfire smoke, is of great concern on the reservation; when wildfire smoke is present outdoor activities cannot occur, ceremonies and gathering

activities are cancelled. Smoke more heavily impacts Tribal members who have asthma, or other respiratory related health issues such as chronic obstructive pulmonary disease (COPD).

Summary

Warming temperatures, drought, increasingly variable rainfall – and ensuing floods – erosion resulting from sea level rise, and wildfires have impacted the people of the Santa Ynez Band of Chumash Indians and their environment. In addition to exposures to temperatures much warmer than they are acclimated to, these changes have altered and disrupted the ecosystems within and around Santa Ynez, impacting many species of cultural importance to the Tribe, and interfering with their ability to carry out traditional practices. The community is actively working to understand, adapt to, and mitigate the effects of climate change. Their goal is to continue to manage and protect their lands and limit the impact of climate change on the Santa Ynez Chumash Tribe's right to hunt, fish, gather, and continue their cultural practices –activities that are integral to their cultural and psychosocial health, well-being, and livelihood.

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Suggested citation: Santa Ynez Band of Chumash Indians (2022). Impacts of Climate Change on the Santa Ynez Band of Chumash Indians. In: OEHHA 2022 Indicators of Climate Change in California.

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Introduction

Across California, some documented changes in the environment, agriculture, and public health are plausibly but not yet established to be influenced by climate change. The potential links to climate change are supported by scientifically likely hypotheses, models, and/or limited data, but confounding factors such as land use change, environmental pollution, and the inherent variability of the climate system, make it difficult to establish a clear link to climate change. These trends and conditions are discussed in this volume as emerging indicators, where the evidence is compelling enough to warrant attention, but has not yet reached the threshold to confirm a climate signal.

Many of the trends documented in this volume intersect with and could amplify climate risks already tracked across water supply, public health, and ecosystems in other volumes of this report. Some cut across multiple sectors – declining winter fog impacts agriculture and coastal systems; rising cyanobacteria bloom threaten drinking water, aquatic ecosystems, and tribal cultural resources; and co-exposure to pesticides and extreme heat represents a compounding burden for farmworkers, an example of how

climate effects have become more pronounced in communities facing multiple, overlapping exposures.

The following chapters – Central Valley Fog, Coastal Fog, Cyanobacterial Harmful Algal Blooms (Freshwater and Estuarine), Bluetongue in Livestock, Bumble Bee Populations, Aeroallergens, Farmworker Exposure to Pesticides, Foodborne and Waterborne Infectious Diseases, and Zoönoses – document current trends, confounding factors, and knowledge gaps for each of these emerging indicators.

7.1 Central Valley Fog

Fog, defined as a cloud (stratus or stratocumulus) at or near the ground or ocean surface, consists of droplets approximately 100 times smaller than raindrops that remain suspended in air. These droplets can coalesce into drizzle or collect on surfaces to form "fog drip" (AMS, 2022). In California's Central Valley, winter fog promotes colder temperatures, a critical factor for achieving a period of dormancy (see the *Winter Chill* chapter) in agricultural regions.

Both anecdotal evidence and field measurements indicate that California's Central Valley winters are less foggy over recent decades. Baldocchi and Waller (2014) used satellite imagery and weather station data to analyze the frequency, spatial extent and long-term trends in "tule fog" — a thick winter ground fog that blankets the valley. Their analysis paired satellite records from the National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration with data from a network of valley weather stations to quantify winter fog days from 1981-2014. Over the 33-year timespan, winter fog events decreased 46%, on average, with much year-to-year variability. The optimal Central Valley fog formation occurs during winters with periodic storms followed by periods of high pressure. This allows humidity from evaporating soil moisture to condense and form fog during the cold, clear nights (Baldocchi and Waller, 2014). According to Dr D. Baldocchi (personal communication, 2026), the winter of 2025-2026 has been unique, with exceptionally persistent Central Valley fog due to the heavy early rains in autumn, followed by a very strong high-pressure system that created an inversion layer, which acts like a lid to trap soil moisture and keep the fog in the valley. The early rain and strong high-pressure system set up conditions that were ripe for dense and prolonged fog to persist until a storm in December 2025 eventually pushed out the fog (NASA, 2025).

Rising air temperatures in densely populated areas (the "urban heat island effect") have been associated with a decline in the frequency and spatial extent of valley fog (Klemm and Neng-Huei, 2016). Higher temperatures prevent the condensation of atmospheric water vapor making it less likely for fog to form, as well as accelerating the evaporation of fog after formation. Drought conditions also tend to suppress the ability of fog to form

because there is less soil moisture that can evaporate – reducing fog days during dry years (Baldocchi and Waller, 2014).

Other studies report that the observed reduction in fog in the Central Valley and in other areas worldwide strongly correlates with a decline in air pollution (Gray et al., 2019, 2016; Klemm and Neng-Huei, 2016). Airborne particles, including dust and other air pollutants, serve as nuclei for water vapor to condense around. One study concluded that climate variables (in particular, the difference between ambient temperatures and dew point) strongly influenced the short-term, year-to-year variability in fog frequency; however, changes in air pollution are driving long-term temporal and spatial trends in Central Valley fog (Gray et al., 2019). This study found that from 1930 to 1970, valley fog significantly increased due to high levels of nitrogen oxide emissions attributed to a surge in use of motor vehicles. In contrast, the downward trend in fog frequency since 1980 is consistent with the trend of decreasing air pollution due to statewide vehicular emissions regulations over the past decades.

