# Climate Change and Health

## Understanding How Global Warming Could Impact Public Health in California

NOVEMBER 2018

CALIFORNIA SENATE OFFICE OF RESEARCH

# Climate Change and Health

## Understanding How Global Warming Could Impact Public Health in California

NOVEMBER 2018

CALIFORNIA SENATE OFFICE OF RESEARCH

# Table of Contents


**INTRODUCTION** . . . . . 2

**PART I. CLIMATE CHANGE AND ITS POTENTIAL IMPACTS ON HUMAN HEALTH** . . . . . 3
- State of Climate Change in California . . . . . 3
- Potential Human Health Impacts of Climate Change . . . . . 4
- State Entities Focused on Climate Change and Public Health . . . . . 4

**PART II. REVIEW OF CLIMATE-RELATED HEALTH OUTCOMES RESEARCH** . . . . . 7
- Heat-Related Death and Illness . . . . . 7
  - Elevated Ambient Temperature . . . . . 7
  - Heat Waves . . . . . 10
  - Vulnerable Populations . . . . . 11
  - Urban Heat Islands . . . . . 13
  - Kidney Stones . . . . . 13
  - Projected Mortality Due to Heat . . . . . 14
  - Access to Air Conditioning . . . . . 15
- Air Quality Impacts . . . . . 16
  - Ambient Air Pollution . . . . . 16
  - Asthma . . . . . 17
  - Wildfire Smoke . . . . . 17
  - Valley Fever . . . . . 20
  - Allergens . . . . . 20
- Extreme Weather Events . . . . . 21
  - Vulnerable Populations . . . . . 22
- Vector-Borne Disease . . . . . 23
  - Lyme Disease . . . . . 24
  - West Nile Virus . . . . . 24
  - Emergent Vector-Borne Disease . . . . . 25
- Water Quality and Access . . . . . 27
  - Agricultural Runoff . . . . . 27
  - Urban Runoff . . . . . 28
  - Harmful Algal Blooms . . . . . 29
  - Emergent Water-Borne Disease . . . . . 30
  - Water Treatment in Coastal Communities . . . . . 30
  - Private Wells . . . . . 30
- Foodborne Disease . . . . . 31
  - Drought . . . . . 31
  - Pest Control . . . . . 32
  - Food Processing . . . . . 32
  - Contaminated Seafood . . . . . 32
- Food Security . . . . . 33
  - Nutritional Value . . . . . 33
  - Access to Food . . . . . 33
  - Food Production . . . . . 34
- Mental Health and Well-Being . . . . . 35
  - Extreme Events . . . . . 35
  - Heat . . . . . 35
  - Vulnerable Populations . . . . . 36

**LOOKING AHEAD** . . . . . 37
- Adaptation and Resiliency . . . . . 37
- Health Equity . . . . . 37
- Future Research . . . . . 38

**REFERENCES** . . . . . 39

# Introduction

Public health is strongly affected by environmental conditions. Therefore, the environmental changes resulting from global climate change have important implications for public health, as do the strategies used to mitigate harmful impacts of climate change. In 2016, the American Public Health Association deemed climate change "the greatest threat to public health."[1]

Climate change is a global phenomenon, but its effects on different regions around the world will vary. Due to higher concentrations of heat-trapping greenhouse gases in the atmosphere, air and sea temperatures are warming, which, in turn, are increasingly altering precipitation levels, air quality, and sea levels. For California, this means there is greater likelihood of heat waves, droughts, reduced snowpack, large wildfires, and extreme storms with heavy precipitation and flooding.

The associated impacts on human health may be direct, such as deaths, illnesses, and injuries from extreme weather events, or the impacts may be indirect, such as by altering the environment in ways that affect public health. For example, warmer sea temperatures indirectly impact public health by fostering more bacterial growth and contributing to greater risks of water-borne diseases among people who eat seafood and swim in the ocean. Exposure to harsher environmental conditions also can affect the population's mental health.

This report was prepared at the request of Senator Ricardo Lara and provides a comprehensive review of the scientific evidence on the potential impacts of climate change on public health in California. Whereas other compendiums approach associations between climate factors and health at an international or national scale, this report was developed to serve as a thorough reference pertaining to California specifically, complete with citations for further study of any particular topic.

The first part of the report describes the state of climate change in California and possible effects on human health. The second part is a detailed summary of research showing how California's population already is affected by extreme heat and other suboptimal environmental conditions that could worsen with climate change. When reviewing this section, it is important to note that public health outcomes involve the interactions of many factors, including those biological, ecological, societal, and economic in nature. Most of the studies cited here look at historic climate-related health outcomes without attributing impacts to climate change that has already occurred. Some studies use the historic data as a basis for making future projections linked to climate change.

Image by Camille Seaman

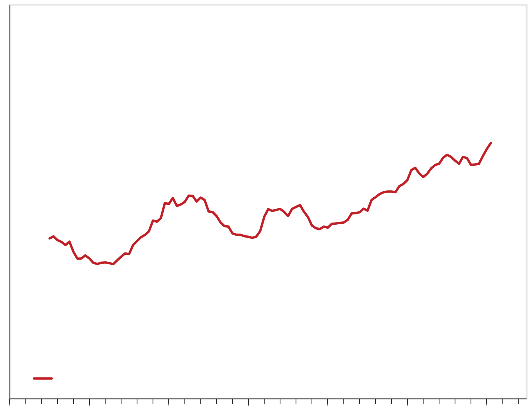
# Part I. Climate Change and Its Potential Impacts on Human Health

## State of Climate Change in California

Reports by the State of California—"2018 Indicators of Climate Change in California" and "California's Fourth Climate Change Assessment"—offer the latest overviews of climate change in the state. According to the evidence, annual average temperatures in California have increased since 1895 at a rate of 1.8 degrees Fahrenheit per century: 2.3 degrees Fahrenheit per century for minimum temperatures and 1.3 degrees Fahrenheit per century for maximum temperatures (Figure 1).[2] The current pace of warming is unprecedented, based on 1,100 years of climatic evidence and accounting for natural variations.[3] The last four years were the warmest in recorded history, signaling an accelerated rate of warming. Additionally, sea levels are six to seven inches higher in some cities than 100 years ago. Extreme heat events are more frequent: the occurrence of nighttime heat waves, in particular, has nearly doubled in the last 30-year period, compared with the average from 1950 to 2016, from 11 days to 21 days per year. The 2012 drought was the most severe in 1,200 years.[4]

There is consensus among experts that by 2100, California will see maximum average temperatures increase by 5.6 to 8.8 degrees Fahrenheit above 1960–2005 temperatures, depending on the specific emissions scenario used in the climate model (Table 1).[6] One end of the scale reflects a decrease in emissions to 80 percent below 1990 levels (accumulating to 550 parts per million (ppm) carbon dioxide in the atmosphere), and the other represents a "business-as-usual" scenario (maintenance of current emissions rates leading to 900 ppm carbon dioxide). Under both scenarios, extreme heat events, such as heat waves, will occur more frequently. By mid-century, the Central Valley may experience heat-health events that last two weeks longer, while the northern Sierra region can expect four to 10 times more heat-health events than currently occur. Droughts also will occur more frequently and are likely to be more severe. By 2100 under the "business-as-usual" scenario, sea levels along the California coast will rise and may reach up to 20 inches higher than current levels, resulting in the disappearance of up to 67 percent of Southern California's beaches. Increasing frequency of extreme wildfires could result in burned acreage up to 77 percent greater than in the present day.

**Figure 1**
Statewide Annual Average Temperature, 1895–2017



Average temperatures have risen 1.8 degrees Fahrenheit per century since the first measurements were recorded in 1895. Compared to previous centuries, this rate of increase is unprecedented. Reproduced with permission from the authors.[5]

**Table 1**
Projected Increase in Annual Average Maximum Daily Temperature under Different Future Emissions Scenarios

| | 2006 - 2039 | 2040 - 2069 | 2070 - 2100 |
|---|---|---|---|
| **Low emissions** | +2.5 °F | +4.4 °F | +5.6 °F |
| **High emissions** | +2.7 °F | +5.8 °F | +8.8 °F |

Adapted from California's Fourth Climate Change Assessment and based on scenarios from the Fifth Intergovernmental Panel on Climate Change Assessment Report on Climate Change.[7,8]

## Potential Human Health Impacts of Climate Change

The human health impacts of climate change have received international attention for more than 20 years. Notable reports from international, national, and California entities include:

- The 1996 report of the UN Intergovernmental Panel on Climate Change (IPCC)[9]
- The 2005 California Climate Change Center report on health impacts in California[10]
- The 2015 report of the International Lancet Commission on Health and Climate Change[11]
- The 2016 U.S. Global Change Research Program compendium of reports focused on climate-related health[12]
- The 2018 IPCC report, in which human health remained a priority[13]

Across this body of work, experts have consistently recognized potential human health impacts from climate change associated with severe heat and other extreme weather events, reduced air quality, vector-borne disease, reduced water quality and access, foodborne disease, food insecurity, and mental health. In 2014, the president of the World Bank asserted that climate change "threatens our fragile existence on this planet."[14] The potential impacts of climate change on public health are summarized in Table 2 and depicted in Figure 2.

## State Entities Focused on Climate Change and Public Health

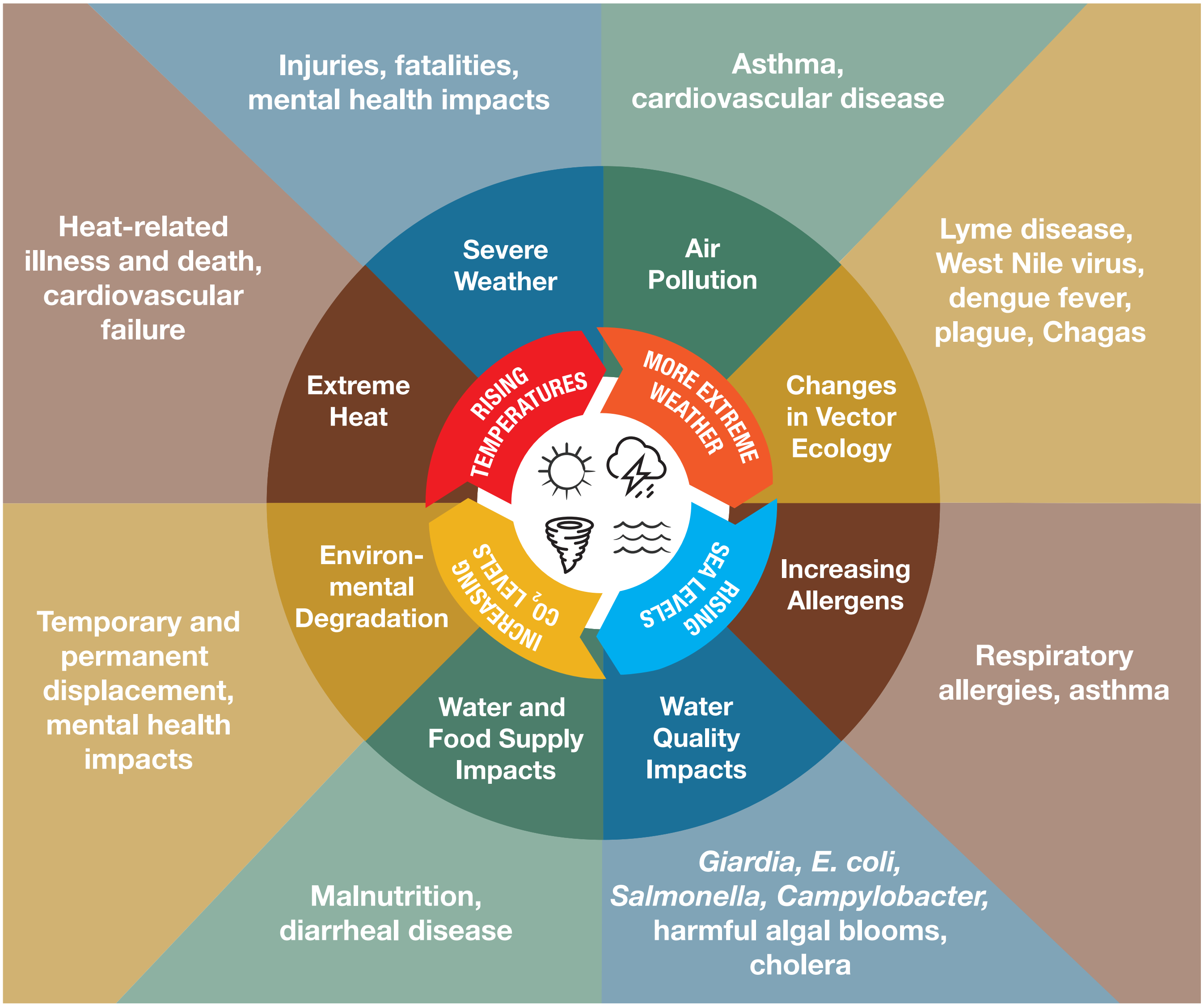
Considering the complex factors that influence public health and the variability associated with different regions, tracking and analyzing climate-related health outcomes is a rigorous endeavor. Researchers and state scientists in California have been leaders in uncovering the variety and severity of local health effects associated with climate change. Several state agencies support in-depth studies and craft policies to limit health risks, including the California Department of Public Health (CDPH), the Governor's Climate Action Team, and the California Environmental Protection Agency (CalEPA). In particular, the CalEPA Office of Environmental Health Hazards Assessment (OEHHA) and the CDPH Climate Change and Health Equity Program continuously compile climate-related health information to contribute to mitigation and adaptation activities.[17]

California was the first state to fund a climate change research program, led by the Energy Commission. Furthermore, state agencies have produced a number of resources for cities and counties, local health departments, and physicians to assess risk and plan accordingly. For example, CDPH and the Public Health Institute have compiled information

