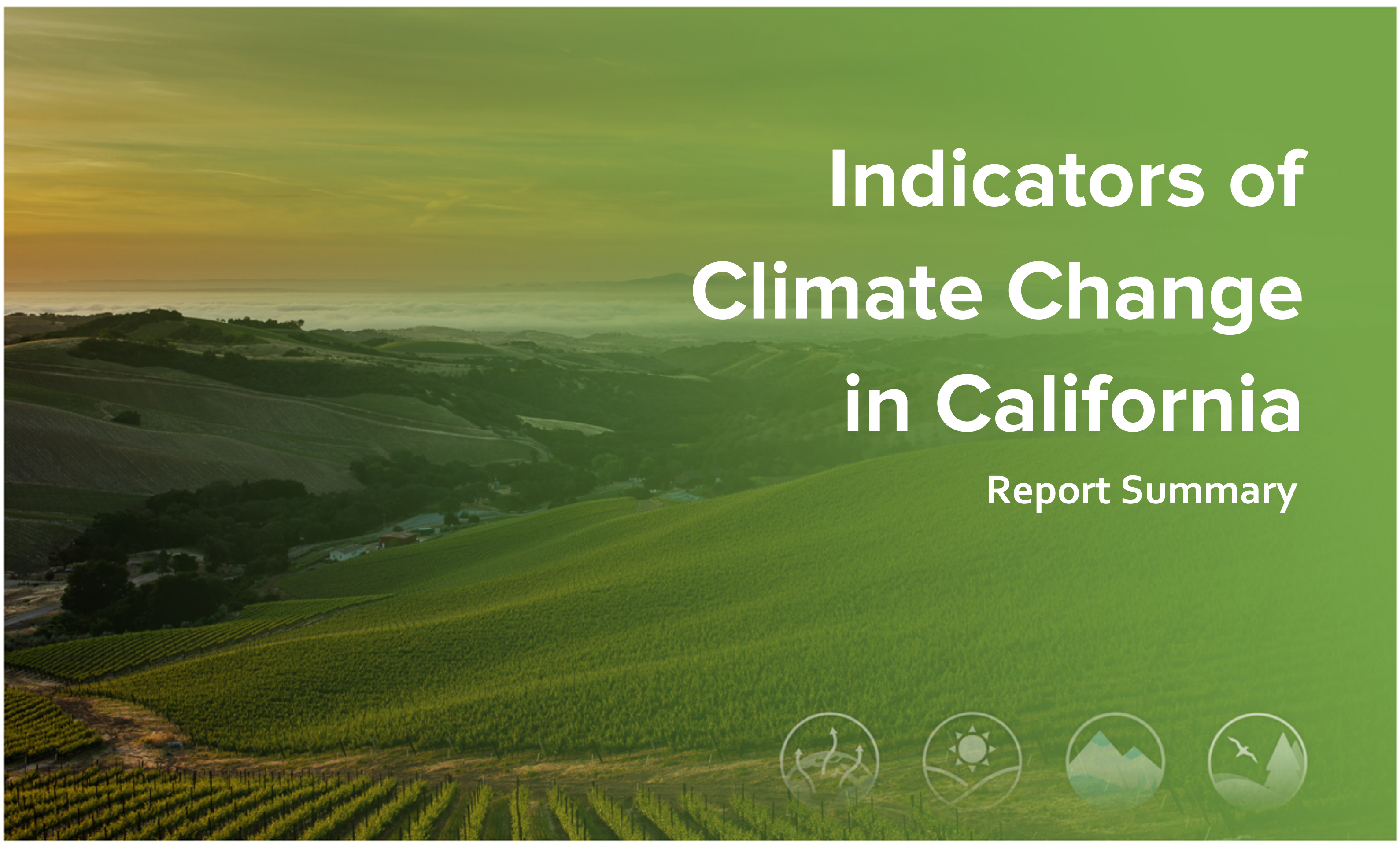
MAY 2018



Indicators of Climate Change in California

Report Summary

Lauren Zeise, Ph.D.
Director, Office of Environmental Health Hazard Assessment

Edmund G. Brown Jr.
Governor

Matthew Rodriquez
Secretary for Environmental Protection

INDICATORS OF CLIMATE CHANGE IN CALIFORNIA

CLIMATE CHANGE DRIVERS

- Greenhouse gas emissions
- Atmospheric greenhouse gas concentrations
- Atmospheric black carbon concentrations
- Acidification of coastal waters

CHANGES IN CLIMATE

- Annual air temperature
- Extreme heat events
- Winter chill
- Cooling and heating degree days
- Precipitation
- Drought

IMPACTS OF CLIMATE CHANGE ON PHYSICAL SYSTEMS

- Snowmelt runoff
- Snow-water content
- Glacier change
- Lake water temperature
- Coastal ocean temperature
- Sea level rise
- Dissolved oxygen in coastal waters

IMPACTS OF CLIMATE CHANGE ON BIOLOGICAL SYSTEMS

On humans

- Vector-borne diseases
- Heat-related mortality and morbidity

On vegetation

- Forest tree mortality
- Wildfires
- Ponderosa pine forest retreat
- Vegetation distribution shifts
- Changes in forests and woodlands
- Subalpine forest density
- Fruit and nut maturation time

On wildlife

- Spring flight of Central Valley butterflies
- Migratory bird arrivals
- Bird wintering ranges
- Small mammal and avian range shifts
- Effects of ocean acidification on marine organisms *(Type III*)*
- Nudibranch range shifts
- Copepod populations
- Sacramento fall-run Chinook salmon abundance
- Cassin's auklet breeding success
- California sea lion pup demography

___

* A "Type III" indicator is conceptual; no ongoing monitoring or data collection is in place in California.

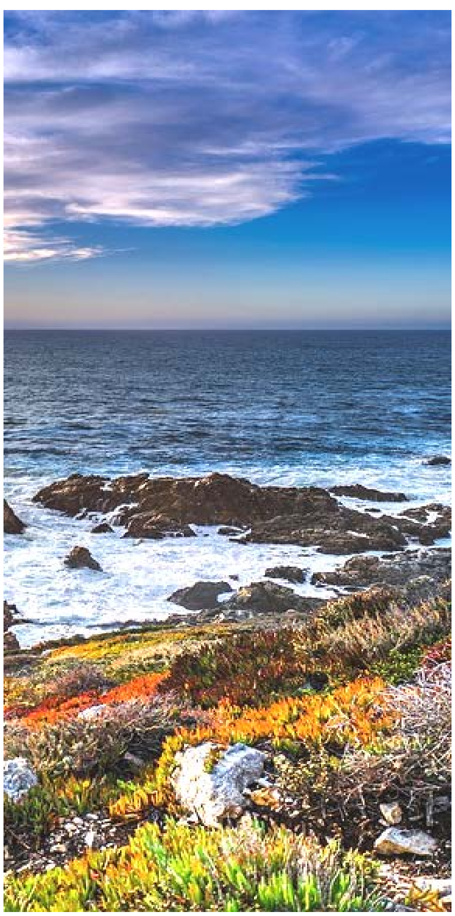
INTRODUCTION

From record temperatures to proliferating wildfires and rising seas, climate change poses an immediate and escalating threat to California's environment, public health, and economic vitality. Recent climate-related events – such as the devastating 2017 wildfires and the record-setting 2012-16 drought – have highlighted the challenges that confront the state as its climate continues to evolve.