While decreasing air pollution appears to be a major factor in the decline of fog formation, rising temperatures also play a role and will likely have an increasingly significant impact as temperatures continue to rise in the future. The concurrent roles of changes in air pollution (including agricultural burning) and climate on changing fog trends in the Central Valley remain an area of ongoing research. Despite advances in remote sensing technology, significant knowledge gaps remain regarding the application of these techniques to fog detection, especially over terrestrial ecosystems. Most methodological research has concentrated on maritime fog detection, with few studies extending these techniques to complex terrestrial environments (Chaverri et al., 2025).

OEHHA acknowledges the expert contributions of the following to this report:

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7.2 Coastal Fog

Coastal fog is a cloud that reaches the land or ocean surface and develops through complex oceanic and atmospheric interactions (Clemesha et al., 2017; Koračin et al., 2014). Coastal fog forms on the western edges of many continents when offshore stratocumulus cloud decks, sustained by cool, moist marine air trapped beneath warmer, drier air, lower towards the ground (Pilié et al., 1979). As coastal fog moves inland from the ocean into coastal California, it provides moisture and shade (Clemesha et al. 2016; Torregrosa et al., 2014; USGS, 2022) and moderates coastal spring and summer temperatures, helping limit periods of unusually high daytime temperatures along the coast (Clemesha et al., 2018; Iacobellis and Cayan, 2013). Anomalously warm coastal land conditions are associated with reduced wind speeds, reduced cloudiness, and warmer sea surface temperatures in the Pacific Ocean (Hale et al., 2024). The importance of fog to California's water balance, energy demand, ecosystems, and human health is receiving increased attention among researchers (Burns, 2017; McLaughlin et al., 2017; Richter, 2026; Torregrosa et al., 2014). Improved understanding of climate change impacts on future fog trends may help researchers and resource managers better anticipate changes in water availability, coastal ecosystem function, energy use, and human exposure to heat.

Data on observed and projected changes to coastal fog linked to climate change in California remains limited, in part because long-term trends of coastal fog in California vary by location, period, and observing method (Werner et al., 2022; Williams et al., 2015), likely reflecting both large natural variability and the many interacting processes that influence coastal fog and low cloudiness (Clemesha et al., 2016, 2017, and 2023; Johnstone and Dawson, 2010; Koračin et al., 2014; Torregrosa et al., 2016). For example, decreases in coastal fog may be linked to increases in sea surface water temperatures. On the other hand, as the land surface warms faster than the ocean, the temperature difference may ultimately lead to increases in coastal fog (Ortiz, 2025). Human-caused global warming may be further altering the many processes that influence fog and low clouds, but the direction and magnitude of future changes along the California coast remain uncertain.

OEHHA acknowledges the expert contributions of the following to this report:

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7.3 Cyanobacterial Harmful Algal Blooms (Freshwater and Estuarine)

Cyanobacterial harmful algal blooms (CyanoHABs) occur when cyanobacteria – nonpathogenic, photosynthetic bacteria commonly found in freshwater and estuarine environments – can quickly multiply under favorable conditions. Some can produce toxins (cyanotoxins) that may pose risks to water quality, ecosystems, and public health when exposure occurs. In California, CyanoHABs mainly occur in freshwater recreational waters, including lakes, reservoirs, rivers and streams, and estuaries. Globally, they are expanding in occurrence, distribution, intensity, and toxicity because of a combination of climate change and anthropogenic eutrophication (the overabundance of nutrients in a waterbody due to the actions of people) (Ho et al. 2019; Paerl and Barnard, 2020; Taranu et al., 2015). In California, reports of CyanoHABs have been increasing over the past 40 years based on periodic and anecdotal data (SWRCB, 2021). Ongoing observational data between 2016 and 2020 also show that reports of CyanoHABs are increasing spatially and temporally throughout the state, occurring in freshwater bodies ranging from high elevations to the coast and sometimes lasting from 6 to 12 months. In 2022, California received 684 voluntary freshwater harmful algal bloom (FHAB) incident reports – the majority of which are cyanobacterial blooms in freshwater systems – through the statewide online reporting system, up from 190 reports in 2018 (SWRCB, 2024).

Tribal Connection 7.3.1.

The culture and health of the Big Valley Band of Pomo Indians is inextricable from the health of their homelands around the shores of Clear Lake, which is one of the most HAB-impacted freshwater bodies in the state. In the *Impacts of Climate Change on the Big Valley Band of Pomo Indians*, the author writes, "*Tribal members and locals around Clear Lake report that HABs have become much more prevalent over the last few decades. […]. HABs on Clear Lake produce very high levels of microcystin and the Lake is often posted with recreational advisories from April through October. […]. When advisories are posted at Clear Lake, Tribal Members can't safely participate in Tribal activities that require them to be in the lake. Important tribal activities that are prevented by trigger level advisories include spiritual activities, water immersion for ceremonies, using plants for ceremonies and basketry, and the collection and consumption of fish and other aquatic organisms. Tribal members are also prevented [by Lake conditions] from swimming or playing in the water, which is important for heat relief. In 2021, cyanotoxin was monitored from April through December. During that time there was never a period in which the whole lake was safe for contact*" (Big Valley Band of Pomo Indians, 2026). Big Valley has monitored cyanobacteria and cyanotoxins in the Lake since 2014 and is a leading contributor to the California Cyanobacteria and Harmful Algal Bloom Network.