Table 2
Potential Human Health Impacts of Climate Change

| Climate Related Environmental and Health Impacts | Examples (not exhaustive) |
|---|---|
| **Heat-related illness and mortality** | Heat is a health risk amplifier that can worsen preexisting conditions, such as heart and lung disease, diabetes, asthma, and kidney problems. As both ambient temperatures and heat waves continue to increase as a result of climate change, negative health outcomes known to be associated with heat are predicted to rise. Increased temperatures disproportionally impact urban areas and vulnerable populations, such as children, the elderly, and disadvantaged communities. By 2050, up to 6,700 to 11,300 annual premature deaths are projected due to rising temperatures under a "business-as-usual" scenario.[15] |
| **Reduced air quality** | Hotter temperatures can exacerbate conditions that reduce air quality, such as levels of smog, airborne allergens, and wildfire smoke. Reduced air quality is known to increase the incidence of respiratory illnesses, including asthma, bronchitis, chronic obstructive pulmonary disease, and pneumonia. As temperatures continue to increase as a result of climate change, negative health outcomes known to be associated with reduced air quality are predicted to rise. |
| **Extreme weather events** | The growing frequency and severity of storms is likely to increase occurrences of traumatic injury and death, population displacement, wastewater treatment facility breaches, and complications with food distribution. |
| **Vector-borne disease** | Hotter temperatures likely will foster the growth of disease-carrying vectors, such as mosquitos and ticks. As a result, higher incidences of Lyme disease and West Nile virus are predicted. Other diseases, such as plague and dengue fever, may become more prevalent due to geographic expansion into California. Pathogens also are likely to become more potent due to warmer conditions. |
| **Reduced water quality and access** | Increased frequency and duration of drought conditions will strain access to clean water. Stronger storms will lead to greater public exposure to contaminated waters from agricultural and urban runoff, and warmer conditions will foster pathogen growth and distribution, such as harmful algal blooms. Reduced water quality will lead to higher incidences of gastrointestinal illness and respiratory tract and skin infections. |
| **Foodborne disease** | Higher temperatures foster foodborne pathogens, such as during transport, increasing the risk of gastrointestinal illness. Disease-carrying pests are likely to contaminate agricultural areas at higher rates, while toxic chemicals from greater use of pesticides and veterinary drugs also may contaminate food and water sources. |
| **Reduced food security** | Warming temperatures and changing precipitation patterns likely will result in geographic shifts of favorable growing conditions for many crops, preventing many areas from growing traditional crops. Increased levels of carbon dioxide also reduce the nutritional value of many crops. |
| **Mental health** | More frequent natural disasters and warming temperatures likely will cause mental health problems, particularly for children, the elderly, disadvantaged groups, and first responders. |

**Figure 2**
Interactions Between Environmental Conditions and Human Health




Adapted from the U.S. Centers for Disease Control and Prevention.[16]

and guidance in "Public Health Impacts of Climate Change in California: Community Vulnerability Assessments and Adaptation Strategies."[18] The Governor's Office of Emergency Services has published its "Contingency Plan for Excessive Heat Emergencies."[19] A joint publication of CalEPA and CDPH provides practical measures for cities and counties in "Preparing California for Extreme Heat: Guidance and Recommendations."[20] The California Energy Commission offers Cal–Adapt, an online resource with location-specific climate change data.[21] OEHHA's CalEnviroScreen tracks air pollution at local scales.[22] Finally, CDPH coordinates its efforts through California Building Resilience Against Climate Effects to assess exposures, social vulnerability, and adaptive capacity.[23]

The state can be doing more, however. Experts from the National Academies of Sciences, Engineering, and Medicine encourage even greater involvement of public health experts and practitioners in addressing climate change effects in traditionally non-health sectors, such as energy, food and agriculture, transportation, and urban planning.[24]

# Part II. Review of Climate-Related Health Outcomes Research

As previously stated, the potential health impacts of climate change are related to increased heat, reduced air quality, extreme weather events, vector-borne disease, reduced water quality and access, foodborne disease, reduced food security, and mental health (Table 2). Each area is explored further in this part of the report. Specifically, the report cites research on how extreme heat and other suboptimal environmental conditions already affect California's population. This provides a backdrop to understand how climate change could exacerbate existing health outcomes and present new challenges, too.

The review was limited to high-quality peer-reviewed research that applied rigorous study methods. Using the scholarly databases PubMed and Google Scholar, more than 250 relevant studies and reports were identified. The following sections summarize key findings from these studies and identify any counties and cities included in the analyses.

When reviewing this information, it is important to note that public health outcomes involve the interactions of many factors, including those biological, ecological, societal, and economic in nature. Most of the studies cited here look at historic climate-related health outcomes without attributing impacts to climate change that has already occurred. Some studies use the historic data as a basis for making future projections linked to climate change.

## Heat-Related Death and Illness

Of all weather-related deaths in the nation, studies have shown that extreme heat is the top contributor.[25] Many illnesses are made worse from hotter temperatures, especially for patients with heart and lung disease, diabetes, asthma, and kidney complications. Children, the elderly, and disadvantaged communities are the most vulnerable populations impacted by heat-related illnesses. The effect of higher temperatures on human health is largely due to an inability to escape the heat.

Understanding historic impacts of heat is critical for reducing impacts in the future, since temperatures are expected to increase from climate change. This summary addresses morbidity and mortality associated with hotter than average temperatures and episodes of heat waves and discusses climate-related factors that exacerbate existing conditions. Urban areas are highlighted here due to the "urban heat island effect," wherein temperatures are further elevated compared with suburban and rural areas, due to paved surfaces and building materials that capture and retain heat.[26] The increased incidence of heat-related kidney stones also is discussed.

### Elevated Ambient Temperature

It is commonly understood that extreme temperatures, both high and low, have the potential to increase the risk of death. However, ambient air temperatures (the normal range of environmental air temperatures that people directly experience in everyday life), that deviate even slightly from seasonal average temperatures can also increase mortality rates.[27,28] Although communities may acclimate to new ambient temperatures, the most vulnerable groups are expected to remain at risk of death and illness from the effects of temperature fluctuations. Most heat-related health complications are associated with the body's inability to regulate its temperature, such as heatstroke, heat cramps, heat exhaustion, and hyperthermia.[29]

The California Environmental Health Tracking Program at OEHHA collects data that are useful for understanding underlying weather effects on human health.[30] Nine counties in California (Contra Costa, Fresno, Kern, Los Angeles, Orange, Riverside, Sacramento, San Diego, and Santa Clara)—accounting for 65 percent of the state's population—were included in a study that examined ambient temperature-related mortality and morbidity as measured by hospitalizations from 1999 to 2003.[31] Researchers concluded that across the counties, a summertime temperature (calculated as a heat index that incorporates temperature and relative humidity) increase of 10 degrees Fahrenheit over the month's

Climate change is projected to increase temperatures throughout the state. As a result, more Californians will experience heat-related illnesses, especially those individuals with preexisting conditions that are exacerbated by warmer conditions.

average temperature corresponded with a 2.3 percent increase in overall mortality. More specifically, coastal counties experienced a 3.4 percent increase, while inland counties experienced a 2 percent increase. The research team inferred that the stronger impact for coastal counties is likely due in part to coastal residents' acclimatization to cooler temperatures and lack of air-conditioning units.

Hospitalizations for various medical conditions were studied to understand the increased health risks during periods of high ambient temperatures.[32] Many preexisting illnesses were shown to be exacerbated by hot days, especially heatstroke, dehydration, and acute renal failure (Table 3). For example, on a day with temperatures 10 degrees Fahrenheit over the local average, individuals experienced a 342 percent higher risk of hospitalization for heatstroke. With the exception of respiratory diseases, the outcomes were independent of the effects of air pollution. Table 3 provides additional results.

For children and teenagers ages 5–18, the study showed a 22.8 percent increase in gastrointestinal infectious diseases. This result is likely due to the effects of environmental bacterial and viral growth conditions, which are dependent on air, soil, and water temperature. During warmer temperatures, changes in bacterial composition of food, skin, soil, and water may occur, resulting in greater risk of intestinal diseases.[33]

**Table 3**
**Summertime Heat-Related Morbidity Across Nine California Counties, 1999–2003**

| | % Increased Risk of Hospitalization |
|---|---|
| Heatstroke | 342 |
| Dehydration | 10.8 |
| Acute Renal Failure | 7.4 |
| Pneumonia | 3.7 |
| Ischemic Stroke | 3.5 |
| Diabetes | 3.1 |
| All Respiratory Diseases | 2 |

Excess risk of hospitalization per diagnosis under conditions of a 10-degree temperature increase above local average in summertime months.[32]

A follow-up study identified three populations within the nine counties most vulnerable to ambient heat-related death, compared with total average: the elderly (2.2 percent increased risk), infants younger than a year old (4.9 percent increased risk), and the black racial group (4.9 percent increased risk).[34]

A similar, targeted study of summertime emergency room (ER) visits across the entire state from 2005–08 showed mortality increased 1.7 percent under conditions of a 10-degree increase over regional averages.[35] Table 4 displays morbidity by diagnosis across the 16 studied climate zones (including parts of Arcata, China Lake, El Centro, El Toro, Fresno, Los Angeles, Mount Shasta, Oakland, Pasadena, Red Bluff, Riverside, Sacramento, San Diego, Santa Maria, Santa Rosa, and Sunnyvale) per summer that correspond with a 10-degree temperature rise above regional average.

The study also included comparisons between racial groups, indicating high risks for Hispanics in ischemic stroke (7.2 percent versus 2.8 percent average), ischemic heart disease (5.2 percent vs. 1.7 percent average), acute renal failure (21.8 percent vs. 15.9 percent average), and intestinal infections (10.4 percent vs. 6.1 percent average). Similar comparisons showed greater risks for Asians in dehydration (37.4 percent vs.

**Table 4**
Summertime Heat-Related Morbidity in California, 2005–08

| | % Increased Risk of ER Visit |
|---|---|
| Heat Illness (including heatstroke, heat exhaustion, and heat cramps) | 393 |
| Dehydration | 25.6 |
| Acute Renal Failure | 15.9 |
| Hypotension | 12.7 |
| Intestinal Infection | 6.1 |
| Diabetes | 4.3 |
| Ischemic Stroke | 2.8 |
| Cardiac Dysrhythmia | 2.8 |
| Ischemic Heart Disease | 1.7 |

Excess risk of ER visit per diagnosis under conditions of a 10-degree temperature increase above local average in summertime months.[35]

25.6 percent average) and primary diabetes (7.6 percent vs. 4.3 percent average). The study's authors speculate the disparities may be due to less preventive care and greater use of the ER by different ethnic groups.

A different study from 1992 showed the elderly (defined as adults older than 65) in four metropolitan cities of Southern California—Los Angeles, San Bernardino, San Diego, and Santa Ana—face a 15 percent increased risk of mortality per 10-degrees temperature increase, while the elderly in two metropolitan cities of Northern California—Oakland and San Jose—face an 8 percent increased risk.[36]

High ambient temperatures also have been associated with preterm births (delivery before 37 gestational weeks), a primary cause of infant mortality and morbidity.[37,38] A study of 16 California counties (Alameda, Contra Costa, Fresno, Kern, Los Angeles, Merced, Orange, Riverside, Sacramento, San Bernardino, San Diego, San Joaquin, Santa Clara, Solano, Tulare, and Ventura) from 1999–2006 showed a significant association of heightened risk of preterm delivery per 10-degree Fahrenheit increase in temperature, as indicated by county in Table 5.[39] The results were independent of air pollution, a known environmental risk factor for preterm births. The association was significant across all demographics, averaging 8.6 percent but higher for younger mothers. The data also reveal that risks of negative health outcomes are different across racial groups: black (14.9 percent), Asian (10.2 percent), Hispanic (8.1 percent), and white (6.6 percent). Previous investigations have indicated similar disparities in birth outcomes by race/ethnicity, without accounting for temperature.

**Table 5**
Risk of Preterm Birth Increases During Warmer Temperatures

| County | Heightened Risk | 95% Confidence Interval |
|---|---|---|
| Alameda | 21.2 | 4.7, 40.3 |
| Contra Costa | 12.4 | -7.2, 36.2 |
| Fresno | 9.9 | 1.7, 18.7 |
| Kern | 7.3 | -1.6, 17.1 |
| Los Angeles | 4.9 | 0.1, 9.9 |
| Merced | -10.7 | -32.5, 18.2 |
| Orange | 15.9 | 2.0, 31.7 |
| Riverside | 1.2 | -7.8, 11 |
| Sacramento | 16.0 | 7.0, 25.9 |
| San Bernardino | 9.0 | 1.4, 17.1 |
| San Diego | 10.7 | 0.0, 22.6 |
| San Joaquin | 13.2 | 2.1, 25.5 |
| Santa Clara | 5.0 | -13.4, 27.3 |
| Solano | -6.7 | -31.4, 27 |
| Tulare | 12.1 | -3.8, 30.5 |
| Ventura | 13.2 | -3.1, 32.2 |

County-level estimates for the percent change associated with a 10-degree Fahrenheit increase in weekly average temperature in preterm births, May–September 1999–2006. The analysis included more than 60,000 births and controlled for air pollution.[40]

## Heat Waves

Heat waves are defined as a period when daily average temperatures rise above the geographic zone– and month–specific 95th percentile for at least two consecutive days. The occurrence of heat waves, particularly at night, has increased in frequency (Figure 3). It is anticipated that some areas of California can expect up to four to 10 times the number of heat waves due to climate change by mid-century. In addition to the health effects from increased ambient temperatures, heat waves are known to further exacerbate risks of mortality and cardiovascular morbidity.[41,42]

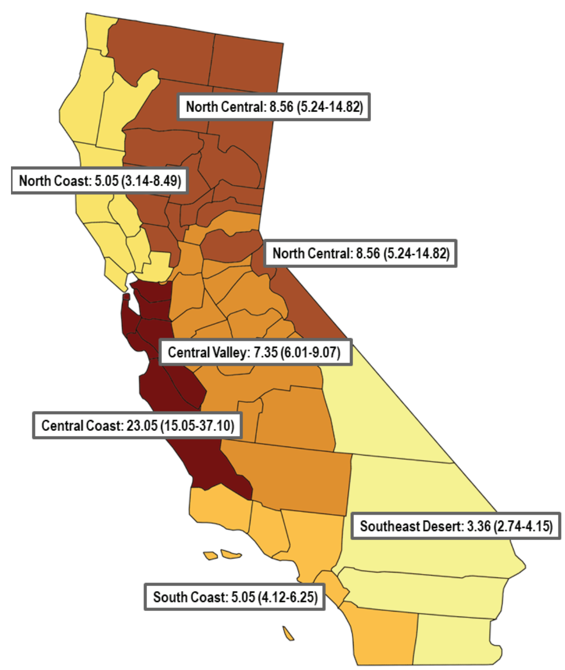
Three independent studies tracked mortality and morbidity following California's 2006 heat wave. One study found a 9 percent increase in mortality per 10-degree Fahrenheit increase in temperature in seven affected counties (Fresno, Imperial, Los Angeles, Kern, Merced, Sacramento, and San Bernardino), causing approximately 600 heat-related deaths over about two weeks. The second report quantified 1,182 excess hospitalizations and 16,166 excess ER visits across the state due to the heat wave, with different regions hit harder than others (Figure 4). The greatest risk increases of negative health outcomes were seen along the Central Coast, North Central, and Central Valley.[43] Of the occupational deaths linked to the heat wave, 71 percent were agricultural.[44] A third analysis of the cost to society for the excess hospitalizations and ER visits during the heat wave estimated that $132 million was spent, primarily for in-hospital expenses.[45]

A wide-ranging study of 19 heat waves across California from 1999–2009 concluded that hospital admissions increase on average by 7 percent on peak heat wave days, with particular impacts on cardiovascular disease, respiratory disease, dehydration, acute renal failure, heat illness, and mental health.[48] In total, 11,000 excess hospitalizations occurred due to extreme heat over the course of the 10-year study period, with the strongest health impacts seen in the North Coast (10.5 percent increase in morbidity), the Central Valley (8.1 percent), Southern Deserts (6.3 percent), and the South Coast (5.6 percent). Figure 5 depicts the relationship between relative temperature increase (left panel) and morbidity (right panel). Daily morbidity per region is shown in Table 6.