California has been a pioneer in addressing climate change. This report helps support policy decisions and facilitates communication about climate change by providing, in a single document, indicators characterizing its multiple aspects in California.

TRACKING CLIMATE CHANGE AND ITS IMPACTS

Indicators are scientifically-based measurements that track trends in various aspects of climate change. Many indicators reveal discernable evidence that climate change is occurring in California and is having significant, measurable impacts in the state.

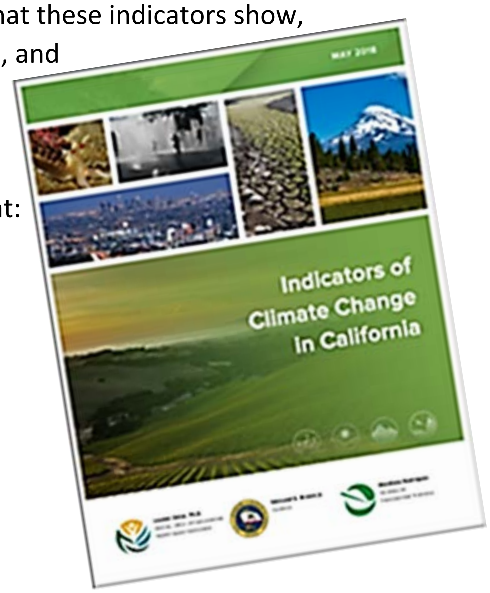


The report's 36 indicators are grouped into four categories:

- Human-influenced (anthropogenic) drivers of climate change, such as greenhouse gas emissions
- Changes in the state's climate
- Impacts of climate change on physical systems, such as oceans, lakes and snowpack
- Impacts of climate change on biological systems – humans, vegetation and wildlife

The report discusses what these indicators show, why they are important, and the factors that may be influencing them.

The report is available at: www.oehha.ca.gov.



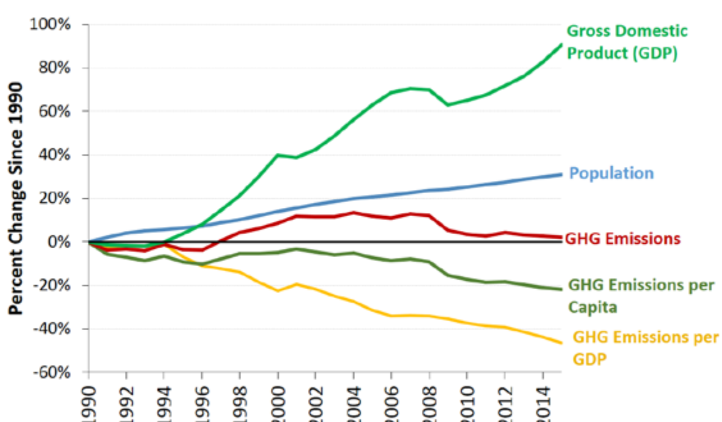
Climate Change Drivers

The Earth's climate is warming, mostly due to human activities such as changes in land cover and emissions of certain pollutants. Greenhouse gases are the major human-influenced drivers of climate change. These gases warm the Earth's surface by trapping heat in the atmosphere.

International climate agreements aim to stabilize atmospheric greenhouse gas concentrations at a level that would prevent "dangerous anthropogenic interference with the climate system." The 2015 Paris Agreement calls for keeping the rise in the global average temperature to well below 2 degrees Celsius (°C) above pre-industrial levels. The Agreement also commits to pursue efforts to further limit the increase to 1.5°C. These efforts would significantly reduce the risks and impacts of climate change.

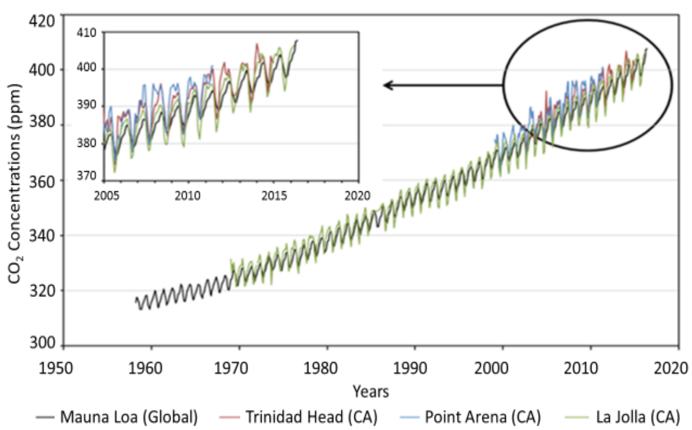
California's **greenhouse gas emissions** show promising downward trends, with emissions per capita and per dollar of gross domestic product declining since 1990. These trends are the result of California's pioneering efforts to curb greenhouse gas emissions, and are occurring despite an increase in the state's population and economic output. Greenhouse gases are emitted from fossil fuel combustion for transportation and energy, landfills, wastewater treatment facilities, and livestock. The major greenhouse gases are carbon dioxide (CO_2), methane, nitrous oxide, and fluorinated gases. CO_2 accounts for 85 percent of greenhouse gas emissions in the state, and transportation is its largest source, accounting for over a third of the total emissions in 2015.

Trends in California's population, economy, and greenhouse gas (GHG) emissions since 1990



Concentrations of black carbon in California's air have dropped by more than 90 percent over the past 50 years despite a seven-fold increase in statewide diesel fuel consumption — its largest anthropogenic source. This is largely due to tailpipe emission standards, diesel fuel regulations and biomass burning restrictions. Black carbon is a "short-lived climate pollutant." Unlike CO_2, it does not persist for long in the atmosphere. It is also a powerful global warming agent. Black carbon is the second most important contributor to global warming after CO_2.