Climate change drivers of CyanoHABs include increasing water temperatures, changing precipitation rates, rising occurrences of extreme storm events, and increasing carbon dioxide levels (Paerl et al., 2016; Paerl and Paul 2012; Paerl et al., 2018; Preece et al., 2025). Increasing temperatures may cause CyanoHABs to grow faster, to appear in places that were previously unsuitable to them, at new times of the year, and for longer durations (Suikkanen et al., 2013). Increasing temperatures also contribute to water stratification and anoxic conditions at the sediment-water interface that allow for phosphorous re-mobilization, which can increase the likelihood of CyanoHABs. Increased precipitation significantly increases the external loading of nutrients from land into surface waters, which can promote the growth and duration of CyanoHABs (IPCC,



2022; Preece et al., 2025). In shallow waterbodies, increased precipitation can also elevate the flux of legacy nutrients stored in the sediment to the surface (Paerl and Barnard, 2020). Extreme storms can promote CyanoHABs through strong winds that mix the water column, which causes sediment resuspension and the release of legacy nutrients (Wells et al., 2015). Decreased levels of precipitation can slow the flow of rivers and streams, leading to hydrologically stagnant waters and limited flushing flows for benthic CyanoHAB mats (Quiblier et al. 2013), which promote the occurrence of CyanoHABs (Paerl, 2008). Another climate driver of CyanoHABs is the increasing level of dissolved carbon dioxide in waterbodies. Elevated carbon dioxide levels can increase the growth rates of cyanobacteria, and subsequent responses may include reduced competitiveness of toxic strains relative to non-toxic strains as well as shifts in phytoplankton community composition, potentially altering bloom frequency, duration, and cyanotoxin production (Ma and Wang, 2021; Raven et al., 2020; Verspagen et al., 2014; Visser et al., 2016).

In addition to increasing event frequency and duration, CyanoHABs in California pose ongoing impacts to aquatic ecosystems and the species that interact with them. The Interagency HAB-related Illness Workgroup has reported CyanoHAB-related impacts to fish and/or wildlife annually since 2018, along with human and domestic animal illnesses (Freshwater HAB-related Illness Tracking in California - OEHHA). People may be exposed to cyanotoxins through drinking contaminated water or recreating in waterbodies with an active CyanoHAB event. People may also be exposed to fish or shellfish harvested from CyanoHAB-impacted waters. In California, the number of public health advisories at recreational waterbodies has doubled since 2016; however, this trend is largely attributed to expanded monitoring, reporting, and response efforts under the Freshwater Harmful Algal Bloom (FHAB) Program (since 2018), rather than a clear increase in underlying HAB occurrence (SWRCB, 2021).

While climate change likely increases the risk and severity of CyanoHABs in California, more data are needed to better understand the relative contribution of climate change compared with direct anthropogenic drivers, such as nutrient enrichment. Planktonic CyanoHABs are also strongly associated with anthropogenic eutrophication, including external nutrient loading from agricultural land use, animal wastes, sewage, and

industrial and household use of products containing phosphorus and nitrogen (Le Moal et al., 2019). Nutrients from these sources enter waterbodies through runoff, storm drains, wastewater, and other direct discharges. Excess nutrients from external loading and re-mobilization of internal sources can lead to enhanced growth of cyanobacteria, phytoplankton, and aquatic vegetation. Anthropogenic eutrophication is increasing due to land use changes, urbanization, and industrial activities, and its influence on planktonic CyanoHABs is difficult to distinguish from climate change (Wells et al., 2021).

OEHHA acknowledges the expert contributions of the following to this report:

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7.4 Bluetongue in Livestock

A warming climate can impact livestock directly by causing heat stress and indirectly by affecting vector-borne disease occurrence (IPCC, 2022). Bluetongue (BT) is a vector-borne viral disease of sheep, goats and cattle transmitted by biting midges of the arthropod genus *Culicoides.* BT infections cause high morbidity and mortality, primarily in sheep, but can cause illness of varying severity and reduced productivity in cattle, including decreases of milk production. Disease outbreaks can also influence international trade, movement of livestock, animal production and welfare, and can have major economic consequences; for example, in Ontario, Canada the detection of infected cattle in 2015 caused the immediate suspension of exports of live animals, semen, and embryos, valued at nearly 300 million Canadian dollars (Mann, 2015). US livestock industries' losses due to trade restrictions and testing for BT have been estimated between $125 and $144 million annually (USDA, 1999; Hoar, 2003; Tabachnick, 2020). In the United States, BT's greatest economic impact has historically been the cattle industry because it is larger than the domestic sheep industry and more affected by international trade restrictions (Bailey, 2014), although cases of infected sheep in California have also been reported (Gamsjäger and Chigerwe, 2024; Pérez et al., 2023).