**Figure 3**
Statewide Nighttime Heat Waves
April–October, 1950–2017

Heat waves have occurred with increasing frequency over the last four decades compared to earlier in the century. Reproduced with permission from the authors.[46]

**Figure 4**
Excess Risks of an ER Visit During the 2006 Heat Wave



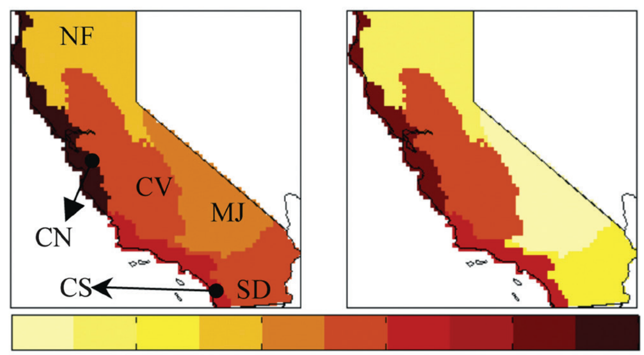

Relative risks (95 percent Confidence Intervals) for ER visits for heat-related illnesses among all ages, during the July 15–August 1, 2006 heat wave, compared with a reference period (July 8–14 and August 12–22, 2006). Reproduced with permission from the authors.[47]

Other research on California-specific heat wave impacts, measured by hospital visits from 1999–2009, identified increased risks especially for acute renal failure (21 percent) and dehydration (20 percent), compared with elevated ambient temperature.[50] The study corroborated earlier research showing risk of hospitalization for the following illnesses also was heightened during generally hot days: appendicitis (11 percent), ischemic stroke (3 percent), mental health (4 percent), noninfectious enteritis (5 percent), and primary diabetes (6 percent). Furthermore, Hispanics were found to have about a 9 percent greater risk of respiratory diseases than Caucasians during heat waves. In general, socioeconomically disadvantaged Californians suffer the impacts the most by heat wave and heatstroke mortality, especially in the inner city.[51] As more intense, frequent, and longer heat waves are predicted for California,[52] health outcomes also are likely to worsen.

## Vulnerable Populations

Not everyone is equally at risk of heat-related mortality and morbidity. Figure 6 shows several components of risk associated with heat, which need to be included when assessing the level of vulnerability. Understanding the multiple factors that characterize risk is essential for adaptation efforts, such as hazard frequency and severity, as well as population exposure and susceptibility. Social determinants of health, such as poverty, education, and land-use elements, contribute strongly to each level of assessment.

**Figure 5**
Coastal Regions at Greater Risk of Heat-Related Illnesses




The pattern of heat-related health outcomes by region in California is represented here by a metric of temperature intensity in relation to average maximum temperatures in the left panel. The increased risk of hospitalization as a result of heat waves is represented in the right panel, showing the coastal regions of California are most vulnerable. The gradient represents the coevolution of temperature and hospitalizations from weakest relationship (light yellow) to strongest (dark red). The acronyms are Central Valley (CV), Southern Deserts (SD), North Coast (CN), South Coast (CS), Northern Forests (NF), and Mojave Desert (MJ). ©American Meteorological Society.[49] Used with permission.

**Table 6**
Average Daily Increase in Hospital Admissions During Heat Waves Across California, 1999–2009

| Region | Daily Average Hospitalizations, All Causes, 1999-2009 Baseline | Average Excess Daily Morbidity (Count) During the Peak Day of a Heat Wave | Average Excess Daily Morbidity (Percent Above Normal) for the Peak Day of a Heat Wave |
|---|---|---|---|
| Central Valley | 533 | 43.4 | 8.1% |
| Southern Deserts | 148 | 9.4 | 6.3% |
| North Coast | 448 | 46.9 | 10.5% |
| South Coast | 1276 | 70.9 | 5.6% |
| Mojave Desert | 62 | 1.7 | 2.7% |
| Northern Forests | 49 | 0.5 | 1.0% |

The degree to which heat waves impact human health varies across different regions.[49]

**Figure 6**

Components of Heat-Related Morbidity and Mortality Risk


Many factors contribute to a person's risk for heat-related morbidity and mortality, including biological predispositions and social determinants of health. Adapted from *Environmental Health Perspectives*.[53]

Outdoor workers, such as those in the agricultural and construction industries, tend to be the most affected by hot temperatures.[54] Several state offices track occupational deaths and illnesses, including the Department of Industrial Relations' Division of Occupational Safety and Health (Cal/OSHA) and the Department of Public Health's Climate Change & Health Vulnerability Indicators for California (CCHVIs).[55,56] Of occupational heat-related deaths and illnesses in 2005, a Cal/OSHA investigation found that 38 percent were agricultural workers, 29 percent were construction workers, and almost all (96 percent) were involved in outdoor work.[57]

Heat waves constitute a grave risk for individuals with preexisting mental illness. A controlled meta-analysis of more than 1,000 heat wave-related deaths found a preexisting mental illness triples one's risk of death due to heat wave exposure.[58] Another study concluded that 52 percent of heat-related deaths during a 2012 heat wave in Wisconsin occurred among individuals with at least one mental illness (14 deaths in a sample size of 27).[59] Further research has shown that patients with a substance abuse diagnosis are at 8 percent and 20 percent greater risk of heat wave-related mortality, related to alcohol and non-alcohol substance abuse, respectively.[60]

## Urban Heat Islands

During regional heat events, urban cities encounter higher temperatures than surrounding rural areas primarily due to more pavement and building materials that capture and retain heat, with differences reaching 6 degrees during the day and up to 22 degrees at night.[61,62] This pattern is called the "urban heat island effect,"[63] and the rate of temperature increase varies for different cities.[64]

The urban heat island effect strengthens the impact of heat waves and affects human health by exacerbating the above-mentioned medical complications associated with heat-induced respiratory issues, heat illness, and heat-related mortality. Not only are daytime temperatures higher, but hotter nighttime temperatures are particularly dangerous, as urban residents are unable to recover and therefore become more vulnerable to heat-related medical complications.[65] Low-income areas also tend to have greater heat-related mortality rates.[66]

In one study, researchers predicted extreme heat events will increase faster in Fresno and San Francisco, compared with Los Angeles and San Diego.[67] Another research team in 2014 examined four extreme temperature events in Los Angeles, spanning about three weeks, and calculated 393 premature heat-related deaths total.[68] Looking forward, the research team predicted that deaths could be avoided by adaptation efforts, such as increasing urban surface reflectance (such as green roofs) and vegetation (such as shade trees).

Outdoor workers bear the majority of occupational heat-related deaths and illnesses.

Greater reductions in hospital admissions also would be expected.

Recent research of the Los Angeles Basin explored opportunities to decrease the urban heat island effect by increasing a city's tree canopy and use of reflective building materials.[69] In the San Fernando Valley, for example, localized heat islands were present in neighborhoods with the lowest vegetation canopy cover. In downtown Los Angeles, localized heat islands were mapped in areas with the least reflective roofs. Further results showed that neighborhoods may be cooler by 5 degrees Fahrenheit during the day with greater use of reflective roofs. With greater canopy cover, neighborhoods may be cooler by 4.1 degrees Fahrenheit during the day and 6 degrees Fahrenheit at night.[70]

CalEPA maintains an Urban Heat Island Index to quantify and track the extent and severity of urban heat islands for individual cities throughout the state.[71]

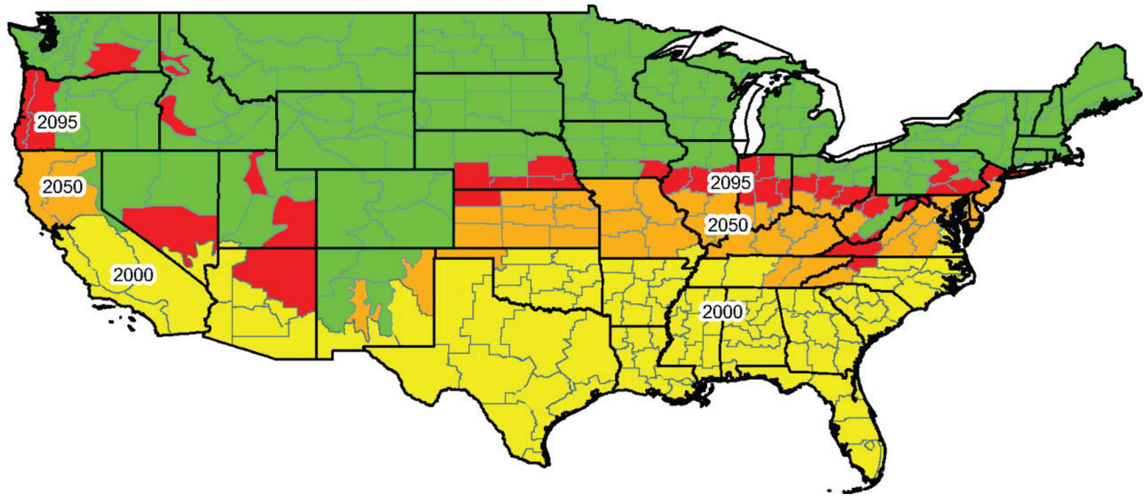
## Kidney Stones

Kidney stone disease, or nephrolithiasis, develops in response to environmental and metabolic risk factors and is more prevalent in warmer climates. As minerals build up in the kidneys, solid crystals can form that aggravate the urinary tract downstream, resulting in pain and occasionally requiring surgical removal. As ambient temperatures increase, more fluid is lost through the skin as sweat. Under conditions of dehydration, minerals in the kidneys are more likely to build up and form kidney stones.

Climate change models anticipate the "kidney stone belt" across the United States, which includes the lower half of California, will encompass the state fully by 2050 (Figure 7), placing all Californians at higher risk of developing kidney stones.[72] The geographic expansion corresponds to a 10.7 percent increase in risk, 542,000 new cases, and annual cost increase of approximately $110 million across the state of California for direct health care services. Indirect costs, such as those associated with lost work time, were not considered but likely would add an additional 15 percent to 20 percent to the computed costs.[73]

**Figure 7**

Predicted Growth in High-Risk Kidney Stone Disease Across the United States, 2000–95




In 2000, 41 percent of the population lived within a high-risk zone. By 2050 and 2095, scientists predict that 56 percent and 70 percent of the national population, respectively, will be at high risk of developing kidney stones due to warmer temperatures. Reproduced from the *Proceedings of the National Academy of Sciences.*[74]

## Projected Mortality Due to Heat

According to CalEPA scientists, an increase of 6,700 to 11,300 annual premature deaths has been projected for California by 2050 due exclusively to higher average temperatures, if emissions continue at current rates.[75]

An analysis conducted in 2006 by the California Climate Change Center, a former program of the California Energy Commission, used data from the National Center for Health Statistics to model summertime deaths due to increasing temperatures from 1971 to 2099. Historical data show that deaths due to heat are already a reality in California. During a typical summer in the 1990s, for example, researchers attributed up to 160 excess deaths to heat in Los Angeles and up to 15 excess deaths in Sacramento.[76] Location-specific projections are based on algorithms that, among other metrics, account for the population size, the city-specific threshold temperature at which mortality is affected, and numbers of total and consecutive days with maximum temperatures.

Table 7 shows the simulated annual mortality events for five cities in California and across two scenarios: high greenhouse gas (GHG) emissions and low GHG emissions. The two emissions scenarios are those presented by the IPCC Special Report on Emission Scenarios, accounting for future societal development and corresponding GHG emissions, which are largely dependent on technological development and political decisions.[77] The high-emissions condition reflects a future society characterized by rapid technological expansion, extensive economic globalization, and a fossil fuel-intensive energy path, reaching six times 1990 levels by 2100 (970 ppm $CO_2$ concentrations). The low-emissions scenario assumes a society that transitions relatively rapidly to service and information economies, with a peak emissions level of about two times 1990 levels at mid-century, followed by a decline to below current-day levels by 2100 (550 ppm $CO_2$ concentrations). The simulation also includes baseline outcomes for 1971–2000.

As an example, the model projects that by the end of the century in Sacramento, the number of excess deaths due to climate change-related heat could rise nearly sevenfold to 104, compared with the 1971–2000 baseline.

**Table 7**
Projections for Annual Citywide Summertime Deaths by Mid-Century and End of Century Without Acclimatization

| | | | Projected Annual Summertime Deaths | |
|---|---|---|---|---|
| **City** | **Scenario** | **1971–2000 Baseline** | **2035–64** | **2070–99** |
| **San Francisco** | High emissions | 1 | 6 | 35 |
| | Low emissions | 1 | 3 | 6 |
| **Los Angeles** | High emissions | 91 | 412 | 868 |
| | Low emissions | 95 | 231 | 385 |
| **San Bernardino** | High emissions | 11 | 45 | 85 |
| | Low emissions | 10 | 27 | 43 |
| **Sacramento** | High emissions | 15 | 49 | 104 |
| | Low emissions | 11 | 36 | 52 |
| **Fresno** | High emissions | 32 | 77 | 130 |
| | Low emissions | 28 | 59 | 79 |

A 2006 analysis used climate and health data to project future heat-related mortality.[78]

## Access to Air Conditioning

Historically, air conditioning has been the most significant factor in reducing high heat-related morbidity and mortality, even more significant than access to electricity and health care.[79] Toward adaptation strategies, one study used data from 1999–2005 and predicted a 10 percent increase in air-conditioning ownership would reduce heat-related morbidity across demographics in California by 20 percent for respiratory diseases, 49 percent for cardiovascular diseases, 12 percent for dehydration, and 4 percent for heatstroke.[80] Another large-scale, statewide study in 2011 predicted a 20 percent increase in air-conditioner use would reduce projected annual premature fatalities by about 33 percent by 2050.[81]

A more targeted study in 2018 explored various regions of San Diego County to understand the relationship between access to air conditioning and health outcomes.[82] In general, coastal residents were more sensitive to heat-related health problems than inland residents. Along the coast, residents are less acclimated to heat and may not have air conditioning in their homes. In areas where fewer residents had access to air conditioning, heat-related hospitalizations increased by 14.6 percent on hot days compared with mild days. In similar areas with greater air-conditioning access, no detectable increase in hospitalizations occurred. Income, ethnicity, and homeownership were all associated with disparities in air-conditioning access.

Researchers also noted that ownership of an air-conditioning unit does not always translate to access, as financial constraints may prevent low-income groups from use.[83] As climate change projections identify steep increases in frequency, duration, and intensity of heat episodes, especially in coastal areas, access to air conditioning will continue to be a significant factor in preventing morbidity and mortality.[84]

# Air Quality Impacts

Climate change is expected to worsen air quality, both directly and indirectly. Weather patterns, such as temperatures, precipitation, wind, and humidity, are influenced by climate change and affect the underlying mechanisms of air quality. These weather changes also exacerbate naturally occurring emissions, such as smoke from wildfires and wind-blown dust. Poor air quality can have a range of adverse effects on human respiratory and cardiovascular systems. Other health impacts are at risk as well, such as allergies, since airborne allergen concentration and distribution are anticipated to grow under climate change scenarios.