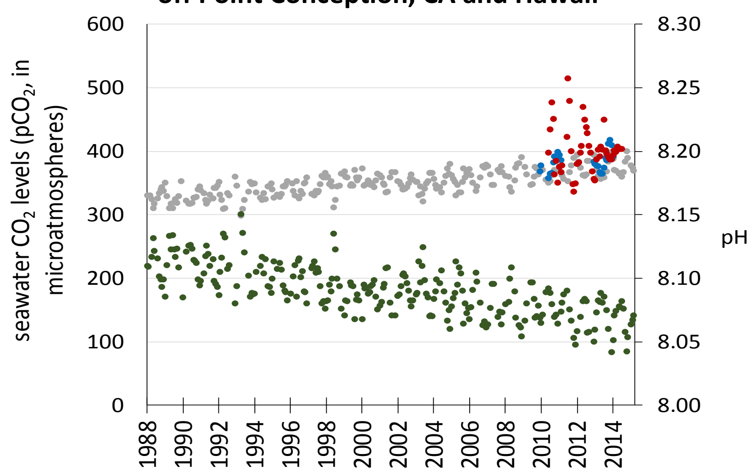
Monthly average atmospheric CO_2 concentrations

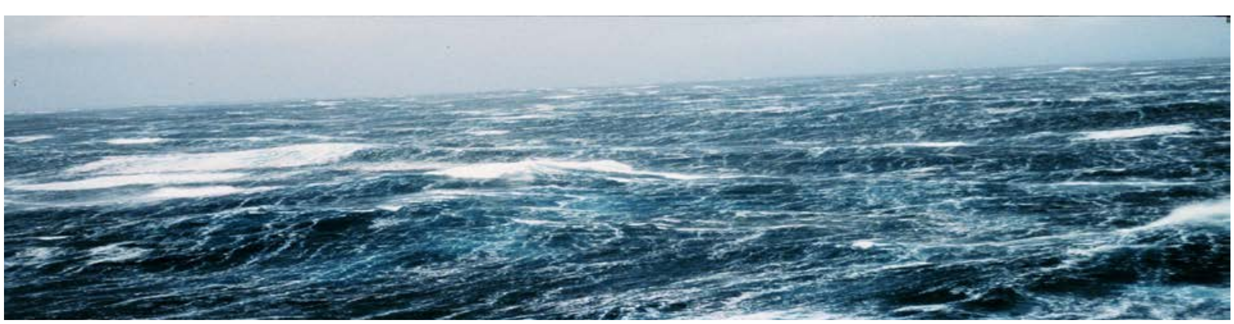


Atmospheric concentrations of CO_2 continue to increase. Measurements at California coastal sites are consistent with those at Mauna Loa, Hawaii, where the first and longest continuous measurements of global atmospheric CO_2 concentrations have been taken. In less than six decades, concentrations of CO_2 have increased from 315 parts per million (ppm) to over 400 ppm in 2015. Since CO_2 persists in the atmosphere for centuries, its levels are expected to remain above 400 ppm for many generations.

As atmospheric concentrations of CO_2 increase, so do levels in the ocean, leading to **ocean acidification**. The ocean absorbs approximately 30 percent of the CO_2 released into the atmosphere each year. Monitoring off Hawaii from 1988 to 2015 shows CO_2 levels in seawater are increasing at a steady rate. The longest-running publicly available data in California from Point Conception, near Santa Barbara, began in 2010. While not measured long enough to discern a trend for California waters, values are similar to those measured at Hawaii at similar times.

Seawater carbon dioxide and pH off Point Conception, CA and Hawaii

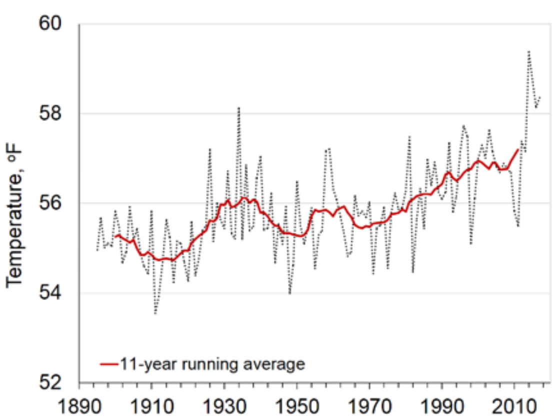




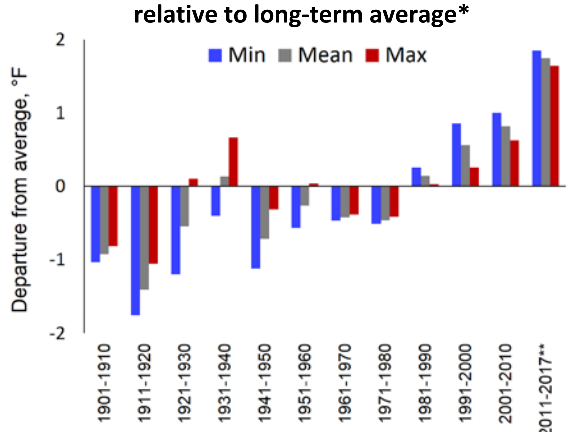
Climate is generally defined as “average weather,” usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time. The evidence that the climate system is warming is unequivocal. In California, consistent with global observations, each of the last three decades has been successively warmer than any preceding decade.

Since 1895, **annual average air temperatures** have increased throughout the state, with temperatures rising at a faster rate beginning in the 1980s. The last four years were notably warm, with 2014 being the warmest on record, followed by 2015, 2017, and 2016. Temperatures at night have increased more than during the day: minimum temperatures (which generally occur at night) increased at a rate of 2.3 degrees Fahrenheit (°F) per century, compared to 1.3°F per century for maximum temperatures.

Statewide annual average temperature



Statewide temperatures by decade relative to long-term average*

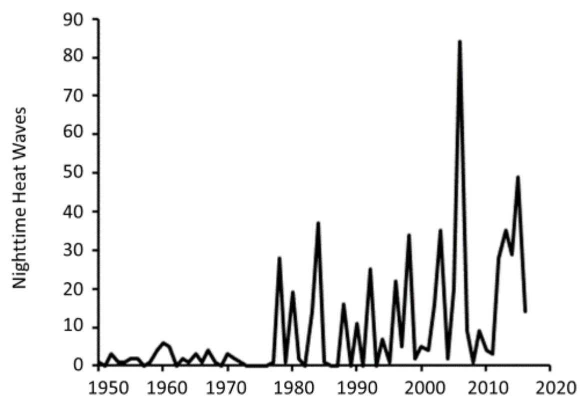


* 1949-2005 base period
** Partial decade

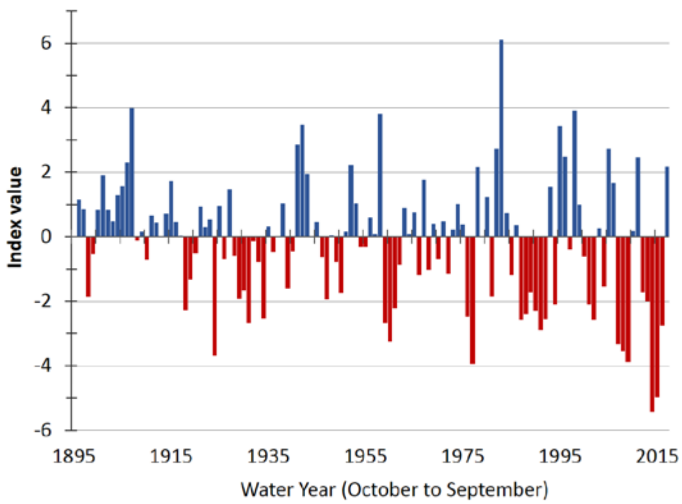
Temperature is a basic physical factor that affects many natural processes and human activities. Warmer air temperatures alter precipitation and runoff patterns, affecting the availability of freshwater supplies. Temperature changes can also increase the risk of severe weather events such as heat waves and intense storms. A wide range of impacts on ecosystems and on human health and well-being are associated with increased temperatures.