Bluetongue occurs globally and is common throughout California with the highest and most consistent activity in the Central Valley, including both the Sacramento Valley and the San Joaquin Valley (Mayo et al., 2016; Moeller, 2016). The virus is maintained in areas where the climatic conditions allow the vector to survive over winter, and generally occurrence of BT parallels vector activity – increasing during periods of warm temperature and rainfall and subsiding in colder weather (WOAH, 2026). Although BT is endemic in the US, climate change may alter the transmission of this and other similar arthropod-borne viruses, increasing risks to both domestic and wild ruminants.

As discussed above, insects are sensitive to changes in temperature, suggesting they are likely to respond to climate change. Warming temperatures can alter the distribution of vectors and accelerate disease transmission (see the *Vector-borne diseases* chapter). BT incidents have expanded northward and persisted in Europe and Canada

and have extended farther south than the traditional range into Victoria, Australia. In the United States, eleven previously non-endemic serotypes of BT virus have been detected since 1999 (serotypes are groups within a single species of microorganisms, such as bacteria or viruses, which share distinctive surface structures) (Mellor et al., 2008; Jimenez-Clavero, 2012; Maclachlan et al., 2018). Some of these non-endemic serotypes are being detected farther away from the southeastern United States where they are usually confined, suggesting increase in distribution and potential for persistence (Schirtzinger et al., 2018). Researchers suggest the *Culicoides* vector is especially responsive to climate change (Purse et al., 2005 and 2008). In general, warm temperatures enhance the recruitment, development, activity and survival rates of *Culicoides* vectors. Scientists expect increases in temperature (particularly at night-time and in winter) as well as increased precipitation in dry areas, to expand the geographical and seasonal incidence of BT virus transmission. Investigators modeling the distribution of *Culicoides* in North America using future climate scenarios predict northward expansion of the vector beyond its current range in the northern United States and southern Canada, with increased risk of Culicoides-borne disease over the next several decades, particularly at the US-Canada border (Zuliani et al., 2015). The northward expansion of BT outbreaks in Europe in recent decades has been examined with climate-driven models that show increasing temperatures may explain aspects of this expansion (Guis et al., 2012) and predict a trend of increasing risk globally using future climate scenarios (Samy and Peterson, 2016). However, BT incidence is influenced by many factors, including vector ecology and transmission cycles, water availability, land use, and agricultural management, which hampers the ability to link climate change with disease outcome.

Research has continued on the ecology of the vector, and what climatic, environmental, and anthropogenic factors may affect disease transmission in California and in North America (Mayo et al., 2016 and 2020). A 3-year study (2018-2021) in a southern California dairy region found that the BT vector did not die off or go dormant during winter months, but that active adult host-seeking midges as well as developing stages were present and captured regularly on warmer days (Zhang and Gerry, 2023). These findings support that persistence of the bluetongue virus in the region through winter

can occur via continuous low-level transmission between *Culicoides sonorensis* and cattle hosts, and that warming temperatures could increase the risk of disease occurrence or spread throughout the year. This information will support direct risk assessment and targeted surveillance for presence of the virus, as well as potential mitigation strategies. Bluetongue occurrence in livestock is currently reportable to and monitored by the California Department of Food and Agriculture's Animal Health Branch.

OEHHA acknowledges the expert contributions of the following to this report:

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7.5 Bumble Bee Populations

Figure 7.5.1. Bumble Bee.



Bumble bees are native to California and play an important role as pollinators for both natural ecosystems as well as agricultural crops. Photo credit: Dennis F. Larsen

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Bumble bees (genus *Bombus*) are major pollinators that assist in the fertilization and the production of seeds by transferring pollen between plants. They significantly contribute to the global agricultural industry and are essential to the environment (Hatfield and Jepsen, 2021). California is home to more than half of the approximately 50 bumble bee species in North America – more than any other state in the country. Two of California's species, Franklin's bumble bee (*B. franklini*) and Crotch's bumble bee (*B. crotchii*), are largely endemic (Hatfield and Jepsen, 2021).

Bumble bee populations are declining worldwide (Cameron and Sadd, 2020), including at least eight species in California (Hatfield and Jepsen, 2021). While the specific causes of bumble bee declines are largely unknown, shifts in temperature and rainfall associated with climate change may be pushing bumble bees beyond their ecological limits (Kerr et al., 2015; Soroye et al., 2020). Other key stressors include pathogen infection (e.g., *Nosema bombi*, *Crithidia bombi*, and viral spillover from managed bee populations used in agriculture) (Cameron et al., 2016), insecticide exposure (Wood and Goulson, 2017; Janousek et al., 2023), and habitat loss (Williams and Osborne, 2009), which may interact, creating synergistic effects and accelerating population declines (Cameron and Sadd, 2020). Climate change may further influence bee disease transmission, parasite dynamics, and predator-prey interactions (Vercelli et al., 2021). In

the western United States, bumble bee occupancy (the likelihood that bumble bees are present in a given area) declined by 57% from 1998 to 2020, with high temperatures, followed by drought and neonicotinoid pesticide exposure identified as the strongest predictors (Janousek et al., 2023). Warmer temperatures are also driving a decline in cold-adapted species and an increase in warm-adapted species among bumble bees in North America, and these shifts have accelerated in recent years (Hemberger and Williams, 2024).