## Ambient Air Pollution

Health issues associated with air pollution are well-documented, and climate change is projected to intensify conditions that for various reasons already pose public health challenges. Two of the most closely tracked air pollutants that impact health are ground-level ozone (a key component of smog) and fine airborne particulate matter with a diameter of less than 2.5 microns ($PM_{2.5}$). Concentration of ozone is affected by heat, the presence of precursor chemicals, and methane emissions. Ozone has been associated with diminished lung function, asthma, and premature death. Ozone exposure results in symptoms that limit normal daily activity (such as shortness of breath) and can cause school absences and hospitalizations. Particulate matter is primarily a product of wildfire smoke and air stagnation, among other conditions. Particulate matter exposure is linked to chronic bronchitis and other respiratory symptoms, loss of workdays, and premature death.

Warm temperatures exacerbate smog conditions, which increase communities' risks of developing respiratory and cardiovascular diseases, such as asthma and cardiovascular failure.

By amplifying the factors that lead to particulate matter and ground-level ozone, including longer ozone season and intensified episodes of high ozone concentration, climate change is projected to reduce air quality in some regions.[85,86] Areas of concentrated emissions, like around motor vehicle traffic and power plants, will be especially affected.

The relationship between higher temperatures and worsened air quality has been explored by researchers. One study in Los Angeles in 1994 found for every 1.8-degree Fahrenheit rise over 72 degrees, the incidence of smog increases by 5 percent.[87] Also, a meta-analysis in 2008 of cities in Southern California reported an increase of 18 degrees Fahrenheit compared with the same day in previous years was associated with an increase in cardiovascular mortality by 8.31 percent for areas with the highest level of ozone concentrations and 1.17 percent for areas with the lowest level of ozone concentrations across all communities.[88,89]

Los Angeles and the San Joaquin Valley already often rank among the areas with the worst air pollution in the nation, with the latter exceeding national air quality standards 80 to 135 days a year.[90] One study in 2004 analyzed the public health effects of San Joaquin Valley's air pollution.[91] Due to substandard air quality, the valley's residents are subject to the following every year (compared with models of air quality conditions that meet federal standards):

- 460 premature deaths among those at least 30 years old
- 325 new cases of chronic bronchitis
- 188,400 days of reduced activity in adults
- 260 hospital admissions
- 23,300 asthma attacks

- 188,000 days of school absence
- 3,230 cases of acute bronchitis in children
- 3,000 lost work days
- More than 17,000 days of respiratory symptoms in children

Bringing air quality in the San Joaquin Valley to current standards would equate to more than $3 billion saved, according to the study. The research reveals Hispanics and non-Hispanic blacks are more likely to be exposed to substandard air quality, and residents of Fresno and Kern counties are hardest hit, compared with the valley as a whole. Fresno County, in particular, accounts for about a third of San Joaquin Valley-wide health-related costs associated with poor air quality.

Outdoor workers, such as those in the San Joaquin Valley, are especially vulnerable to reduced air quality caused by activities such as "tilling of dry soil, agricultural burning, crop harvesting, and diesel-powered water pumping."[92] The main air pollutants that cause negative outcomes for outdoor workers include ground-level ozone, particulate matter, and diesel soot.[93,94]

Considering air quality statewide, the California Air Resources Board in 2005 reported the following adverse outcomes occurred annually due to concentrations of ozone and $PM_{2.5}$ that do not meet state standards:[95,96]

- 8,800 premature deaths
- 9,500 hospitalizations and emergency room visits
- 4.7 million school absences
- 2.8 million lost work days
- $2.2 billion for hospitalizations and medical treatment
- $69 billion lost from premature deaths[97]

## Asthma

Asthma is a common health challenge related to air quality. Currently, about 8.1 percent of adults (2.3 million) and 9.4 percent of children (851,000) in California live with asthma.[98] A 2009 study of children

As air quality challenges increase due to climate change, rates of asthma are expected to climb.

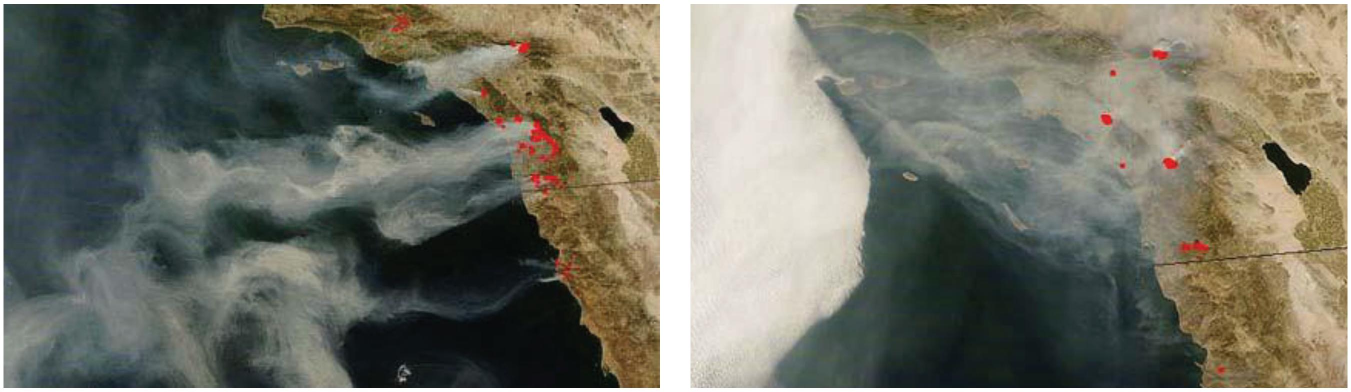
admitted to hospitals due to respiratory symptoms across six California counties (Fresno, Kern, Riverside, Sacramento, San Diego, and Santa Clara), demonstrated that health risks for pneumonia, acute bronchitis, and asthma were associated with components of $PM_{2.5}$, including elemental carbon, organic carbon, nitrates, and sulfates.[99] Children presented with the following excess risks: 4.1 percent excess risk of hospitalization from $PM_{2.5}$, 5.4 percent excess risk from elemental carbon, 3.4 percent excess risk from organic carbon, 3.3 percent excess risk from nitrates, and 3 percent excess risk from sulfates.

Another study from 2002 followed 265 new cases of childhood asthma (9–16 years old) over five years in 12 Southern California communities and linked higher risks with outdoor aerobic activities (3.3 percent greater risk) and time spent outside (1.4 percent greater risk).[100] A higher-than-average level of ozone was the primary factor contributing to asthma risk.

## Wildfire Smoke

With climate change there is greater risk of California experiencing large wildfires and communities being exposed to harmful wildfire smoke.[101-103] California has already seen the results of climate change on the frequency, size, and duration of wildfires, primarily due to more intense droughts and higher temperatures.[104] During and after a drought, especially under hotter conditions, vegetation is drier,

**Figure 8**
Concentration and Dispersion of Smoke Plumes



Smoke plumes are concentrated during wildfires in Southern California, left, and become more widespread after days of air movement, right. Reproduced with permission from the authors.[111]

and heat-induced winds can cause a fire to spread more rapidly.[105]

Large wildfires of more than 494 acres are expected to increase 21 percent by 2034, and to increase 84 percent between 2070 and 2099.[106] Some climate models predict a doubling of wildfire emissions in California by the end of the century.[107] More than 2.7 million Californians presently live in high-risk wildfire areas.[108] Besides injuries, deaths, and the temporary or permanent displacement of people that result from wildfires, the effects on public health primarily are linked to the inhalation of wildfire smoke, which is a significant source of $PM_{2.5}$, carbon dioxide, carbon monoxide, and other components.[109]

The characteristics of individual episodes of wildfire smoke exposure depend heavily on weather conditions and terrain. The intense heat of a wildfire lofts smoke high into the air, where it cools before descending back to the ground level. Initial fire plumes tend to be wind-driven events, but as the smoke moves downwind, it often becomes more widespread before reaching the ground. Figure 8 illustrates one example of wildfire smoke dispersion over Southern California wildfires.[110]

Studies have examined the public health problems associated with large wildfire events, often measured by ER visits, hospitalizations, and outpatient visits. An analysis of the entire 2015 wildfire season across northern and central parts of the state explored cardiovascular and cerebrovascular health impacts attributable to wildfire smoke.[112] More than 800,000 acres burned, and millions of people were exposed to dense concentrations of smoke. The areas that withstood the greatest burden of smoke days were also the most heavily populated: the North Coast, Sacramento Valley, and San Joaquin Valley. The study found ER visits increased across all adult age groups. Adults older than 65 were most affected, visiting the ER during periods of heaviest smoke conditions at rates 115 percent and 122 percent higher than non-smoke days for cardiovascular and cerebrovascular conditions, respectively. For this age group, the greatest changes in risk were observed for pulmonary embolism (171 percent), myocardial infarction (142 percent), ischemic heart disease (122 percent), and heart failure (122 percent). Adults ages 19 to 44 also were visiting the ER 190 percent more frequently for ischemic stroke in the days following the peak smoke days.

A study of the 2007 San Diego wildfires' effects on Medi-Cal healthcare utilization also revealed a number of health issues related to smoke exposure.[113] During the most intense days of the fire, ER visits for asthma increased by 112 percent and for general respiratory conditions by 34 percent relative to days without smoke exposure. For five days following the peak of the wildfire, outpatient visits for acute bronchitis remained 72 percent above the usual rate. Infants and young children were the most affected: emergency departments processed 243 percent more visits for infants up to a year old for asthma and 136 percent more visits for children from birth to 4 years of age. Such exposure to wildfire smoke during early childhood is concerning for the potential long-term harm to lung development.

The October 2003 wildfires in Southern California also have been studied by linking respiratory hospital admissions with air quality.[114] At peak smoke conditions, some sites averaged 240 micrograms per cubic meter ($\mu g/m^3$) $PM_{2.5}$ over 24 hours, 12 times higher than normal and 6.9 times the national standard for acceptable concentrations. The wildfires destroyed about 5,000 structures and generated smoke that potentially affected 20.5 million California residents. Heavy smoke conditions (with average increases of 70 $\mu g/m^3$ $PM_{2.5}$) led to a 34 percent increase in hospitalizations across all ages due to asthma, with the highest increases among children and the elderly. Risks were sustained during the two weeks after the fires, with increases of 56 percent for 5- to 19-year-olds and 36 percent for 20- to 64-year-olds. In heavy smoke conditions, acute bronchitis admissions increased on average by approximately 67 percent across all ages, chronic obstructive pulmonary disease admissions increased by approximately 48 percent for people ages 20–64, and pneumonia admissions increased by approximately 45 percent for ages 5–18. In total, the number of hospital admissions across all illnesses peaked while the wildfires were actively burning. Following the fires, admission rates still increased by 137 percent for acute bronchitis and 30 percent for pneumonia for 20- to 64-year-olds (48 percent increase and 27 percent to 46 percent across all ages, respectively). Following the fires, risks of congestive heart failure and combined cardiovascular admissions were 11.3 percent and 6.1 percent higher, respectively.

A second study of the same series of wildfires explored preventative measures and demonstrated benefits of remaining indoors, reducing physical activity, using air conditioning, and wearing air filtration masks when outdoors.[115]

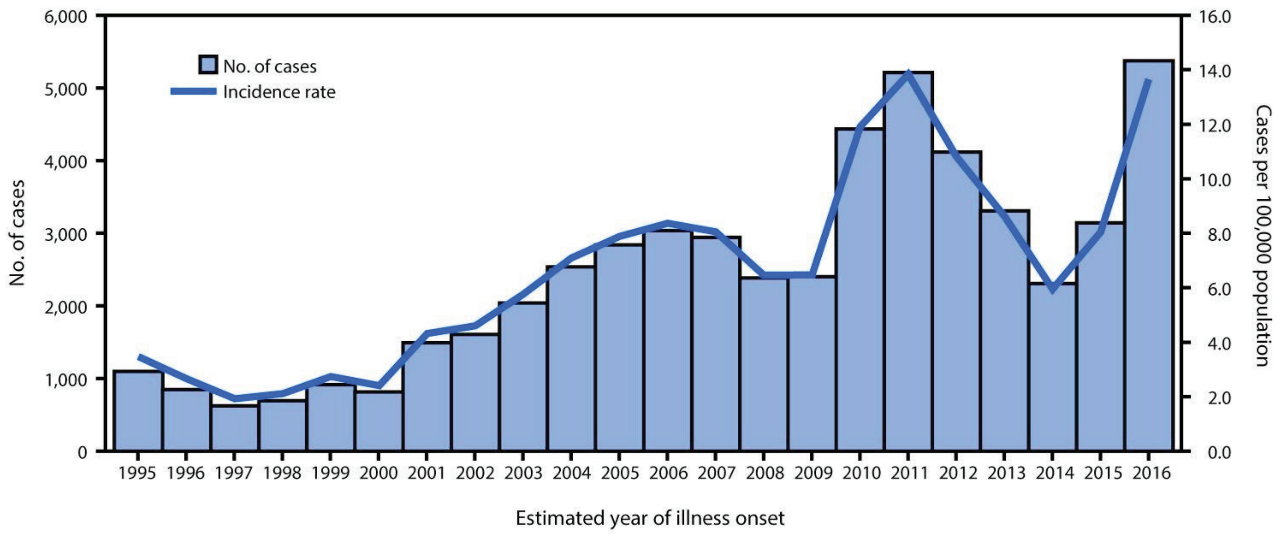
Tribal communities are one of the most vulnerable groups to the effects of climate change, wildfire risk included, since tribes do not have the same capacity to relocate following fire damage.[116] As a case study, some researchers quantified the public health effects of the 1999 wildfires on the residents of the Hoopa Valley National Indian Reservation in Humboldt County.[117] During the wildfires, respiratory-related clinical visits increased by 217 visits, a 52 percent increase over the previous year. Additionally, a survey revealed 62.6 percent of residents reported respiratory symptoms, especially those with preexisting cardiopulmonary conditions.

Urban areas also are increasingly at risk under climate change projections. A 1991 wildfire in Alameda County that followed years of drought conditions was associated with 25 fatalities and 241 fire-related hospital emergency room visits.[118] Of the hospital visits, smoke-related injuries were double those of burns or trauma. Most of the patients with smoke-related disorders (61 percent) presented with difficulty breathing from bronchospasms.

Limiting smoke exposure by encouraging evacuation helps stem negative health outcomes. Following a 2002 fire in Arizona, researchers found people who were not evacuated from the area affected by smoke reported significantly more respiratory symptoms than people who were evacuated. Prevalence of self-reported asthma exacerbation increased 86 percent among people living in the non-evacuated area, compared with 39 percent among evacuees.[119]

Climate change is contributing to increasing frequency, size, and duration of wildfires. In addition to injuries and displacement, smoke inhalation is a primary driver of negative public health effects.

**Figure 9**
Statewide Rates of Valley Fever, 1990–2016




Reproduced from the U.S. Centers for Disease Control and Prevention.[125]

## Valley Fever

Climate change also has implications for Valley fever. When soils dry due to high temperatures or drought conditions, fungal spores (*Coccidioides immitis*) are carried alongside dust through the air, causing coccidioidomycosis, or Valley fever. Symptoms include fever, chest pain, coughing, and blistering rash. In severe cases, the disease can result in meningitis (infection of the brain and spinal cord), ulcers, and painful lesions in the skull or spine. Research has shown that black and Filipino people are at greatest risk,[120,121] as are the elderly, pregnant women, and people who have diabetes or weakened immune systems, such as HIV/AIDS and organ transplant patients.[122,123]

In 2017, 5,121 cases of Valley fever were reported throughout California, 34 percent more cases than in 2016.[124] Figure 9 illustrates statewide trends in annual incidence rates.