Extremely hot days and nights — that is, when temperatures are at or above the highest 2 percent of maximum and minimum daily temperatures, respectively — have become more frequent since 1950. Both extreme heat days and nights have increased at a faster rate in the past 30 years. Heat waves, defined as five or more consecutive extreme heat days or nights, are also increasing, especially at night. Nighttime heat waves, which were infrequent until the mid-1970s, have increased markedly over the past 40 years.

Nighttime heat waves (April to October)



Palmer Drought Severity Index



A universally used indicator of **drought** — the Palmer Drought Severity Index — shows that California has become drier over time. Five of the eight years of severe to extreme drought (when index values fell below -3) occurred between 2007 and 2016, with unprecedented dry years in 2014 and 2015. The record warmth from 2012 to 2016 coincided with consecutive dry years, including a year of record low snowpack, leading to the most extreme drought since instrumental records began in 1895.

Other indicators of changes in climate show that:

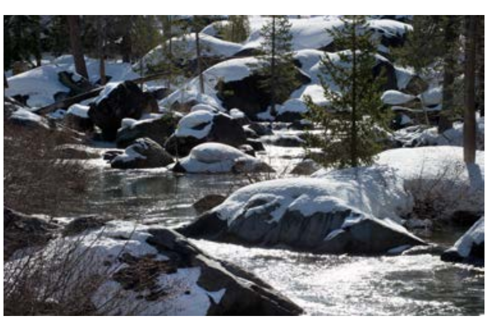
- **Winter chill** has been declining in certain areas of the Central Valley. This is the period of cold temperatures above freezing but below a threshold temperature needed by fruit and nut trees to become and remain dormant, bloom, and subsequently bear fruit. When tracked using "chill hours," a metric used since the 1940s, more than half the sites studied showed declining trends; with the more recently developed "chill portions" metric, fewer sites showed declines.
- With warmer temperatures, the energy needed to cool buildings during warm weather — measured by "**cooling degree days**" — has increased, while the energy needed to heat buildings during cold weather — measured by "**heating degree days**" — has decreased.
- Statewide **precipitation** has become increasingly variable from year to year. In seven of the last ten years, statewide precipitation has been below the statewide average (22.9 inches). In fact, California's driest consecutive four-year period occurred from 2012 to 2015. In recent years, the fraction of precipitation that falls as rain (rather than snow) over the watersheds that provide most of California's water supply has been increasing — another indication of warming temperatures.

Impacts on Physical Systems

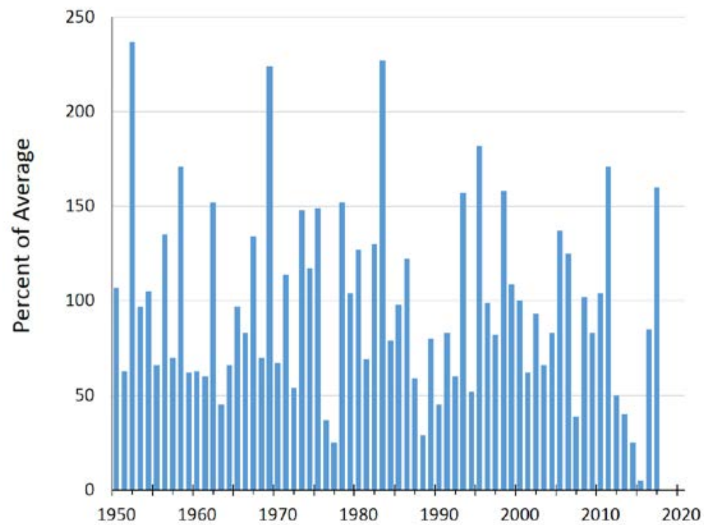
Warming temperatures and changing precipitation patterns have altered California's "physical systems" — the ocean, lakes, rivers and snowpack – upon which the state depends. Winter snowpack and spring snowmelt runoff from the Sierra Nevada and southern Cascade Mountains provide approximately one-third of the state's annual water supply.

The amount of water stored in the state's snowpack — referred to as **snow-water content** — is highly variable from year to year, ranging from a high in 1952 of about 240 percent of the long-term average to a record low of 5 percent in 2015. Less snowpack accumulates when winter temperatures are warmer because more precipitation falls as rain instead of snow.

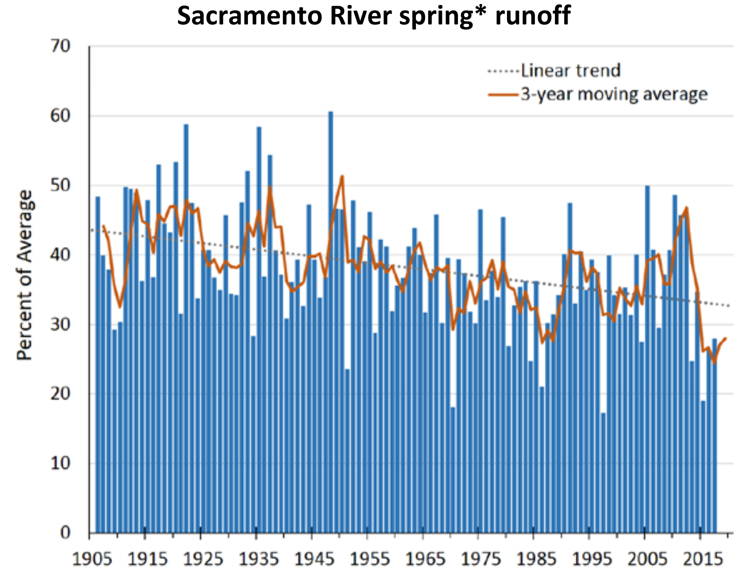
The fraction of **snowmelt runoff** reaching the Sacramento River between April and July has decreased by about 9 percent since 1906. This reduction is influenced by earlier spring warming and more winter precipitation falling as rain. With less spring runoff, less water is available during summer months to meet the state's domestic and agricultural water demands. These reductions also affect the generation of hydroelectricity, impair cold-water habitat for certain fishes and stress forest vegetation. The latter has consequences for wildfire risk and long-term forest health.