Bumble bees have both contracted their ranges in warmer regions and expanded into cooler regions, although the extent of range loss far exceeds their range expansion. A study that mapped 66 bumble bee species across North American and European sites from 1900 to 2014 found that increases in frequency and severity of hotter temperatures between 1900-1974 and 2000-2014 correlated with increased local extinction rates, reduced colonization (spread to new areas), and declines in species richness (the number of different bumble bee species present together in local regions) (Soroye et al., 2020). The effects were independent of land use and were most pronounced in warmer regions of the Northern Hemisphere. Other analyses indicate that climate change and land use can also act together to influence bumble bee occurrence, with combined pressures reducing the likelihood of bumble bees being present across the same regions in natural habitats (Newbold et al., 2025). In contrast, climate warming increased occurrence probability in human-modified habitats, which may suggest a subset of more resilient species (Newbold et al., 2025). Because these studies evaluate broad patterns across multiple species and regions, they do not provide species-specific or statewide trends for California. Continued monitoring efforts are needed to better understand California bumble bee diversity and abundance statewide and the influence of climate change (Fisher et al., 2022).

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7.6 Aeroallergens

The prevalence of hay fever and asthma, including forms known to be triggered by aeroallergens, is on the rise worldwide (Schmidt, 2016). The risk of respiratory diseases associated with aeroallergens (as well as ozone) is projected to increase in the future (Pörtner et al., 2022). Aeroallergens are airborne substances such as pollen, dust mites, or spores from molds that trigger allergic reactions in sensitized individuals. Most aeroallergens come from trees, weeds, and grasses that rely on wind to distribute their pollen or spores.

A growing number of experimental and field studies provide compelling evidence that warming temperatures and changing patterns of precipitation, along with increasing carbon dioxide (CO_2) levels, are increasing plant growth and pollen production. Climate-related changes include pollen yields, pollen season timing and length, and allergen content of pollen grains (Anderegg et al., 2021; Anenberg et al., 2017; Ray and Ming, 2020; USGCRP, 2018; Zhang and Steiner, 2022; Ziska et al., 2019). Elevated CO_2 concentrations have also been experimentally shown to amplify allergenic mold spore production from leaves of timothy grass, a common livestock feed (Wolf et al., 2010).

Heavy short-term rainfall can significantly reduce atmospheric pollen concentrations by wet deposition while changes in long-term precipitation patterns enhance or inhibit plant growth and alter total pollen production (Zhang and Steiner, 2022). Thunderstorms, which have become more frequent with warming ocean temperatures, have also been linked to increases in aeroallergen levels. Thunderstorms during the pollen season have been reported to trigger severe asthmatic symptoms in people with underlying asthma, hay fever, and allergic rhinitis (D'Amato et al., 2020; Ray and Ming, 2020). Scientists have hypothesized that during rainy storms, pollen grains are broken up into smaller allergenic particles that can induce severe asthma. There is also evidence that thunderstorms increase atmospheric mold and fungal spore concentrations and contribute to asthma-related hospital emergency visits (D'Amato et al., 2020; Domingo et al., 2024).

Pollen seasons are already increasing in length and intensity, and are expected to increase further as the climate warms (Nolte et al., 2018). Over the last several

decades, warmer temperatures have driven pollen season start dates for spring-flowering plants (e.g., deciduous trees) to advance by 3 to 22 days, while late-flowering plants (e.g., grasses) have delayed pollen season start dates by up to 27 days (Zhang and Steiner, 2022). Since 1995, the ragweed pollen season has lengthened by more than 20 days in parts of the northern United States, with the largest increases observed at higher latitudes in the north-central region (Rudolph et al., 2018). Eleven locations across North America, Europe, and Asia showed a significant increase in pollen season duration over a 20-year period, with an average of 0.9 additional days per year (Ziska et al., 2019). Pollen records from 1990-2018 at 60 stations across North America, including Fresno, Los Angeles, Sacramento, San Diego, and San Francisco, show an approximately 20-day advance and 8-day lengthening of the pollen season (Anderegg et al., 2021). Climate model simulations suggest that human-caused climate change was the dominant driver of recent increases in pollen season length and contributed to increases in pollen concentrations, particularly from 2003 to 2018. In addition to influencing pollen production and seasonality, climate change affects respiratory health through other pathways, including more frequent and intense extreme heat events. Adults in the United States who were most exposed to extreme heat from 1997 to 2013 had a higher likelihood of hay fever compared to those with the lowest exposure, especially when exposure occurred during the spring (Upperman et al., 2017).

In addition, dust mites and mold thrive in warmer, more humid conditions which are expanding globally due to climate change; hydrological disasters such as flooding and intense storms also increase indoor humidity which promotes dust mite, mold, and fungal growth (Beggs et al., 2023; Domingo et al., 2024; Seidel et al., 2024). One study of the San Francisco Bay Area found that the annual duration of mold spore exposure increased by an average of 0.51 weeks per year between 2002 and 2019, based on the number of weeks in which mold spores are detected (Paudel et al., 2021). Climate change is also linked to increased concentrations of air pollutants such as ozone, nitric oxide, and other volatile organic chemicals which may also be partially responsible for the increase in allergic respiratory disease reported over the past several decades (Ray and Ming, 2020). Large wildfires, which are becoming more frequent in California, can increase fungal outbreaks and dispersal (Seidel et al., 2024).