The highest average annual incidence rates between 2009 and 2012 were in the counties of Kern (205.1 cases per 100,000 residents), Kings (191.7 per 100,000), Fresno (64.5 per 100,000), San Luis Obispo (47.2 per 100,000), Tulare (39.2 per 100,000), and Madera (20.7 per 100,000).[126] Between 2000 and 2011, prevalence of the disease increased fivefold in California, with 75 percent of cases concentrated in the San Joaquin Valley.[127] By the end of 2012, the drought of 2012–16 had caused a 67.7 percent increase in annual rates of Valley fever statewide, equating to approximately 1,672 additional cases per year, mostly in the San Joaquin Valley.[128]

Risk is greatest among outdoor workers. A study in 2015 analyzed rates of Valley fever among workers at solar power-generating facilities in San Luis Obispo County, where the work involved soil disruption. Forty-four cases were identified over three years (1.2 cases/100 workers), with nine hospitalizations (median of three days), 34 missing work (median of 22 days), and two disseminated cases in which the infection spread to other areas of the body.[129]

## Allergens

With climate change, heavy rainfall and storms will become more frequent and winter temperatures will become milder. As a result, airborne allergen concentrations are likely to grow and allergy seasons will extend, amplifying the potential for increased cases and severity of allergic illnesses and asthma complications.[130,131] Californians are exposed to plant-based allergens during three distinct seasons: tree pollen in the spring, grass pollen in the early summer, and weed pollen throughout the summer and fall.[132] Higher levels of carbon dioxide and warmer seasonal air temperatures both contribute to shifts in flowering time and pollen initiation, exacerbating the production of plant-based allergens and elongating the allergy season. One study in 2010 projected that pollen seasons in Southern California are likely to occur five to eight days earlier than historic averages by mid-century due to climate change, increasing residents' exposure to airborne allergens.[133] Around mid-century, it is possible that pollen production may decrease by up to 10 percent due to drier conditions.

Plant species already have moved into new areas due to climate change. In the Santa Rosa Mountains of Southern California, for example, changes in regional climate between 1977 and 2007 resulted in the expansion of plant distribution. The average elevation of dominant plant species was more than 200 feet higher.[134]

Furthermore, by 2000, the frost-free season in California had already increased by three weeks, compared with pre-1960. Researchers anticipate the frost-free season in California likely will increase by eight weeks by the end of the century if climate change mitigation is unsuccessful.[135]

Rates of Valley fever increase during periods of dry weather conditions, when fungal spores are carried into the air alongside dust during activities that disrupt the soil.

The most common allergic diseases linked to exposure to airborne allergens include asthma, hay fever, and eczema. In the United States, the rate of hay fever in 2000 was 30 percent of the population, up from 10 percent in 1970. A survey of U.S. cities most affected by allergies, including Riverside–San Bernardino, Sacramento, Los Angeles, San Diego, and San Francisco, indicated a 15 percent increase in allergies triggered by ragweed, the most common allergen, between 2005 and 2008.[136]

## Extreme Weather Events

The frequency and severity of extreme events are expected to increase in California and include storms, floods, droughts, and wildfires.[137] Table 8 shows some of the health impacts associated with extreme events that could worsen with climate change.

Associations between extreme weather events and injuries, death, and illness are well documented, such as an uptick in road collisions during inclement weather.[139] Other health measures also are affected around the time of an extreme weather event, including during disaster preparation or post-event cleanup. Property damage, destruction of assets, environmental degradation, and loss of health care and emergency response infrastructure and public services also are expected to worsen health outcomes for the most affected areas, as well as surrounding regions.

Extreme precipitation events are linked to higher levels of pathogens in drinking water resources due to storm runoff, as discussed later in the report.[140] A 2010 study in a major U.S. metropolitan area looked further into the health impacts associated with rainfall and concluded a significant relationship with gastrointestinal illness in children: up to four days after a rainfall event, ER visits increased by 11 percent for pediatric acute gastrointestinal illness.[141] The authors noted that municipal water systems may be overwhelmed during heavy precipitation events, despite meeting current water quality standards.[142]

Health effects may be indirect and occur several months after an extreme weather event. For example, Tulare County experienced an outbreak of

**Table 8**
Summary of Health Impacts of Extreme Events

| Event Type | Example Health Risks and Impacts (not exhaustive) |
|---|---|
| Severe Storms | • Traumatic injury and death<br>• Illness from reduced water quality<br>• Carbon monoxide poisoning related to power outages<br>• Hypothermia and frostbite<br>• Disruptions to food distribution<br>• Mental health impacts |
| Flooding Related to Extreme Precipitation | • Traumatic injury and death (drowning)<br>• Mental health impacts<br>• Preterm birth and low birth weight<br>• Infrastructure disruptions and post-event disease spread<br>• Carbon monoxide poisoning related to power outages |
| Droughts | • Reduced water quality and quantity<br>• Respiratory impacts related to reduced air quality<br>• Higher incidence of West Nile virus<br>• Mental health impacts |
| Wildfires | • Smoke inhalation<br>• Burns and other traumatic injury<br>• Asthma exacerbations<br>• Mental health impacts |

Adapted from the U.S. Global Climate Research Program.[138]

Valley fever in 1991 after an unusually heavy rainfall following several years of relative drought.[143] Compared with an annual average of 450 cases in the preceding years, 1,208 cases were reported. The outbreak continued through 1993, with 4,516 cases reported in 1992 and 4,137 in 1993.

Some populations are affected by climate change at greater rates than others. A growing body of research shows that social determinants of health contribute alongside biomedical factors.

This pattern of disease outbreak is due to the high fungal growth rate (of *Coccidioides immitis*) during the heavy rainfall, allowing more of the fungus to be present in the soil during dry conditions, when soil disruption releases the fungus into the air. Notably, the incidence rate differed by race, with residents of Asian ethnicity 3.8 times more likely to contract the disease (153 cases per 100,000 residents; primarily Filipinos and Laotians).

## Vulnerable Populations

A growing field of health equity research is amplifying the role of social determinants of health alongside traditional biomedical approaches, especially in response to the growing likelihood of extreme weather events.[144,145] The U.S. Centers for Disease Control and Prevention (CDC) define social determinants of health as external conditions that influence one's physical and mental well-being, such as factors that are socioeconomic, psychosocial, and behavioral in nature.[146] Inequitable quality of and access to resources often are rooted in systemic, societal, and economic drivers, fostering suboptimal living conditions that undermine well-being over time. Recognizing the impacts that physical environment, access to health services, and social and individual behaviors have on a person's health, in combination with biomedical and genetic predispositions, is critical to addressing the compounding effects of climate change on public health.

Reducing a community's vulnerability to climate change-related health impacts is possible by strengthening its resilience or its capacity to prepare for, recover from, and adapt after disruptions.[147] In the context of extreme weather events, resilience would manifest in a community's ability to evacuate, recover, or relocate when necessary.[148] Researchers have identified practical measures for building resilience among diverse communities, such as investing in climate-ready health facilities.[149]

Flooding risks in particular escalate the vulnerability of coastal populations, which make up nearly three-quarters of the state's population. Residents with disabilities and other disadvantaged communities are especially susceptible. Risk levels will invariably change as a result of local adaptation strategies, such as avoiding land development in flood-prone areas.[150]

Studies have demonstrated that disaster recovery is largely dependent on a population's access to health insurance, as previous events have shown uninsured people receive about half as much medical care, are less likely to receive preventive care, and have overall worse health outcomes.[151] As of 2017, 2.9 million Californians remain uninsured. More than half of them are Latino.[152]

## Vector-Borne Disease

Weather and long-term climate trends can influence human health by changing how communities are exposed to and contract infectious disease. Disease vectors are insects or animals that carry and transmit pathogens that cause sickness in people. The most common vectors are mosquitos, ticks, fleas, and rodents, all of which exhibit sensitivities to weather through distinct seasonal patterns and geographic distributions. For example, in areas with freezing

Vectors are insects or rodents that carry pathogens and can transmit disease to humans, such as ticks, mosquitos, and rodents. Climate change will likely result in the growth of vector populations across the state.

wintertime temperatures, insects and the microbes they carry often die in the winter, maintaining a check on population growth. Rainfall also may influence the transmission of disease by affecting survival rates, vector behavior, and pathogen virulence.

Insects, in particular, are cold-blooded and rely on their surrounding environment to control their internal organs. Accordingly, an increase in temperature potentially would favor insect growth and survival. As a result of climate change, vectors are expected to become more prevalent and more broadly distributed as temperatures and precipitation patterns shift toward warmer conditions with stronger storms.

Throughout California, seasonal risk and geographic expansions of diseases are expected, in addition to enhanced potency of existing disease pathogens and the emergence of new pathogens. The current research landscape includes the following diseases and their vectors in light of anticipated climate change: Lyme disease (transmitted by tick), West Nile virus (mosquito), dengue fever (mosquito), Rocky Mountain spotted fever (tick), plague (flea and rodent), tularemia (tick and deer fly), Chagas (triatomines, also known as "kissing bugs"), chikungunya (mosquito), and Rift Valley fever viruses (mosquito).

The CDPH drives a number of programs that monitor disease, in collaboration with the CDC. Such programs include collecting samples of mosquitos and birds, testing sentinel chicken, monitoring equine

Samples of vectors and human disease cases are regularly tested by local health departments in collaboration with the California Department of Public Health.

infections, and requiring health care providers to report human cases.

## Lyme Disease

Lyme disease is the most common vector-borne disease in the United States and has been tracked since 1982. The disease is caused by a bacterial infection (*Borrelia burgdorferi*) and, in California, is transmitted to humans by "blacklegged" ticks (*Ixodes pacificus*). In 2016, 141 cases of Lyme disease were reported across 33 counties, mostly in the north, with Santa Clara County presenting the greatest number (11).[153,154] For comparison, 75 cases total were reported in 2007 throughout the state. The 2016 incidence rate was 0.2 cases per 100,000 persons per year.

The disease has rapidly spread since the 1980s due in large part to changes in land-use patterns, including reforestation and residential development in wooded areas.[155] The research consensus identifies climate change as a primary cause of expansions of tick-borne diseases, especially Lyme disease.[156] Temperature rise projections are expected to lead to a doubling in the reproductive capacity of ticks in the United States by 2100.[157]

In Mendocino County, a 2010 study reported Lyme disease infection prevalence is highest in woodlands (especially hardwoods) and in warmer areas with more stable humidity. Of the dense woodlands in Mendocino County, 37 percent were found to pose an elevated risk of Lyme disease exposure.[158] Another study in Mendocino County in 2003 demonstrated that peak tick activity lasted 82 percent longer in warmer and drier habitats than in cooler and more humid habitats.[159] A San Francisco Bay Area multicounty study in 2015 reported a 3.7 percent total prevalence of infected ticks, ranging from 2.4 percent to 33.3 percent across sites, distributed widely throughout the area.[160] As of 2014, the statewide prevalence is 0.6 percent to 0.8 percent, depending on the species, with greater risk along the northern and central coasts, as well as the Sierra Nevada foothill region.[161,162]

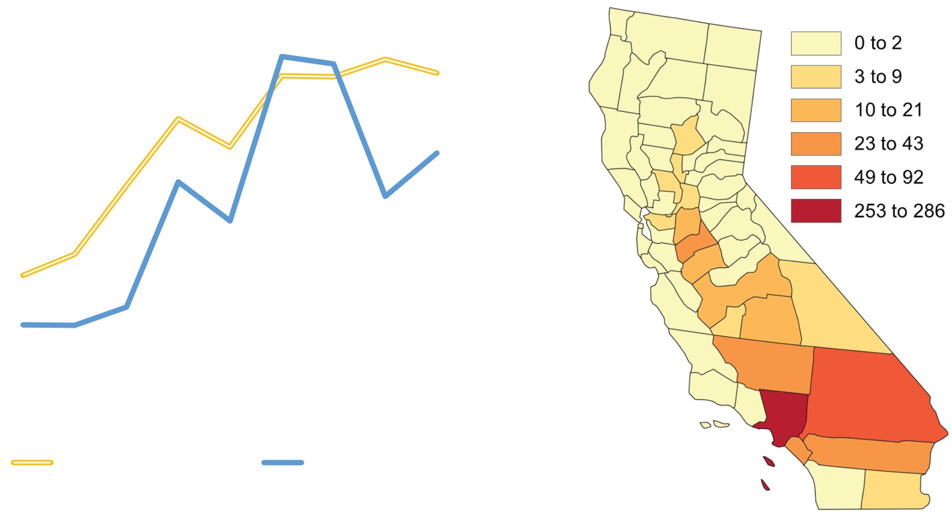
## West Nile Virus

West Nile virus (WNV) is transmitted by mosquitos and was first detected in the United States in 1999, reaching California by 2002.[163] Monitoring data between 2002 and 2004 exhibit the consistent pattern of WNV expansions into new areas during years with above-normal temperatures.[164] CDPH reported 6,565 cases total across at least 44 counties between 2003 and 2017, including 289 fatalities.[165,166] In 2017, 30 percent of the deaths due to WNV in the United States were in California.[167]

Research suggests the prevalence of WNV in California is affected both by temperature and levels of precipitation. County-level mosquito infectivity of birds has been correlated with temperatures 3.6 degrees to 9 degrees Fahrenheit above average.[168] In a study that assessed more than 16,000 human cases of WNV between 2001 and 2005 in 17 states, including California, higher ambient temperatures were associated with a 35 percent to 83 percent higher incidence of WNV infection.[169] Further, the presence of at least one day of heavy rainfall was associated with a 29 percent to 66 percent higher incidence.