Snow-water content, as a percentage of average



Sacramento River spring* runoff



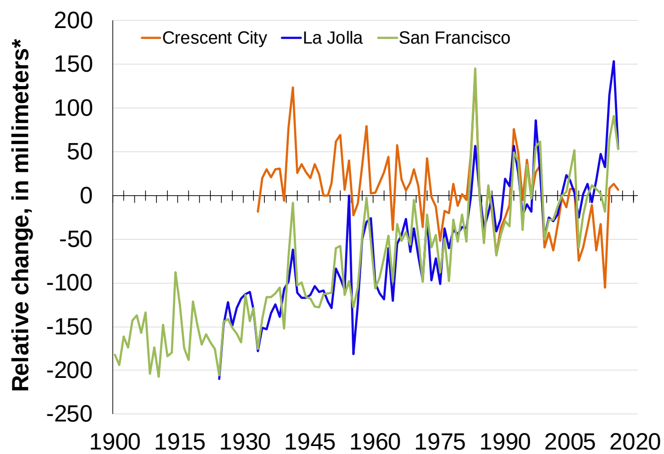
*April to July as a percent of total year runoff

From the beginning of the 20th century to 2014, some of the largest glaciers in the Sierra Nevada have lost an average of about 70 percent of their area. Reductions ranged from about 50 to 85 percent of each glacier's area in 1903. Glaciers are important indicators of climate change: winter snowfall nourishes the glaciers, and spring/summer temperatures melt ice and snow. Winter air temperature determines whether precipitation falls as rain or snow, affecting glacier mass gain; summer air temperature affects glacier loss. Glacier shrinkage worldwide is an important contributor to global sea level rise.

Historical and contemporary photographs of the Dana Glacier

Along the California coast, sea levels have generally risen. Since 1900, mean sea level has increased by about 180 millimeters (7 inches) at San Francisco and by about 150 millimeters (6 inches) since 1924 at La Jolla. In contrast, sea level at Crescent City has declined by about 70 millimeters (3 inches) since 1933 due to an uplift of the land surface from the movement of the Earth's plates. Sea level rise threatens existing or planned infrastructure, development, and ecosystems along California's coast.

Annual mean sea level trends



** Relative to tidal datum (reference point set by the NOAA)*

Other indicators of the impacts of climate change on physical systems show that:

- Average lake water temperatures at Lake Tahoe have increased by nearly 1°F since 1970, at an average rate of 0.02°F per year. During the last four years, warming accelerated about 10 times faster than the long-term rate. The lake surface warmed faster — almost 0.04°F per year. The warming of Lake Tahoe's waters can disrupt the lake's ecosystem by affecting key physical and biological processes.
- Coastal ocean temperatures at three sites in California have warmed over the past century. Over 90 percent of the Earth's observed warming over the past 50 years has occurred in the ocean. Warming sea surface temperatures can alter the distribution and abundance of many marine organisms, including commercially important species. Ocean warming accounts for about half of the sea level rise that has occurred globally over the past century.
- Oxygen concentrations at three water depths offshore of San Diego indicate overall decreases as well as low-oxygen events. Declining oxygen concentrations can lead to significant ecological changes in marine ecosystems, including wide-ranging impacts on species diversity, abundance, and marine food webs. Changing ocean chemistry, in concert with changes in temperature, may lead to even greater and more widespread impacts on coastal marine ecosystems.

Impacts on Biological Systems

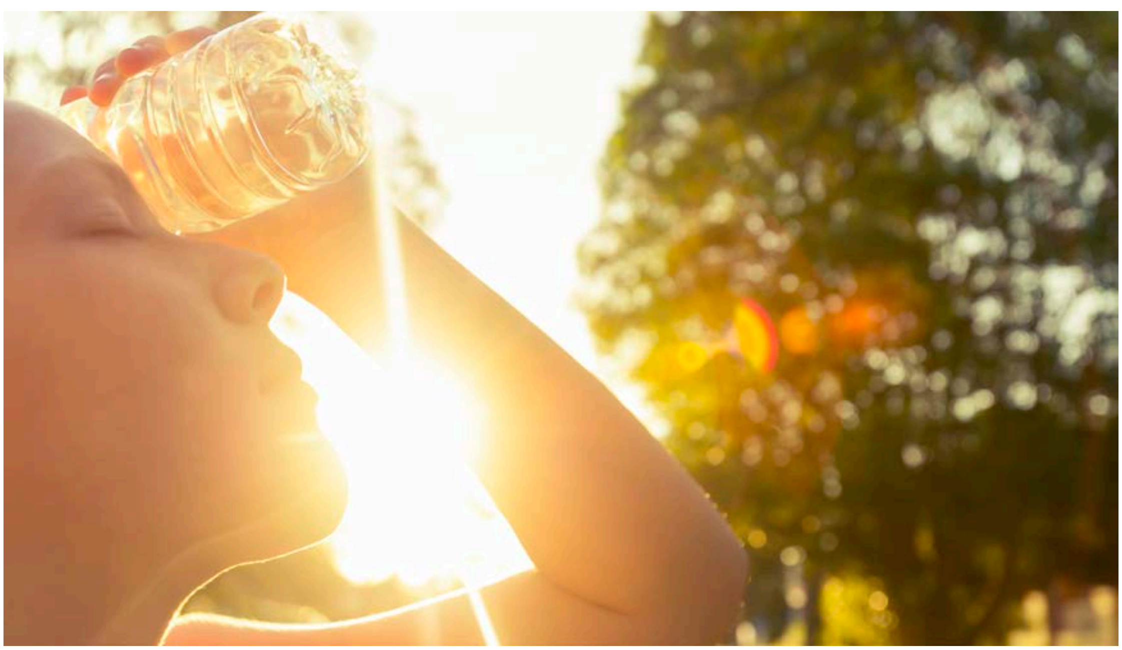
Climate change impacts on terrestrial, marine and freshwater ecosystems have been observed in California. As with global observations, species responses include those consistent with warming: elevational or latitudinal shifts in range; changes in the timing of key plant and animal life cycle events (known as “phenology”); and changes in the abundance of species and in community composition. With continued climate change, many species may be unable to adapt or to migrate to suitable climates, particularly given the influence of other factors such as land use, habitat alteration, and emissions of pollutants.

HUMANS

Humans are better able to adapt to a changing climate than plants and animals in natural ecosystems. Nevertheless, climate change poses a threat to public health. While it is difficult to track its influence using indicators, climate change can impact human well-being in many ways. Examples include injuries and fatalities from extreme events and respiratory stress from poor air quality. Indicators of the impacts of climate change on human health show that:

- Warming temperatures and changes in precipitation can affect **vector-borne** pathogen transmission and disease patterns in California. West Nile Virus currently poses the greatest mosquito-borne disease threat.

- **Heat-related deaths and illnesses,** which are severely underreported, vary from year to year. In 2006, they were much higher than any other year because of a prolonged heat wave.

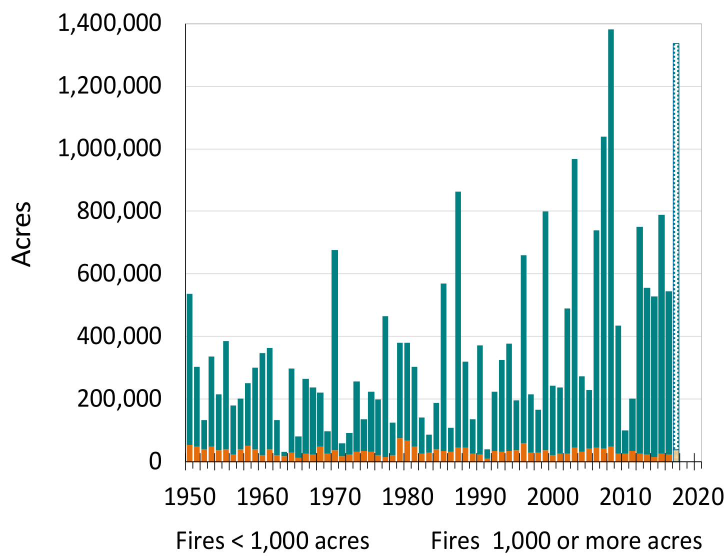


VEGETATION

Warming temperatures, declining snowpack, and earlier spring snowmelt runoff can create stresses on vegetation. A measure of plant stress, climatic water deficit, reflects the demand plants have for water relative to the availability of water in the soil. Increases in climatic water deficit are associated with a warming climate.