Populations that may experience greater health impacts associated with a spread of aeroallergen exposure include children and infants, the elderly, and people with fewer resources to manage these impacts. People with lower incomes and some racial/ethnic groups, including African Americans and residents of historically redlined and under-resourced areas in the US, many of which are predominantly Black and experience higher rates of asthma, asthma exacerbation rates, asthma-related emergency visits, and worse asthma outcomes (Domingo et al., 2024). Despite the relevance of seasonal allergies to public health and climate change, spatiotemporal patterns of seasonal allergies are poorly understood. Most cases are mild and go unrecorded, and as a result, medical records often fail to capture how seasonal allergies change across regions and over time. In addition, aeroallergen measurements are sparse, geographically limited, and often restricted to pollen—particularly in the United States. Internet-based surveillance could be used to track seasonal allergies (Stallard-Olivera and Fierer, 2024), although long-term monitoring in California is needed to assess how allergies are responding to climate change.

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7.7 Farmworker Exposure to Pesticides

Climate change is increasingly influencing pesticide use patterns that may impact pesticide exposure among California's agricultural workforce. For example, rising temperatures and extreme weather events may directly increase pest pressures which can increase pesticide use, enhance volatilization and drift, and alter exposure pathways for workers in agricultural settings. Additionally, increased temperatures and humidity may create more favorable conditions for the spread of pathogens that cause plant diseases, possibly requiring increased use of pesticides, like antimicrobials and/or fungicides. Changing precipitation patterns can also impact the spread and severity of plant diseases and spread spores, which may increase the growth of soil-borne pathogens (possibly requiring increased use of soil fumigants and/or fungicides) (Elad and Pertot, 2014). California agricultural workers are vital to both the state's economy and the nation's food supply, yet they often work under challenging conditions and are disproportionately affected by widening social inequalities, extreme heat, wildfires, and limited safety net resources (Brown et al., 2022; Edgerly et al., 2024). Climate change impacts are adding to these overlapping stressors, compounding and influencing pesticide exposure risk, a longstanding occupational hazard to farmworker health.

Farmworkers may be exposed to pesticides directly via mixing, loading, and applying them to crops; through contact with treated plants, soil, dust, and equipment; and from drift from nearby fields. Farmworkers and their families who live in or near agricultural areas may also face residential exposure through proximity to treated fields, particularly during and after pesticide application (Castillo et al., 2021). Pesticide residues can adhere to farmworkers' clothing, shoes, and vehicles, resulting in potential exposure to these chemicals in the workers' homes. Children in these households face elevated exposure through hand-to-mouth behaviors, and their increased vulnerability due to their developing bodies (Hyland & Laribi, 2017). Chronic exposure to certain pesticides has been linked to cancer, diabetes, and neurological disorders (Shekhar et al., 2024). A study of California farmworkers conducted by University of California, Merced found that among the 85 participants who had applied pesticides in the past year and received pesticide safety training, only 21% reported being able to fully understand the training.

The study specifically recruited a predominantly Indigenous group to fill a gap in existing research on health risks faced by this population (Brown et al., 2022).

Climate change is likely to increase the risk of exposure to certain pesticides. Higher temperatures increase pesticide evaporation and volatilization, elevating the risk of drift and off-target exposure. Greater evaporation can also mean additional applications are needed for the pesticide to be effective (Delcour et al., 2015; Kannan, 2023). Additionally, warmer conditions support more pest generations and expand species' ranges, contributing to more pesticide use across California (Jha et al., 2024; Pathak et al., 2021). Pesticide labels already account for some of these risks; some restrict applications when temperatures exceed 85°F to limit volatilization and protect crops. Recognizing the compounding burden of heat on workers required to wear protective equipment, California recently updated regulations to reduce thermal load on workers required to wear chemical-resistant suits (DPR, 2026). As temperatures continue to rise, conditions that elevate pesticide exposure risk, such as increased volatilization and heat-related barriers to protective equipment, may occur with greater frequency. This highlights the importance of regularly evaluating whether existing worker protections remain effective. Heat exposure is a concurrent and urgent hazard. Farmworkers have a 35-fold higher risk of extreme heat-related death than workers in other sectors (Gubernot et al., 2015). As temperatures rise, farmworkers face a compounding risk: the protective clothing and equipment required to reduce pesticide exposure including long sleeves, long pants, boots, hats, masks, and gloves, can increase heat stress under extreme conditions. Studies have identified heat as a barrier to wearing full protective gear among farmworkers working in high-temperature agricultural settings. California's occupational heat illness prevention standard requires agricultural employers to take protective measures for outdoor workers (Heinzerling et al., 2020). The specific implications of these requirements for workers managing both heat stress and pesticide exposure simultaneously are not yet well understood and warrant further research. Higher temperatures may also increase pesticide volatilization which may also increase inhalation exposure, with potential for greater absorption through the skin (Tudi et al., 2022). Extreme heat can also disrupt harvest timing; if crops are not harvested on

time or are left unharvested because outdoor work is unsafe, pest populations may increase, leading to greater pesticide use.