Studies have illuminated how higher temperatures increase the amount of virus transmitted from mosquitos (viral load), accelerate mosquito reproductive activity, and shorten incubation periods while carried by mosquitos, which ultimately increases transmission rates of WNV.[170,171] This fits well with associations of drought and human incidences of WNV in the United States.[172,173]

**Figure 10**
Summary of West Nile Virus Monitoring, 2009–17




The left panel shows incidence rates of West Nile virus (WNV) over time. The right panel offers county-level specificity of all human cases of WNV reported in 2017.[182]

Research conducted in Kern, Los Angeles, Riverside, and Yolo counties in 2010 imply that climate change likely extends the mosquito season and boosts risk factors of WNV through the effects of warm winters.[174] Further study in 2013 extended that risk to all locations in California.[175]

Riverside, Los Angeles, Kern, and Yolo counties already exhibit higher mosquito populations (ranging from 83 percent to 671 percent of average) resulting from warmer winters.[176] A study of San Diego County predicts greater prevalence of WNV-transmitting mosquitos as the climate changes.[177] In 2008, San Diego County experienced its highest number of WNV cases with 35 diagnoses. In Kern County, an outbreak occurred during the unusually hot and dry year of 2007 with 140 human cases reported, representing a 205 percent to 280 percent increase since 2004.[178] The outbreak is attributed in part to a high number of abandoned swimming pools during the housing crisis.[179]

In addition to hotter temperatures, drought also is acknowledged as a significant climatic driver of WNV infections. During a drought, natural water resources are scarce, drawing mosquitos to man-made sources of water, like watered lawns and fountains. The closer proximity to people accordingly leads to higher infection rates.[180]

Studies show the drought of 2012–16 contributed to greater incidences of WNV in California, totaling 379 cases in 2013 alone and concentrated in the San Joaquin Valley. Compared with statewide infection levels of one case per 100,000 residents that year, the county of Stanislaus had 3.25, Kern had 2.90, Madera had 1.97, and San Joaquin had 1.14 cases.[181] Figure 10 displays the results of WNV monitoring from 2009 to 2017 (left panel) and numbers of human cases reported in 2017 per county (right panel).[182]

## Emergent Vector-Borne Disease

While many climate-sensitive, vector-borne diseases are not currently present in California, the risk of spread is increasing, as vector populations expand into areas previously inhospitable due to unfavorable temperatures and rainfall patterns. As weather trends change, disease vectors are expected to follow. Several dangerous diseases considered at high risk of expanding into the state are described next.

Plague is caused by a bacterial infection from the bite of an infected flea or by direct contact with an infected rodent. Between 1927 and 2015, 63 cases of human plague were reported in California. Earlier in the century, 426 cases were the result of outbreaks between 1900 and 1925.[183] Research has demonstrated that climate plays a role in the geographic spread of plague, which is expected to shift slightly northward.[184] Climate models suggest the risk of plague will decrease in Southern California and increase along the Northern/Central Coast and northern Sierra counties by 2050. Campgrounds in Yosemite are regularly closed due to the presence of plague-infected squirrels, with two human cases reported in 2015.[185]

Dengue fever, also known as "bone-breaking fever," may be transmitted by two species of mosquito present in some Central and Southern California counties. While there have been no locally acquired infections, approximately 150 California residents contract the disease annually while traveling.[186] Researchers predict local transmission in the southernmost United States is not far off—including in California—due to warmer winters, which expand the suitable area for mosquito vectors and extend the dengue transmission season.[187,188] Across the border in Mexico, where more than 18,000 human cases are currently reported annually, research warns dengue incidence may increase 40 percent by 2080 due to climate change.[189]

Monitoring and controlling the expansion of disease-carrying vector populations into new regions is a priority as climate change is likely to make many areas of the state more favorable to insect and rodent survival and growth. As minimum temperatures warm, for example, more insect larvae will survive the winter months, allowing for population expansion.

Tularemia is caused by a bacterial infection often spread by tick bites and exposure to infected rodents and occasionally by ingestion of contaminated water. Symptoms include skin ulcers, chest pain, and difficulty breathing. Studies show climate change will induce a northward spread of tularemia, possibly into California, due to rising temperatures and shifting precipitation patterns.[190]

Chagas is a rare disease in California transmitted by triatomines, also known as "kissing bugs," which are native to the state and found in desert regions, as well as the foothill areas in Southern California and surrounding the Central Valley. Almost all of the state's 70,000 to 100,000 cases occur in immigrants primarily from Mexico, Central America, and South America (1.24 percent of Los Angeles residents born in Latin America have tested positive).[191] The only known case of locally acquired Chagas disease occurred in Tuolumne County (Lake Don Pedro) in 1982.[192]

A 2010 study of Chagas monitored vector infection rates in Los Angeles County (Glendora) and San Diego County (Escondido) and found 36 percent and 19 percent of the kissing bugs were infected, respectively, comparable to historic accounts.[193,194] A similar study in 2016 found 55 percent of bugs in Calaveras County (Vallecito), 34 percent in San Diego County (Escondido), and 20 percent in Los Angeles County (numerous cities) were infected. Molecular analysis revealed that strains found in California likely are equally capable of causing human disease.[195] Researchers anticipate that rising temperatures due to climate change will expand the geographical region at risk of Chagas disease transmission by up to 23 percent across the United States by 2030.[196]

Malaria poses less risk to Californians considering there are approximately 1,700 cases per year in the United States. Still, vectors with the potential to carry and transmit such pathogens (like *Anopheles hermsi* and *Anopheles freeborni* mosquitos) exist in California.[197] Historically, between 1950 and 1990, 14 outbreaks of malaria (caused by *Plasmodium vivax*) were detected in California.[198] The nation's largest outbreak since 1952 occurred in San Diego County in 1988, with 30 cases reported.[199] Another San Diego-based outbreak, in 1986, amounted to 28 cases.[200] Studies elsewhere in the world have

Studies demonstrate how climate change is likely to reduce water quality in ways that will affect human health through water-related contaminants and water-borne pathogens.

linked climate change with expansion of malaria distribution.[201]

St. Louis encephalitis (SLE) is a mosquito-transmitted viral disease associated with unseasonably warm multiday periods with temperatures above 85 degrees Fahrenheit.[202] SLE also is affected by precipitation patterns, particularly by increased snowpack and river runoff.[203] California experienced an outbreak of SLE in 1984. Studies suggest a 5.4-degree to 9-degree Fahrenheit increase in average temperature in California (possible under current emissions scenarios) may cause a northern shift in the distribution of both SLE viruses and western equine encephalitis (WEE).[204,205] Following a flood of the Kern River in 1952, 100 cases of WEE and 89 cases of SLE occurred in Kern County.[206]

## Water Quality and Access

With climate change, higher temperatures, rising sea levels, and the increased frequency and duration of drought conditions in California mean reduced snowpack, greater evaporation of surface waters, and seawater intrusion (the movement of ocean water into fresh groundwater supplies). As a result, access to clean water for essential purposes, such as drinking, cooking, sanitation, and irrigation, is expected to be reduced.

There also are important implications for water quality. Extreme storms with heavy precipitation can result in storm runoff from agricultural and urban areas, causing water-related contaminants (chemicals used in agricultural practices) and water-borne pathogens (bacteria and viruses derived from human and animal waste) to spread into surface waters, ground water, and coastal waters.

Water-borne pathogens currently cause 8.5 percent to 12 percent of acute gastrointestinal illness cases nationwide, affecting 12 million to 19 million people annually.[207] Historically, about 68 percent of outbreaks have been preceded by extreme precipitation events.[208,209] Almost all of the most prevalent pathogens are affected by climate, including *Giardia, E. coli* O157:H7*, Salmonella enterica, Vibrio cholerae, Cryptosporidium, Campylobacter jejuni*, norovirus, rotavirus, and adenovirus.[210] Higher water temperatures due to climate change are expected to promote the growth of water-borne pathogens as well as toxic algal blooms that can occur in coastal waters.

The potential for public exposure to water-related contaminants and pathogens is through drinking water, recreation, and seafood. Communities along the coast and those dependent on small water systems and private wells will face challenges in particular. These water quality issues are discussed further below.

### Agricultural Runoff

Agricultural runoff is likely to include animal waste, fertilizers, pesticides, and soil particles. Animal waste, in particular, can be a rich source of pathogens, such as bacteria. For example, research in Marin County's Tomales Bay watershed, popular for its oyster industry, found *Giardia* in 16 percent of storm runoffs from regional dairy farms following precipitation.[211] Of the runoff samples collected from farms with cattle younger than 2 months old, 41 percent were positive for *Giardia*.

Runoff from agricultural lands results in more than the spread of illness-associated chemicals and animal waste; common components of commercial fertilizers, including nitrogen and phosphorus, serve as nutrients that promote rapid and excessive growth of naturally occurring pathogens and algae. This cycle is known as "nutrient loading."

During storms, runoff from farms, city streets, and residential neighborhoods often carries with it fertilizer chemicals, oils, pathogens, and other contaminants. As storms become increasingly strong as the climate changes, greater health challenges are expected as a result of more storm runoff.

Soil washed from agricultural lands also is damaging to lakes and streams, as sediment can cloud the water and reduce the penetration of sunlight that aquatic plants rely on. Large amounts of sediment also can clog the gills of fish or smother fish larvae. Other pollutants, including fertilizers, pesticides, and heavy metals, have been known to cause algal blooms, which deplete water sources of oxygen, ultimately killing fish.

Extreme precipitation events also may threaten local infrastructure responsible for processing drinking water, wastewater, and storm water. For example, in 2000, a heavy rain over Ontario, Canada, led to excessive agricultural runoff that contaminated a town well and resulted in 2,300 illnesses and seven deaths related to *E. coli* O157:H7 and *Campylobacter.*[212] This is notable here since well systems in Canada and California are largely similar.

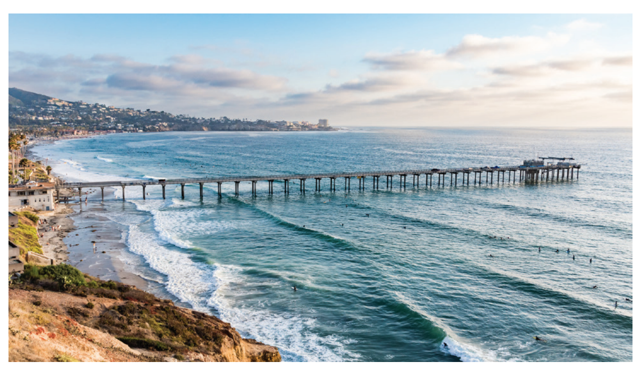
As agricultural practices adapt to a changing climate, many studies predict that increased pesticide use and more and new forms of pathogens and vectors, such as mycotoxins, will further heighten the risks of contamination from extreme precipitation events.

## Urban Runoff

Urbanization increases the variety and amount of pollutants carried into streams, rivers, lakes, and beaches. Pollutants include oil and toxic chemicals from motor vehicles, pesticides from lawns and gardens, and harmful viruses and bacteria from pet waste and failing septic systems. Such pollutants can harm fish and wildlife populations, kill native vegetation, affect drinking water supplies, and render recreational areas unsafe.[213] The effects of urban development on water quality are exacerbated by extreme precipitation events that cause runoff of pollutants into fresh and marine waters.

One study in 2011 looked at the bacteria concentrations of 78 beaches in Southern California. Water contamination correlated with the amount of development: heavily developed watersheds registered bacteria concentrations approximately 18 times higher than in undeveloped watersheds.[214]

Another study in 2004 demonstrated that Californians who engage in coastal water recreation in developed areas, such as in North Orange County, are generally more likely to report symptoms of water-borne illness (such as vomiting, diarrhea, and sore throat) than in undeveloped areas, such as in Santa Cruz County. The effect is more extreme during seasons with above-average rainfall.[215] During the high-precipitation 1998 El Niño winter months, surfers near cities were almost twice as likely to be ill as surfers in undeveloped coastal areas. In comparison, during the low-precipitation El Niña winter of 1999, surfers near cities were only slightly more symptomatic (approximately 17 percent) than surfers in undeveloped coastal areas. Across both areas, longer water exposure times correlated to more severe symptoms: for every 2.5 additional hours in the water, surfers experienced a 10 percent greater likelihood of becoming ill.



Following rain events, coastal waters are more likely to present higher concentrations of contaminants and pathogens, especially in developed areas.

Several studies have identified effects of water pollution in Southern California on actual diagnoses and medical costs. Researchers estimate 36,778 gastrointestinal illnesses occur annually due to recreational exposure to polluted water at Newport and Huntington beaches in Orange County, in addition to 38,000 other illnesses, including respiratory, eye, and ear infections.[216] For the two beaches, the approximate cost of excess illnesses due to water pollution amounts to $3.3 million per year in direct healthcare costs.

A larger study assessed dozens of beaches across Los Angeles and Orange counties in 2006 and estimated that between 600,000 and 1,500,000 excess gastrointestinal illnesses each year are caused by swimming in contaminated coastal waters.[217] The total annual associated medical cost across the two counties is estimated between $21 million and $51 million.

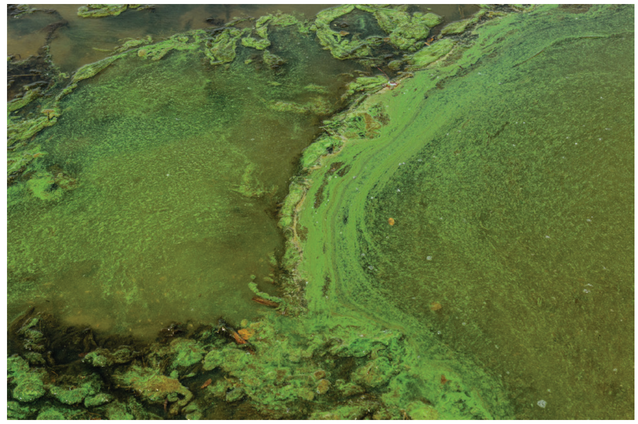
## Harmful Algal Blooms

Harmful algal blooms (HABs) produce toxins such as microcystins and cylindrospermopsin and may occur in marine and fresh waters (Figure 11). Many factors can contribute to an HAB. For one, warmer waters resulting from climate change are expected to shift geographic range and seasonal windows of many algal species. Extreme precipitation events also are known to increase nutrient loading in storm runoff, which increases the likelihood of HABs.[218]

Researchers have noted signs that California's risk of HABs is likely to increase as the climate changes.[219] Since approximately 29 million Californians rely on rivers, lakes, reservoirs, and other surface water sources for drinking water, increasingly frequent HABs in freshwater systems due to climate change are of deep concern.[220,221]

A study of two lakes in Siskiyou County in 2007 demonstrated that an HAB produced microcystin toxins detectable in the nasal passages of recreational lake users.[222] As demonstrated in other studies, recreational activities that disrupt the water surface are known to generate toxin-containing aerosols, potentially infecting people through air transmission. Nasal swabs of study participants exhibited microcystin deposition, but the number of participants in the study precluded any conclusion regarding whether those in contact became ill with acute dermal or respiratory symptoms due to the exposure.

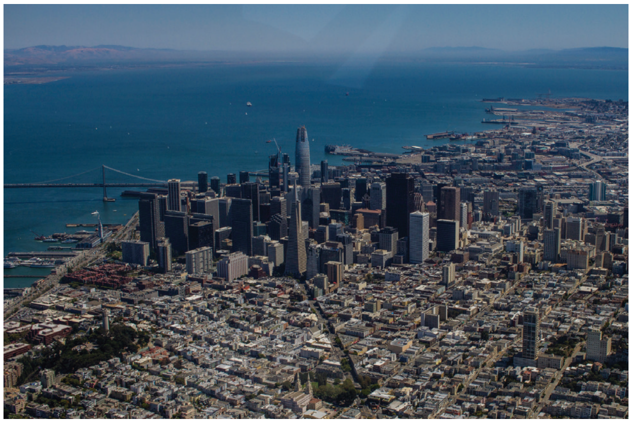
**Figure 11**
Harmful Algal Blooms Affect Freshwater and Marine Water Sources



Increasing water temperatures are projected to foster more and larger algal blooms, which can produce toxins that cause illness in people.