Since 1950, the area burned by **wildfires** each year has been increasing, as spring and summer temperatures have warmed and spring snowmelt has occurred earlier. During the recent "hotter" drought, unusually warm temperatures intensified the effects of very low precipitation and snowpack and created conditions for extreme, high severity wildfires that spread rapidly. Five of the largest fire years have occurred since 2006. The largest recorded wildfire in the state (Thomas Fire) occurred in December 2017.

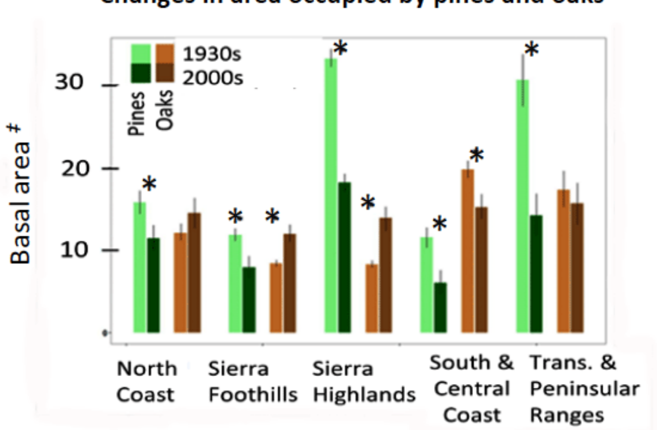
Annual area burned by wildfires



Note: 2017 data preliminary, subject to change

Evidence of how the state's **forests and woodlands** are responding to climate change has been found in studies that compared historical and current conditions. Historical data are from a 1930s survey of California's vegetation.

Changes in area occupied by pines and oaks

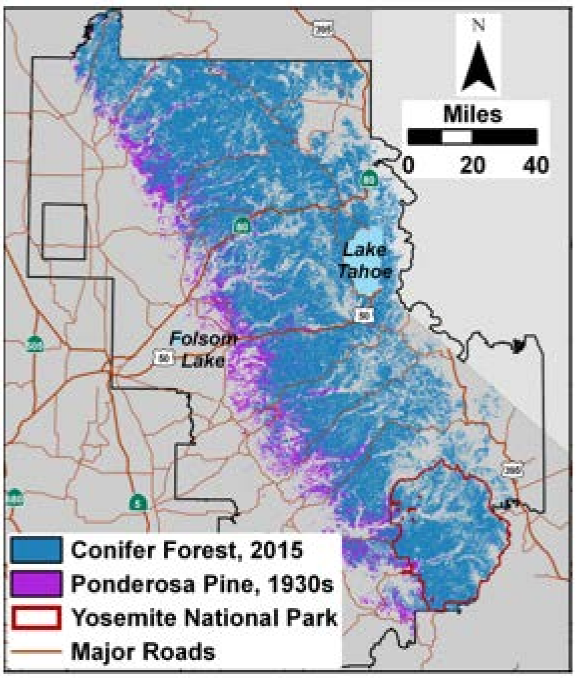


The structure and composition of the state's forests and woodlands are changing. Compared to the 1930s, today's forests have more small trees and fewer large trees. Pines occupy less area statewide and, in certain parts of the state, oaks cover larger areas. The decline in large trees and increased abundance of oaks are associated with statewide increases in climatic water deficit.

‡ Basal area refers to the area occupied by tree trunks
*Statistically significant differences

On the western side of the northern Sierra Nevada Mountains, the lower edge of the Ponderosa pine forest has moved upslope. Since the 1930s, the forest has retreated from elevations that no longer experience freezing winter temperatures at night. The loss of conifers in this elevation was accompanied by an expansion of forests dominated by broadleaf trees.

Ponderosa Pine forest retreat in the Sierra Nevada Mountains since 1934



Other indicators of the impacts of climate change on vegetation show that:

- **Tree deaths** have increased dramatically since the 2012-2016 drought. Approximately 129 million trees died between 2012 and December 2017. Higher temperatures and decreased water availability made the trees more vulnerable to insects and pathogen attacks.

- **Vegetation distribution** has shifted across the north slope of Deep Canyon in the Santa Rosa Mountains in Southern California. Dominant plant species have moved upward by an average of about 65 meters (213 feet) in the past 30 years.

- Compared to the 1930s, today's **subalpine forests** (forests at elevations above 7,500 feet) in the Sierra Nevada are denser, as small tree densities increased by 62 percent while large tree densities decreased by 21 percent.

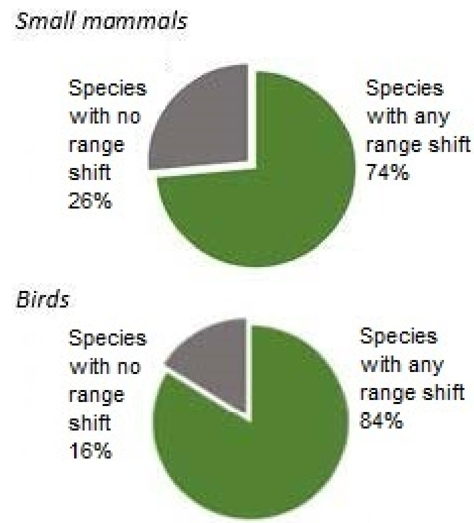
- In parts of the Central Valley, certain **fruits and nuts** (prunes and one walnut variety) are maturing more quickly with warming temperatures, leading to earlier harvests. Shorter maturation times generally lead to smaller fruits and nuts, potentially causing a significant loss of revenue for growers and suppliers.