Despite increasing awareness that pesticides and extreme heat pose dual threats to farmworker health, observational data capturing these exposures remain limited. Similarities between heat stroke and pesticide exposure symptoms may further complicate reporting and treatment, compounded by limited access to medical care and gaps in physician screening for occupational exposures among farmworker populations (US EPA, 2025; Castillo et al., 2021). Improved data collection is urgently needed (e.g., including monitoring of airborne pesticide concentrations during extreme heat events, expanded biomonitoring among farmworkers, and stronger tracking of pesticide-related occupational illness) to support targeted interventions as climate conditions continue to change.

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7.8 Foodborne and Waterborne Infectious Diseases (No Update)

Climate change is expected to adversely impact both food- and water-borne diseases. Factors such as increased air and water temperature as well as fluctuations in relative humidity and precipitation patterns could extend the time period and expand the geographical range of climatic conditions favorable to the survival, proliferation, and transmission of food- and water-borne microbial pathogens. As climate and the environmental landscape changes, too will the residential, occupational, and recreational patterns of California residents, potentially increasing their opportunity to intersect with pathogens that formerly enjoyed comparatively restricted distribution, thus amplifying risk of infection.

Vibrio bacteria

Vibrio species bacteria, which exist naturally in coastal waters and are associated with shellfish, increase in numbers as seawater temperature rises and salinity profiles change (e.g., due to sea level rise). Illness occurs among persons who eat raw shellfish such as oysters and persons with fresh skin wounds exposed to contaminated seawater or shellfish. Although uncommon, *Vibrio vulnificus* is a leading cause of death from seafood contamination in the US. And globally, toxigenic *Vibrio cholerae* remains the cause of cholera outbreaks and epidemics, often waterborne. Rapidly changing global oceanic conditions have pushed *Vibrio* geographical ranges farther north into historically colder regions (Vezzulli et al., 2016), with detection of Vibrio in areas where the bacteria were previously absent or rarely reported (Baker-Austin et al., 2010). The spread of Vibrio will increase the potential exposure of shellfish consumers and recreational ocean water users throughout the coastal regions of the US, including in California.

Legionnaires' disease (LD)

Legionnaires' disease (LD) is a severe form of pneumonia usually caused by inhalation of aerosolized water containing *Legionella* bacteria. *Legionella* are found naturally in freshwater sources and can grow and spread in artificial water systems such as cooling towers, hot water tanks, hot tubs, decorative fountains, and large buildings with complex

water systems. People are exposed to the bacteria when devices aerosolize the contaminated water.

LD is more common during warm summer months, with increased rates of LD during periods of increased relative heat, humidity or greater rainfall (Fisman et al., 2005, Gleason et al., 2016; Hicks et al., 2007; Ricketts et al., 2009; Simmering et al., 2017). This is likely due to both ecological and human factors. *Legionella* proliferate in warm, wet environments with temperatures between 77 and 113°F (CDC, 2020; Yu et al., 2019). Increased numbers of *Legionella* in the environment, including in water supplies (e.g., water reservoirs) could facilitate further downstream amplification within artificial water systems used by humans and subsequent exposure (Walker, 2018). In artificial water systems already contaminated with *Legionella*, these conditions encourage bacterial proliferation. Increased use of cooling devices such as cooling towers during warm weather increase the aerosolization of *Legionella*. Once aerosolized in water, warm and humid environments increase the distance that aerosolized water can travel as well as survival of *Legionella* within that water, increasing the potential infectious range.

Increased frequency and severity of extreme weather events and natural disasters may also lead to intrusion of contaminated water into artificial water systems (e.g., damaging water infrastructure, flooding events contaminating water supply; Brigmon et al., 2020; Walker, 2018). Storm events may themselves enhance conditions for *Legionella* growth in water systems by favorably altering oxygen levels and biological and chemical makeup of the water supply (Brigmon et al., 2020). Droughts may cause further reliance on alternative water collection and storage methods (e.g., rainwater collection), which can increase the risk of *Legionella* growth due to favorable environmental conditions including contamination, stagnation and warm outdoor temperatures (Walker, 2018).

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* Note: The findings and conclusions in this report are those of the author and do not necessarily represent the views or opinions of the California Department of Public Health or the California Health and Human Services Agency.

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7.9 Zoönoses (No Update)

“Zoönoses” is the classic term for an infectious disease that is shared between humans and animals. The roles that animals play in “sharing” zoönoses are varied. Animals can serve as the incubator from which bacteria or viruses emerge that can cause illness in humans. Measles, AIDS, and most recently COVID-19 are examples of diseases that originated in animals—cattle, non-human primates, and bats, respectively—but have evolved to be efficiently transmitted directly between humans (Düx et al., 2020; Furuse et al., 2010; Lytras et al., 2021; Sharp et al., 2011). Animals can also serve as a reservoir for microbial pathogens, maintaining infection but without suffering any ill health themselves. *Borrelia burgdorferi*, the bacterial agent of Lyme disease, and Sin Nombre virus, the cause of hantavirus pulmonary syndrome (HPS), are both maintained in wild mice. Infected mice do not develop disease but can transmit the pathogens to humans indirectly (via ticks for Lyme disease) or directly (through aerosolized urine or feces for HPS). Finally, some zoönotic pathogens cause disease in both human and animal hosts; for example, the bacterial agents of anthrax and plague can cause severe and often fatal disease in wild animals, domestic animals, and humans.