In 2014, researchers assessed the effects of a freshwater HAB in Lake Erie on a metropolitan area of Ohio. Approximately 500,000 residents lost access to their drinking water once toxins from an algal bloom were detected.[223] Other HABs in the United States have resulted in illnesses and hospitalizations, including dermatologic, gastrointestinal, respiratory, and neurological diagnoses.[224] Children and people with preexisting respiratory conditions, such as asthma, tend to have higher risks of negative health outcomes after HAB exposure.[225]

There are no U.S. regulations defining acceptable levels of cyanobacterial toxins in drinking or recreational waters. Drinking water treatment systems can be adjusted to specifically remove cyanobacteria and toxins, but cost is frequently noted as a limiting factor. In California, HABs may be voluntarily reported to the State Water Resources Control Board's (SWRCB) Surface Water Ambient Monitoring Program.[226] In 2017, 21 freshwater blooms were reported.



Many coastal cities are at higher risk of water contamination from larger storms and sea level rise in part due to vulnerable low-lying water treatment facilities.

## Emergent Water-Borne Disease

Warming sea surface temperatures enhance the expansion of existing disease agents, as well as the emergence of new bacterial and viral pathogens. Bacteria and viruses are part of a normal water ecosystem; studies have shown that a drop of seawater, under typical conditions, contains 10 million viruses and 1 million bacteria (per milliliter).[227] Warmer temperatures, like those predicted with climate change, tend to boost bacterial and viral growth and survival, resulting in greater prevalence of water-borne pathogens where they already exist.[228]

Pathogenic species, such as *Vibrio cholerae* bacteria, which are present in more tropical regions of the planet, are projected to expand northward into the coastal waters of Southern and Northern California by the end of the century.[229] Cholera is a severe diarrheal disease transmitted by contaminated drinking water or seafood and has not posed a domestic threat since the 1880s due to advancements in water treatment infrastructure. Global prevalence has been steadily increasing since 2005.[230]

## Water Treatment in Coastal Communities

Coastal communities, in particular, are at greater risk of groundwater contamination, flooding, water-borne disease, and sewage overflows due to changing oceanic patterns, sea level rise, and increasing sea surface temperature.

More frequent and severe precipitation events are expected to place additional stresses on water treatment facilities and distribution systems to treat sewage and provide clean drinking water to municipalities.[231] Whether by exceeding system capacity or pipe breaches, numerous research teams warn of the increasing risks posed by climate change on the state's drinking water infrastructure.

Sea level rise will exacerbate marine flooding of coastal areas, which historically have built wastewater treatment plants at low elevations. One study in 2018 identified 36 wastewater treatment plants in California that are increasingly vulnerable to marine and groundwater flooding across various climate change scenarios.[232] Of those, 30 plants are in the San Francisco Bay Area. Under the climate scenario in which GHG emissions are not reduced from current levels, parts of the state can expect up to 20 inches of sea level rise, which would impact approximately 13 water treatment plants serving 2.6 million Californians.[233] A more modest scenario in which sea levels rise 12 inches would affect eight plants serving more than 1 million Californians.

## Private Wells

Communities with private or small water systems are particularly susceptible to contamination following heavy rainfall.[234,235] As of 2015, about 2 million Californians depend on private domestic wells or water systems serving 15 or fewer connections, which are not regulated by SWRCB's Division of Drinking Water.[236] Most drinking water outbreaks in the United States have been associated with inadequately treated groundwater.[237,238] Even short-term loss of access to potable water after floods and storms has been linked to increases in illnesses, such as gastroenteritis and respiratory tract and skin infections.[239] This is particularly important considering predictions that surface and groundwater supplies in the western United States will continue to diminish, exacerbating issues of access and quality.[240]

Table 9
Rates of County-Level Cases of Select Foodborne Diseases Per 100,000 Jurisdiction Population in 2013

| County | Campylobacteriosis Cases Per 100,000 Residents | Salmonellosis Cases Per 100,000 Residents |
|---|---|---|
| Statewide Average | 20.1 | 13.1 |
| Colusa | 41.0 | 18.2 |
| Fresno | 43.7 | 20.5 |
| Glenn | 34.9 | 20.9 |
| Imperial | 27.7 | 23.3 |
| Kern | 39.6 | 7.8 |
| Lake | 6.2 | 21.6 |
| Madera | 33.5 | 15.1 |
| Mendocino | 36.3 | 14.8 |
| Modoc | 10.4 | 20.8 |
| San Benito | 8.8 | 21.1 |
| San Francisco | 46.7 | 21.3 |
| San Joaquin | 26.5 | 15.2 |
| San Mateo | 27.5 | 22.3 |
| Sierra | 0 | 31.4 |
| Siskiyou | 20.2 | 26.9 |
| Sutter | 24.9 | 21.8 |
| Tulare | 42.3 | 12.5 |
| Yuba | 28.2 | 33.6 |

## Foodborne Disease

As the climate changes, Californians likely will be exposed to more pathogens and toxins via food consumption. Climate factors such as temperature, precipitation, and extreme weather events (particularly flooding and drought) are expected to be the primary drivers. Foodborne diseases often originate from contamination of agricultural products by flooding and storm runoff, as well as toxins from HABs.[241] Warmer temperatures also have the capacity to increase the number of existing pathogens on produce and seafood.[242] Future rates of illness are difficult to quantify, depending on how well food safety systems adapt and are maintained as changing climate conditions strain current practices.[243]

Higher ambient temperatures associated with climate change foster faster growth of numerous foodborne pathogens, including *Salmonella, Campylobacter,* and *E. coli*, by shortening their replication cycles. Such bacteria can be transmitted to people via raw or undercooked food or exposure to contaminated water or milk.

### Drought

In the absence of natural rainfall, droughts increase demand for water. Reduced water supplies for irrigation, food processing, and livestock management have been associated with poor water quality and historical infectious outbreaks.[244,245] In addition, when precipitation events are preceded by dry conditions, overland storm runoff may be exacerbated, spreading contaminants more widely.

In California, several counties experienced a significant increase in cases of campylobacteriosis (diarrheal illness) and salmonellosis linked to the 2013 drought.[246] In 2013, 7,696 cases of campylobacteriosis were detected in 55 of 58 counties statewide, compared with 6,759 cases two years earlier.[247] Compared with the statewide campylobacteriosis incidence rate in 2013, many counties experienced rates that were much higher, including several in the San Joaquin Valley. Table 9 presents details for select counties. The most impacted demographics were children from birth to age 4 and Latinos.[248] The same trend follows for salmonellosis. In 2013, 5,040 cases were detected in 52 counties, up from 4,027 cases two years earlier, with some county-level rates far exceeding the statewide average.[249]

## Pest Control

Climate change is expected to impact the biology of plant and livestock pests, such as weeds, insects, and rodents, in ways likely to exacerbate current challenges in many areas of the state. California farmers already invest heavily in the management of disease-carrying and nuisance pests. One study in 2013 examined pest populations on agricultural farms in Monterey and San Benito counties, including produce farms, cow–calf operations, and a beef cattle feedlot. Researchers found that wild rodents, which shed feces near or on agricultural commodities, were carriers of *Cryptosporidium* (26.0 percent), *Giardia* (24.2 percent), *Salmonella* (2.9 percent), and *E. coli* (0.2 percent).[250]

Scientists have shown that rising average winter temperatures and longer growing seasons will foster larger and more widespread pest populations.[251,252] Higher levels of carbon dioxide concentrations, too, have been associated with more persistent insect infestations and crop vulnerabilities.[253,254] As a result, agricultural farmers will need to apply greater volumes and more potent varieties of pesticides to maintain current standards of productivity.[255] Increased use of pesticides likely will raise the incidence rate of foodborne illness due to contamination in the fields and in agricultural runoff, especially under conditions of progressively frequent extreme storms.

## Food Processing

Hotter temperatures set the stage for higher risks of bacterial growth on crops during harvest, transport, handling, and storage as the climate changes.[256,257] Researchers also anticipate the spread of pathogens into new geographic locations.[258]

Researchers also have suggested that while the "farm-to-fork" movement has the potential to cut down on transportation of food across long

As air temperatures warm due to climate change, bacterial growth on crops during food processing and distribution is likely to accelerate, heightening risks of foodborne illness.

distances, tighter public health measures likely will be necessary to curb bacterial proliferation due to higher temperatures during harvest and handling.[259,260]

## Contaminated Seafood

Disease also may result from contaminated fish and seafood from fresh and marine waters that support higher bacterial growth and HABs due to changing climate conditions.

In 2015, an HAB (*Pseudo-nitzschia*) affected the entire West Coast, from California's Channel Islands to Alaska, resulting in unusually prolonged health advisories and closures of fishing and shellfish industries to prevent exposure to the highest concentrations of domoic acid, a dangerous neurotoxin, ever reported in the region. In Monterey Bay, concentrations were 10 to 30 times more extreme than a typical HAB.[261] This form of HAB was first detected in Central California in the 1990s and has recurred annually in Southern California since 2003.[262] The first recorded outbreak of domoic acid occurred off the coast of Prince Edward Island in Canada in 1987, resulting in three deaths and more than 100 illnesses.[263]

CDPH has been monitoring aqueous biotoxins since 1927 in response to a paralytic shellfish poisoning event that caused several deaths and more than 100 illnesses due to consumption of contaminated mussels.[264] The state has recorded more than 520 cases of paralytic shellfish poisoning over

90 years, including 32 deaths.[265] Cases continue to arise, such as an illness contracted in March 2018 in Marin County, when poison levels reached 37 times the alert level.[266]

## Food Security

Food security occurs "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life."[267] Food security at global, regional, and local levels is expected to decrease as the climate changes due to reduced quality of and access to food.[268]

### Nutritional Value

As temperatures rise and extreme weather events occur more frequently, greater rates of agricultural contamination, spoilage, and disruptions in food distribution are expected. In addition to considering agricultural productivity, food quality also is essential for basic health. Heightened levels of carbon dioxide have been shown to reduce the nutritional value of many staple crops, including wheat, rice, and potatoes.[269] When more carbon dioxide is available to plants for basic photosynthesis, protein content decreases. Researchers have quantified that a 200 percent increase in atmospheric carbon dioxide levels results in approximately 15 percent and 14 percent less protein in barley and potato, respectively.[270] The impacts from higher carbon dioxide on essential minerals content also range from 5 percent to 10 percent lower in most plants under likely future climate scenarios.[271]

While malnutrition is not a primary concern in the United States compared with developing countries, challenges persist among vulnerable groups, such as disadvantaged communities and elderly people. At present, approximately 38 percent and 45 percent of the U.S. population fail to consume sufficient calcium and magnesium, respectively, which can have long-term health impacts. Since climate scenarios range in projections of carbon dioxide levels from 137 percent to 225 percent above current levels by 2100, issues around malnutrition for essential vitamins and minerals likely will grow.[272]

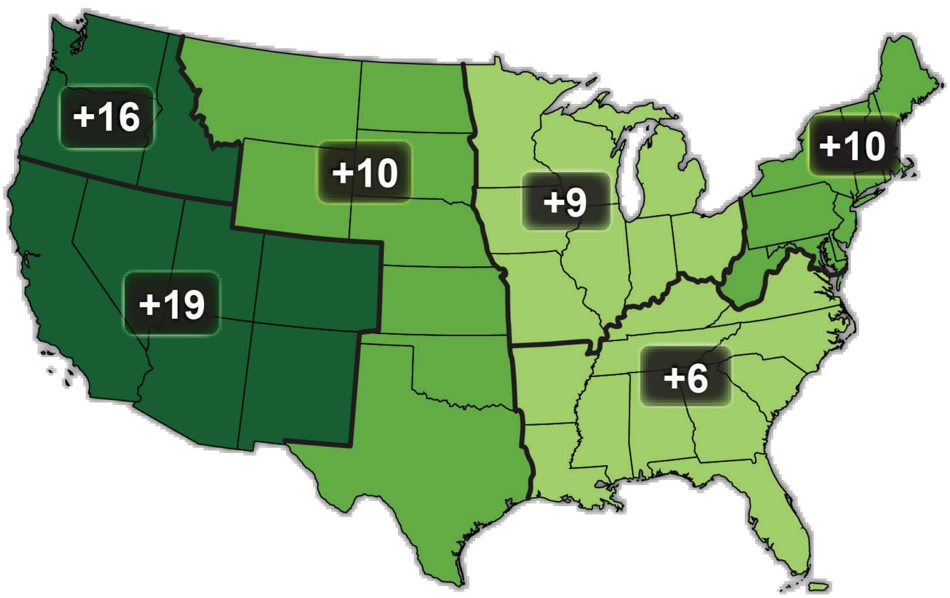
Higher carbon dioxide in the atmosphere results in lower nutritional value of some crops, including wheat, rice, and potatoes.

### Access to Food

Resilient and reliable food distribution systems are essential for healthy communities. Modern infrastructures have developed as a global network, as agricultural products often are transported long distances by road, rail, and waterways. With the looming increase in extreme weather events, access to a safe and nutritious food supply depends on policies that consider the pressures that climate change-related disruptions will exert on transportation infrastructure, storage capacity, and trade management.[273]

Longer and warmer droughts also will impact food security. California's Fourth Climate Change Assessment in 2018 included supporting research that links the 2012–16 drought with food insecurity in the San Joaquin Valley, among other socioeconomic effects, including employment, water security, and health.[274] The results were derived from surveys of rural community residents, ultimately pointing to increasing vulnerabilities related to climate change. The study identified employment as a major driver of food insecurity, but other factors were involved as well; due to weakened vegetable and fruit production, farms offered fewer donations to supply regional food banks. Home gardens also were hindered by water rationing and dried wells, preventing families from producing their own food.

**Figure 12**
Observed Increase in Frost-Free Season Length (in Days), 1958–2012




The frost-free season has grown particularly in the West.[278] Climate change is expected to further increase the frost-free season, which affects the productivity of many crops.