WILDLIFE

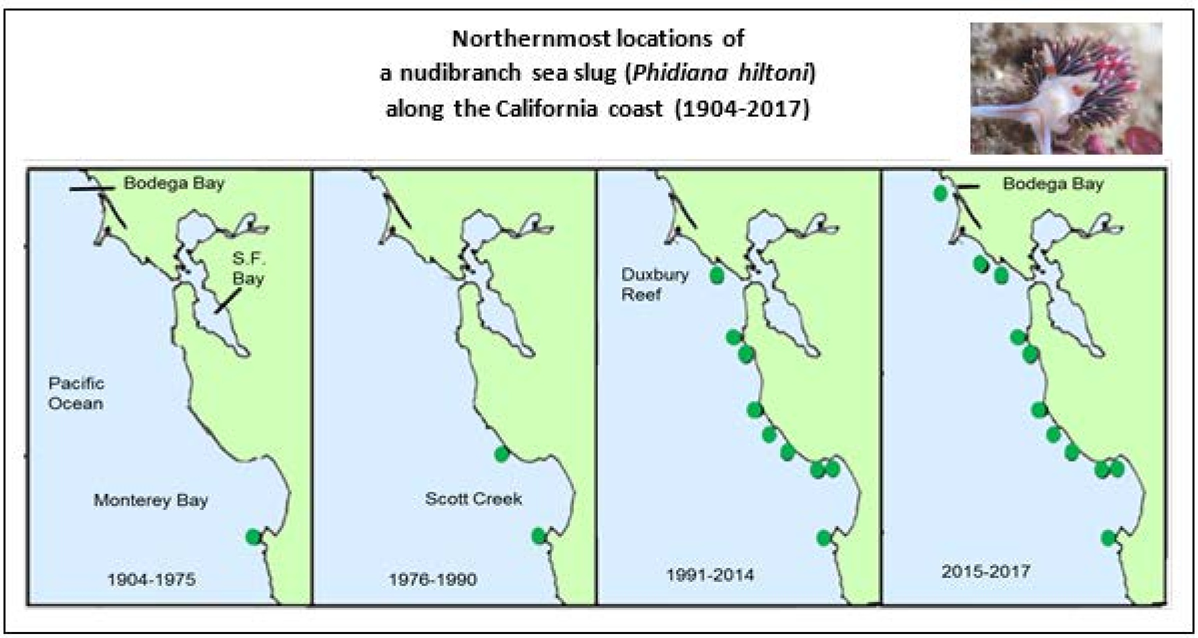
Changes in temperature, precipitation, food sources, competition for prey, and other physical or biological features of the habitat may force changes in the timing of key life cycle events for plants and animals and shift the ranges where these plants and animals live. These factors, along with the inherent sensitivity of the species, interact in ways that can affect species responses differently.

Certain birds and mammals are found at different elevations in three study regions of the Sierra Nevada Mountains today compared to a century ago. **Range shifts** have been observed in almost 75 percent of the small mammal species and over 80 percent of the bird species surveyed. High-elevation mammals tended to move upslope; birds and low-elevation mammals moved downslope as frequently as upslope. Across the three study regions, species did not show uniform shifts in elevation. The varied responses reflect the influence of intrinsic sensitivity to temperature, precipitation or other physical factors. They may also be due to changes in food sources, vegetation and interactions with competitors.

Sierra Nevada range shifts over the past century



Marine species respond to changing ocean conditions, especially during periods of unusually warm sea surface temperatures. A **nudibranch** sea slug, *Phidiana hiltoni*, has expanded its range northward by 210 kilometers (130 miles) — from the Monterey Peninsula to Bodega Bay — since the mid-1970s in response to warming ocean conditions. This nudibranch was found for the first time in Bodega Bay in 2015. Unlike other nudibranch species, *P. hiltoni* has persisted at this northernmost location after warm water conditions ended.



Other indicators of the impacts of climate change on wildlife show that:

- Over the past 45 years, **Central Valley butterfly** species have been appearing earlier in the spring. Their earlier emergence is linked with hotter and drier regional winter conditions.
- Since 1980, the timing of spring and fall **migratory bird arrivals** at a coastal site in northern California have shown a diversity of changes.
- Across the state, **wintering bird species** have collectively shifted their range northward and closer to the coast over the past 48 years. In both cases, species' responses have not been uniform: some species have shifted to higher elevations or latitudes, and the shifts have occurred to varying degrees.
- The **effects of ocean acidification on marine organisms** involve a wide range of biological processes. The most widely observed effect is interference with shell-formation in mollusks. (Since there are no trend data tracking these effects, this is a "Type III" indicator.)
- Ocean conditions strongly influence marine organisms in the California Current, as seen with **copepod populations.** At the base of the food chain, the abundance and types of copepod species have been correlated with the abundance of many fish species.
- The number of adult **Chinook salmon** returning from the ocean to the Sacramento River has become more variable over the last two decades. This number is impacted by extreme mortality events among juvenile salmon. As residents of both marine and freshwater environments, salmon are at risk from the impacts of climate change on these habitats.
- Over a 45-year period, the **breeding success of Cassin's auklets** on Southeast Farallon Island near San Francisco has become increasingly variable. It is associated with the abundance of prey species that are influenced by ocean conditions such as warming.
- During years when sea surface temperatures are unusually warm in their breeding area, there have been fewer **California sea lion pup** births, higher pup mortality, and poor pup conditions at San Miguel Island off Santa Barbara. Sea lions are vulnerable to fluctuations in the abundance and distribution of their primary prey, which are directly influenced by ocean conditions.

EMERGING CLIMATE CHANGE ISSUES

Changes and impacts in California's environment that are plausibly influenced by climate change, though not yet established, are referred to in the report as emerging climate change issues. Scientifically defensible hypotheses, models, and/or limited data support the assertion that certain observed or anticipated changes are in part due to climate change.

Among the emerging issues described in this report are:

- Increased frequency, severity, and duration of harmful algal blooms in marine and freshwater environments, which are known to be influenced by water temperature and drought conditions.
- Reduced duration and extent of winter fog in the Central Valley and coastal fog, with warming winter temperatures and other climate changes.
- Increased survival and spread of forest disease-causing pathogens and insects, along with increased susceptibility of trees, which are affected by temperature, precipitation, and forest fires.
- More favorable conditions that allow invasive agricultural pest species like the Oriental fruit fly to thrive in places where they previously could not survive.

ACKNOWLEDGEMENTS

The Office of Environmental Health Hazard Assessment is grateful to the CalEPA Office of the Secretary and to the technical staff and researchers who contributed their ideas, data, findings and other information for inclusion in *Indicators of Climate Change in California*. (A full list of these contributors can be found in the full report.)

Photo credits: **Cover:** Nudibranch sea slug—Jeffrey Goddard/UC Santa Barbara; vineyard and Los Angeles cityscape—California Department of Water Resources. **Page 2:** Los Angeles freeway traffic. **Page 3**: Ocean waters—NOAA. **Page 6:** Snow runoff in a Sierra Nevada mountain stream, Placer County, Northern California—Dale Kolke/California Department of Water Resources. **Page 10**: Ponderosa pine tree—Monty Rickard. **Page 11:** Nudibranch sea slug (*Phidiana hiltoni*)—Jeffrey Goddard/UC Santa Barbara. **Page 12:** Flock of Snow Geese take flight above a field on Twitchell Island in the California Delta—Kelly M. Grow/California Department of Water Resources.

Cover and graphic elements: Brandon Lee Design
Editorial consultant: Krystyna von Henneberg, Ph.D., Creative Language Works

References

Sources of the data used in the graphs presented in this document are as follows. For a full listing of references, please see the technical report.