Transmission of disease agents between humans and animals is in part dependent on their respective populations’ distributions, densities, and proximity. For animals, these population dynamics are defined by the type of habitat in which the animal exists. Habitat—food, shelter, and water are largely determined by the prevailing climatic conditions. Significant changes to these conditions can alter the character of a geographic region to render it conducive to the species’ survival.

Animals may adapt to changing environments through the random mechanism of natural selection. However, the dramatic environmental transformations wrought by anthropogenic climate change outpace the ability of most species to evolve. The only other responses available to most animal species are to reduce their population to a size that the altered habitat can continue to support, or to adjust their geographic range to areas that remain hospitable. For California, these climatologic changes will likely favor those species that can endure higher temperatures and more arid conditions, or can relocate to regions that remain relatively cooler and wetter. Both responses could

change the frequency and intimacy with which some animals and humans interact, enhancing opportunities for zoönotic disease transmission (Heffernan, 2018; Hoberg and Brooks, 2015; Lorentzen et al., 2020; Morand and Walther, 2023).

Hotter, drier conditions can impact the size or density of zoönotic animal host and vector populations. Sustained elevated temperatures result in mosquitoes maturing more quickly and lead to larger populations (Mills et al., 2010). Protracted drought may reduce aquatic breeding habitat for some mosquito species but can benefit others by transforming previously free-flowing rivers and creeks into stagnant pools (Bartlow et al., 2019). Changes to local conditions that favor some generalist species but reduce or eliminate species with unique habitual needs can reduce local biodiversity, potentially to the benefit of zoönotic disease reservoirs. For example, reduced diversity of bat species can facilitate perpetuation of rabies virus, leading to greater incidence among viable host species and increased risk of transmission to non-hosts such as humans (Patil et al., 2017).

Species that are unable to adapt to hotter or drier conditions may adjust their ranges toward higher elevations or polar latitudes. These movements could alternatively introduce zoönotic diseases into previously unaffected human populations or dissociate disease agents from human contact. For example, the bacteria that cause plague (*Yersinia pestis*) and tick-borne relapsing fever (*Borrelia hermsii*) in California are maintained in wild rodents and transmitted via flea and tick bite, respectively; with incrementally hotter average temperatures, their current foci in mid- and upper elevations of the Sierra Nevada may shift to higher and constricted elevations, possibly farther displaced from areas where humans reside or visit. Approximately half of the 28 species surveyed in Yosemite National Park—including squirrel (*Spermophilus* spp.) and chipmunk (*Tamias* sp.), reservoir species for Y. pestis—had upslope shifts of range limits compared with similar surveys conducted approximately 100 years earlier, when minimum temperatures were 3°C lower (Moritz et al., 2008). This shift from temperate to alpine regions parallels a similar shift of hosts and vectors of zoönoses previously concentrated in tropical and subtropical latitudes to temperate regions. In the last decade, vampire bats (*Desmodus rotundus*) and mosquitoes (*Aedes aegypti*, *Ae. albopictus*) have encroached northward from Latin America, threatening local

transmission of rabies and arboviruses (e.g., Zika, Chikungunya, dengue), respectively, in North America (Hayes and Piaggio, 2018; Iwamura et al., 2020; Ryan et al., 2019).

Loss of natural food, water, or harborage may stimulate some animal species to seek these essentials from areas of human development and residence. Deforestation, including via climate-enhanced mega-wildfires, has been cited as possibly contributing to displacement of bats from natural roosting sites in favor of concentration around human habitations, leading to the emergence of bat-borne zoönotic viruses such as Nipah and Hendra (Halpin et al., 2000) and the SARS-type coronaviruses (Afelt et al., 2018). Water stored near human communities may attract wild mammals such as skunks, raccoons, and coyotes, increasing the peri-residential risk of zoönoses such as rabies and Toxocara and Baylisascaris larval migrans. Standing water in eaves, yards, and patios can provide habitat for mosquito breeding, increasing peri-residential risk of West Nile virus and other mosquito-borne arboviruses.

As hospitable habitat contracts, individual animals are drawn into more confined areas, resulting in more frequent competition and contact which enables transmission of zoönotic pathogens. In 2021, 29 cases of salmonellosis among human residents of eight states, including California, were traced to unusual concentrations of songbirds densely congregating at backyard feeders and bird baths (CDC, 2021), possibly as a result of reduced natural food and water sources. Avian influenza viruses have traditionally resided in and emerged from wild birds, particularly migratory waterfowl. As drought and development displace natural wetlands along avian flyways, this traditional breeding ground for avian influenza might diminish. If wild waterfowl seek alternative water and food resources near poultry operations, this proximity can enhance transmission of influenza viruses to domestic poultry and one step nearer to humans (Gilbert et al., 2008).

The impact of climate change on zoönotic disease epidemiology in California and the western U.S. has yet to be fully understood. Effective preparation will require an integrated collaboration of human health and animal health professionals and environmental scientists to identify and respond to climate-induced changes in zoönotic disease incidence and distribution in a timely, comprehensive, and effective manner.

OEHHA acknowledges the expert contributions of the following to this report:

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* Note: The findings and conclusions in this report are those of the authors and do not necessarily represent the views or opinions of the California Department of Public Health or the California Health and Human Services Agency

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