Climate Change Drivers

Trends in California's population, economy and GHG emissions since 1990

CARB (2007). California Air Resources Board: 1990-2004 Inventory. Retrieved October 2017, from https://www.arb.ca.gov/cc/inventory/1990level/1990data.htm

CARB (2017). California Air Resources Board: Greenhouse Gas Inventory 2017 Edition, Years 2000-2015. Retrieved October 2017, from https://www.arb.ca.gov/cc/inventory/pubs/pubs.htm

Census (1992). US Department of Commerce, Bureau of the Census. *1990 Census of Population and Housing, Population and Housing Unit Counts, United States* (1990 CPH-2-1). Washington DC: US Government Printing Office. Available at https://www.census.gov/prod/cen1990/cph2/cph-2-1-1.pdf

DOF (2016). California Department of Finance. *E-6 Population Estimates and Components of Change by County July 1, 2010-2017.* Sacramento, CA. Available at http://www.dof.ca.gov/Forecasting/Demographics/Estimates/E-6/

DOF (2017). California Department of Finance. *California Gross Domestic Product.* Retrieved October 2017, from http://www.dof.ca.gov/Forecasting/Economics/Indicators/Gross_State_Product/

Monthly average atmospheric CO_2 concentrations

Conway T; Lang P and Masarie K (2011). Atmospheric carbon dioxide dry air mole fractions from the NOAA/ESRL Carbon Cycle Global Cooperative Network, 1968–2010; version 2011-06-21. Retrieved from ftp://ftp. cmdl. noaa. gov/ccg/co2/flask/event: 2011.

NOAA (2016a). National Oceanic and Atmospheric Administration, Earth System Research Laboratory, Global Monitoring Division. Retrieved December 12, 2016, from http://www.esrl.noaa.gov/gmd/

SIO (2012). Scripps Institution of Oceanography Monthly Atmospheric CO_2 Concentrations (ppm) Derived from Flask Air Samples. La Jolla Pier, California. Retrieved December 20, 2016, from http://scrippsco2.ucsd.edu/data/ljo.html

Seawater carbon dioxide and pH off Point Conception, CA and Hawaii

Hawaii Ocean Time-Series (2017). *Hawaii Ocean Time-series surface CO_2 system data product*. [As adapted from: Dore JE, Lukas R, Sadler DW, Church MJ, and Karl DM (2009).] Physical and biogeochemical modulation of ocean acidification in the central North Pacific. *Proceedings of the National Academy of Sciences USA* **106**:12235-12240] Retrieved December 22, 2017, from http://hahana.soest.hawaii.edu/hot/products/HOT_surface_CO2.txt

NOAA PMEL (2017). National Oceanic and Atmospheric Administration, Pacific Marine Environmental Laboratory. CO_2 Moorings and Time Series Project, California Current Ecosystem 1 (CCE1) Mooring at 33.5°N, 112.5°W. Retrieved December 22, 2017 from https://www.nodc.noaa.gov/ocads/oceans/Coastal/CCE1_122W_33N.html

Sutton A, Sabine C, Send U, Ohman M, Dietrich C, et al. (2011). High-resolution ocean and atmosphere pCO_2 time-series measurements from mooring CCE1_122W_33N. http://cdiac.esd.ornl.gov/ftp/oceans/Moorings/CCE1_122W_33N/. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tennessee.

Changes in Climate

Statewide annual average temperature and *Statewide temperatures by decade relative to long-term average*

WRCC (2018). Western Regional Climate Center: California Climate Tracker. Retrieved January 10, 2018, from http://www.wrcc.dri.edu/monitor/cal-mon/index.html

Nighttime heat waves

WRCC (2017). Western Regional Climate Center. National Weather Service Cooperative Observation Network, accessed 10 March 2017 via the Applied Climate Information System. Data analyzed by Ben Hatchett, Desert Research Institute.

Palmer Drought Severity Index

NOAA (2017). National Oceanic and Atmospheric Administration, National Centers for Environmental information: Climate at a Glance, Time Series. Palmer Drought Severity Index, 12-month starting October. Retrieved December 26, 2017, from http://www.ncdc.noaa.gov/cag/

IMPACTS ON PHYSICAL SYSTEMS

Snow-water content

DWR (2017). California Department of Water Resources: Snow Course Data, California Data Exchange Center. Retrieved July 2017, from http://cdec.water.ca.gov/cgi-progs/snowQuery and http://cdec.water.ca.gov/cgi-progs/selectSnow

Sacramento River spring runoff

DWR (2016). California Department of Water Resources: Chronological Reconstructed Sacramento and San Joaquin Valley Water Year Hydrologic Classification Indices. Retrieved August 16, 2017, from http://cdec. water. ca. gov/cgi-progs/iodir/WSIHIST. (2017 data provided by California Department of Water Resources).

Annual mean sea level trends

NOAA (2017). National Oceanic and Atmospheric Administration, Center for Operational Oceanographic Products and Services: Tides and Currents. Retrieved July 2017, from www.co-ops.nos.noaa.gov.

Historical and contemporary photographs of the Dana Glacier

US Geological Service (1883), photo station ric046 and H. Basagic (2013).

IMPACTS ON BIOLOGICAL SYSTEMS

Annual area burned by wildfires

CalFire (2018). FRAP Mapping, Fire Perimeters Version 16_1. Statewide data set "fires_100.xls" California Department of Forestry and Fire Protection. Retrieved February, 2018, from http://frap. fire. ca. gov/data/frapgisdata-sw-fireperimeters_download. Preliminary data for 2017 provided by CalFire.

Changes in area occupied by pines and oaks

McIntyre P, Thorne JH, Dolanc CR, Flint A, Flint L, et al. (2015). Twentieth century shifts in forest structure in California: denser forests, smaller trees, and increased dominance of oaks. *Proceedings of the National Academy of Sciences* **112**: 1458–1463.

Ponderosa Pine forest retreat

Thorne JH, Morgan BJ, and Kennedy JA (2008, updated 2017). Vegetation change over 60 years in the central Sierra Nevada. *Madroño* **55**:223-237.

Sierra Nevada range shifts

Rowe KC, Rowe KMC, Tingley MW, Koo MS, Patton JL, et al. (2015). Spatially heterogeneous impact of climate change on small mammals of montane California. *Proceedings Royal Society B* **282**: 20141857.

Tingley MW, Koo MS, Moritz C, Rush AC and Beissinger SR (2012). The push and pull of climate change causes heterogeneous shifts in avian elevational ranges. *Global Change Biology* **18**: 3279-3290.

Northernmost locations of Phidiana hiltoni

Goddard JHR, Gosliner TM and Pearse JS (2011, updated 2017). Impacts associated with the recent range shift of the aeolid nudibranch Phidiana hiltoni (Mollusca: Opisthobranchia) in California. Marine Biology **158**: 1095–1109.

For more information contact:
Office of Environmental Health Hazard Assessment
P. O. Box 4010, Mail Stop 12-B
Sacramento, California 95812-4010
(916) 324-7572
www.oehha.ca.gov

Printed on recycled paper