## Food Production

Climate change-related warmer temperatures, drier conditions, sea level rise, and the effects of extreme storms are all predicted to negatively affect food production overall. Although some areas may experience benefits, such as regions at higher elevations due to increased opportunity for agriculture, the overwhelming proportion of effects will be detrimental. The projected environmental changes would result in longer annual frost-free seasons and shorter winter chill periods, which are major determinants of the types of crops that can grow in a given area.[275] Figure 12 illustrates the change in frost-free season duration that has already occurred due to climate change across the United States.[276] Seawater intrusion is another issue posed by climate change scenarios that is likely to strongly affect agricultural water supplies along the California coast.[277]

California produces about 95 percent of many of the nation's nuts and fruits, but climate change likely will disrupt yields and shift traditional areas of production northward, displacing existing agricultural lands and affecting farming communities.[279]

Historic agricultural yields illustrate variable climate sensitivities of different crops helpful for projecting future changes. One study in 2006 modeled the impact on California crops using county-level data obtained from the California County Agricultural Commissioners.[280] Using multiple climate models and statistical crop models, it found that a 3.6-degree Fahrenheit increase would prevent any of California's 18 counties that grow walnuts from producing at equivalent levels.[281] In 2016, the value of the walnut industry in California was $1.34 billion and supported approximately 60,000 jobs.[282,283]

Similarly, counties that grow almonds, table grapes, and avocados also would see significant decreases in yield and necessary shifts in production to other areas of the state to align with more favorable weather patterns. Modeling studies predict that if temperatures warm by 7.2 degrees Fahrenheit, counties that grow walnuts, almonds, table grapes, oranges, and avocados (worth $7.3 billion in 2016, combined)[284] would see less than 5 percent of their current area capable of supporting production by 2050.[285]

The Salinas and San Joaquin valleys have been identified as regions that are most vulnerable to negative agricultural effects from climate change, including seawater intrusion and temperature increases. Meanwhile, agriculture in the Imperial Valley and between Fresno and Merced is categorized as "very vulnerable" to the effects of climate change.[286]

Across the state, crop yields of strawberries, walnuts, peaches, almonds, and cherries are expected to decline due to warmer temperatures.[287] Heat waves are likely to reduce the yields of maize, rice, sunflower, and tomato by 1 percent to 10 percent.[288] Finally, an increase of 7.2 degrees Fahrenheit likely would reduce most fruit yields from 5 percent to 40 percent.[289]

## Mental Health and Well-Being

During and following weather-related disasters, communities are vulnerable to heightened cases of clinical post-traumatic stress disorder (PTSD), depression, and general anxiety. Heat, too, has been documented as posing a significant threat to individuals with preexisting mental health diagnoses. As the frequency of extreme weather events increases alongside episodes of elevated temperatures, cases of acute and chronic psychological distress will be more common.

Some populations are more vulnerable to adverse mental health outcomes, including children, the elderly, economically disadvantaged, communities more reliant on the natural environment for sustenance and livelihood (including tribal communities and those in agricultural or fishing industries), and people with preexisting mental illness.

Beyond local extreme events, mental health also is expected to be influenced by the perceived threat of climate change, such as through frequent media coverage of potential health and social impacts. Simple exposure to information that presents

Following extreme weather events, such as flooding or wildfire, mental health diagnoses increase and can last several years.

impending effects of climate change has been reported to affect perceptions of well-being and security of a community's future.[290]

### Extreme Events

Studies of historic events have found that extreme weather events, such as floods, heat waves, and wildfires, exacerbate rates of mental illness. Mental health effects of weather-related trauma include increased substance abuse, suicidal thoughts, depression, PTSD, grief and bereavement, and even aggression.[291-293] After hurricanes Katrina and Rita, the rates of suicides and attempted suicides among women living in temporary housing were recorded at levels 78.6 times and 14.7 times the regional average, respectively.[294] Even years after a natural disaster, suicidal thoughts and plans can be up to 2.5 times higher for the affected population.[295]

Although research on individual resilience suggests most people who are psychologically affected by a traumatic event will recover over time, up to 20 percent of individuals who directly experience a disaster are likely to develop chronic levels of psychological distress.[296]

### Heat

A comprehensive study in 2018 on temperature– and mental health-related outcomes in California identified several links.[297] Upon analyzing data from 2005 to 2013 across 16 regions in the state, higher

Some groups are disproportionately affected by the trauma of extreme weather events, including children, the elderly, and disadvantaged communities.

temperatures were associated with increased ER visits for mental health disorders, self-injury, and intentional injury/homicide. During warmer months (May–October), emergency clinics across the state experienced 4.8 percent more visits for mental health disorders, 5.8 percent more visits for self-injuries, and 7.9 percent more visits for intentional injuries/homicides per 10-degree Fahrenheit increase above regional average. Similar associations persisted even during the cool season (November–April). At greatest risk of temperature-related ER visits for mental health were Hispanics, whites, 6- to 18-year-olds, and females.

## Vulnerable Populations

Children exhibit long-term emotional and behavioral responses following extreme weather events, including social withdrawal, depression, and aggressiveness. In fact, children are more likely than adults to exhibit PTSD symptoms more than two years after a disaster.[298,299] Studies suggest that, depending on a child's age and level of exposure, chronic stress may alter the natural development of a healthy biological stress response system, placing an individual at greater risk for acquiring mental health disorders later in life.[300]

In general, the elderly population tends to be challenged by physical ailments and untreated depression at higher rates than the average American adult and therefore is at greater risk of climate change-related mental health problems.[301] Among the elderly, specifically, chronic exposure to air pollution is associated with reduced cognitive function and greater cognitive decline.[302,303]

Veterans comprise another group that tends to be more vulnerable to extreme events. One study showed veterans with preexisting mental illness were 6.8 times more likely to develop additional mental illness after a natural disaster than veterans without mental illness.[304]

As a group, first responders also are prone to mental health illness as a result of their exposure to disaster. Following a traumatic event, firefighters, emergency providers, and public health and public safety workers have been shown to be at increased risk for short- and long-term mental health effects, such as substance abuse. One study demonstrated that 77 percent of firefighters presenting with PTSD developed additional mental health issues, such as depression, panic disorder, or phobic disorders.[305] Overall, research indicates that 13 percent to 18 percent of first responders demonstrate PTSD up to four years after a traumatic event.[306]

# Looking Ahead

For decades, scientific evidence has unequivocally shown that climate change is a reality and the observed atmospheric changes are irreversible, at least in the foreseeable future. While state, national, and international climate assessments confirm that opportunities to entirely prevent the effects of climate change have already passed, there is still a role for strong leadership in the public and private sectors to reduce the levels of projected damage and hardship; efforts to mitigate climate change must be paralleled by adaptation strategies. By building communities that are resilient to a changing environment, the most extreme effects of climate change may be minimized.

Studies of historic climate variations and health outcomes clearly demonstrate the connections between climate and health. Though the factors that contribute to public health are complex, such as an individual's preexisting health condition or a community's level of socioeconomic vulnerability, modern epidemiological research methods have allowed scientists to isolate critical variables and their interactions for a given environmental scenario, such as age and the extent of heat exposure. Such rigorous scientific investigation helps society to understand and prepare for the most prominent risks of future adverse health outcomes.

## Adaptation and Resiliency

Awareness of climate change-related health impacts, enhanced surveillance and monitoring of climate risks, reinforced public health infrastructure, expanded research, and resilient communities would help to effectuate lasting adaptation efforts.

Fortunately, many climate mitigation strategies also present health co-benefits.[307] That is, efforts that would limit GHG emissions could also likely improve public health and reduce health inequities. For example, modernizing transportation infrastructure to limit vehicle miles traveled would promote walking, biking, and use of public transit around urban landscapes. Not only would emissions drop, residents would be exposed to less air pollution, and healthy physical activity would be encouraged. Also, the development of more green space and trees

would reduce the urban heat island effect, as well as cut down on ground-level air pollution.

Greater involvement of public health experts with traditionally non-health sectors, such as transportation, urban planning, and agriculture, around climate change mitigation strategies would invariably improve health outcomes.

## Health Equity

The health impacts of climate change may be either exacerbated or improved by the decisions that guide each community, both at a local and regional scale. Scientific insight into climate-related health outcomes has emphasized the social and environmental disparities that lead to vulnerabilities. The term "vulnerability" encompasses a given group's sensitivity and exposure to climate-related health risks as well as capacity for responding to or coping with environmental variability due to climate change.

This report identifies a number of vulnerable groups in connection with numerous types of health risks. The most often cited across these areas are tribal communities, older adults, immigrant groups, communities of color, persons with disabilities, young children, and communities with low income. To understand and respond to the health impacts of climate change and reduce existing health disparities, public health officials, planners, physicians, social service providers, scientists, and policy-makers must consider how vulnerable communities experience disproportionate risks to their health, especially in the context of a changing climate.

## Future Research

The published literature tends to be inconsistent in its approach to different health impacts of climate change. There exists a substantial body of research on some key topics, such as heat illness due to rising temperatures. Other fields are comparatively lacking, such as climate-related water quality and the impact of climate change on mental health. Although it is beyond the scope of this report to assess which research needs persist, most of the indirect health impacts of climate change, such as the spread of vector-borne diseases or the implications of temporary or permanent displacement, would benefit from further inquiry.

There also is limited research on short-term adaptation strategies to mitigate adverse health outcomes linked to climate change. While climate trends are measured in decades and across vast areas, local decision-makers require guidance that is often urgent, hyperlocal, and above all, practical. One review commented on the disconnect and emphasized the difficulty of disentangling climate and non-climate factors for informed decision-making.[308]

In general, health research investigations that align with future projections of environmental changes

are integral for effective public health responses and policies. In addition, a policy-oriented audience may be reached more effectively by designing experiments and analyses with results that also express the public health burden as a number of patients and/or an estimate of medical costs, rather than solely a percentage risk increase of illness or mortality.

While the research community necessarily progresses incrementally, the dramatic environmental changes that are already happening must be met by an equally robust expansion of further evidence to inform communities that are taking action toward a more resilient and healthy future.

# References


1 Terri Wright et al., "Climate Change and Health Strategic Plan," American Public Health Association, August 2016, p. 1-21, https://www.apha.org/-/media/files/pdf/topics/climate/apha_climate_change_strategic_plan.ashx?la=en&hash=03D148BBD2A45E2A2B98BC4C98D33F32118244E1.

2 Office of Environmental Health Hazard Assessment, CalEPA, "Indicators of Climate Change in California," 2018, https://oehha.ca.gov/media/downloads/climate-change/report/2018caindicatorsreportmay2018.pdf.

3 U.S. National Research Council of the National Academies, "Surface Temperature Reconstructions for the Last 2,000 Years," 2006, https://www.nap.edu/resource/11676/Surface_Temps_final.pdf.

4 Daniel Griffin and K.J. Anchukaitis, "How Unusual is the 2012–14 California Drought?" *Geophysical Research Letters*, vol. 41, 2014, p. 9,017–9,023, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1002/2014GL062433.

5 Office of Environmental Health Hazard Assessment, CalEPA, "Indicators of Climate Change in California," 2018, https://oehha.ca.gov/media/downloads/climate-change/report/2018caindicatorsreportmay2018.pdf.

6 Louise Bedsworth et al., "Statewide Summary Report. California's Fourth Climate Change Assessment," publication no. SUMCCCA4–2018–013, 2018, http://www.climateassessment.ca.gov/state/docs/20180827-StatewideSummary.pdf.

7 Detlef P. van Vuuren et al., "The Representative Concentration Pathways: An Overview," *Climate Change*, vol. 109, 2011, p. 5-31, https://link.springer.com/content/pdf/10.1007%2Fs10584-011-0148-z.pdf.

8 David W. Pierce, Julie F. Kalansky, and Daniel R. Cayan, "Climate, Drought, and Sea Level Rise Scenarios for California's Fourth Climate Change Assessment," Division of Climate, Atmospheric Sciences, and Physical Oceanography, Scripps Institution of Oceanography, August 2018, http://www.climateassessment.ca.gov/techreports/docs/20180827-Projections_CCCA4-CEC-2018-006.pdf.

9 Anthony J. McMichael et al., "Human Population Health," chapter 18 of "Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific–Technical Analyses," contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change, 1996, p. 561–584, http://www.ipcc.ch/ipccreports/sar/wg_II/ipcc_sar_wg_II_full_report.pdf.

10 Deborah M. Drechsler et al., "Public Health-Related Impacts of Climate Change in California," California Climate Change Center, December 1, 2005, p. 1–80, https://escholarship.org/uc/item/9gq3j11r; The California Climate Change Center was established in 2003 by the California Energy Commission and funded by the Public Interest Energy Research Program.

11 Nick Watts et al., "Health and Climate Change: Policy Responses to Protect Public Health," *Lancet*, vol. 386, no. 10006, 2015, p. 1,861–914, https://www.thelancet.com/journals/lanet/article/PIIS0140-6736(15)60854-6/fulltext.

12 Allison Crimmins et al., "Impacts of Climate Change on Human Health in the United States: A Scientific Assessment," U.S. Global Change Research Program, 2016, p. 1–312, http://dx.doi.org/10.7930/J0R49NQX.

13 Intergovernmental Panel on Climate Change, "Global Warming of 1.5 °C: An IPCC Special Report on the Impacts of Global Warming of 1.5 °C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty," http://www.ipcc.ch/report/sr15/.

14 Jim Yong Kim, president, World Bank Group, speech at Brown University, March 7, 2014, http://www.worldbank.org/en/news/speech/2014/03/07/world-bank-group-president-jim-yong-kim-brown-university; referenced in Linda Rudolph et al., "Climate Change, Health, and Equity: A Guide for Local Health Departments," Public Health Institute and American Public Health Association, 2018, https://www.apha.org/-/media/files/pdf/topics/climate/climate_health_equity.ashx?la=en&hash=14D2F64530F1505EAE7AB16A9F9827250EAD6C79.

15 Bart Ostro et al., "Quantifying the Health Impacts of Future Changes in Temperature in California," *Environmental Research*, vol. 111, 2011, p. 1,258–1,264, https://www.ncbi.nlm.nih.gov/pubmed/21975126.

16 U.S. Centers for Disease Control and Prevention, "Climate Effects on Health," https://www.cdc.gov/climateandhealth/effects/default.htm, accessed August 19, 2018.

17 California Department of Public Health, "California Building Resilience Against Climate Effects," https://www.cdph.ca.gov/Programs/OHE/Pages/CC-Health-Vulnerability-Indicators.aspx, accessed August 19, 2018.

18 Paul English et al., “Public Health Impact of Climate Change in California: Community Vulnerability Assessments and Adaptation Strategies, Report No. 1: Heat-Related Illness and Mortality, Information for the Public Health Network in California,” California Department of Public Health, July 2007, p. 1–49, http://cehtp.org/download/climate_change/public-health-impacts-of-climate-change-in-ca-report-no-1-heat-related-illness.

19 Mark Ghilarducci, “Contingency Plan for Excessive Heat Emergencies: A Supporting Document to the State Emergency Plan,” California Governor’s Office of Emergency Services, June 2014, http://www.caloes.ca.gov/PlanningPreparednessSite/Documents/ExcessiveHeatContingencyPlan2014.pdf.

20 Heat Adaptation Workgroup, Subcommittee of the Public Health Workgroup, California Climate Action Team, “Preparing California for Extreme Heat: Guidance and Recommendations,” California Environmental Protection Agency and California Department of Public Health, October 2013, http://www.climatechange.ca.gov/climate_action_team/reports/Preparing_California_for_Extreme_Heat.pdf.

21 Geospatial Innovation Facility, “Cal–Adapt,” UC Berkeley and California Energy Commission, http://cal-adapt.org/, accessed September 27, 2018.

22 CalEnviroScreen 3.0, https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30, accessed October 6, 2018.

23 California Department of Public Health, “California Building Resilience Against Climate Effects,” https://www.cdph.ca.gov/Programs/OHE/Pages/CalBRACE.aspx, accessed September 27, 2018.

24 National Academies of Sciences, Engineering, and Medicine, “Protecting the Health and Well-Being of Communities in a Changing Climate,” proceedings of a workshop in brief, 2017, https://www.nap.edu/catalog/24797/protecting-the-health-and-well-being-of-communities-in-a-changing-climate.

25 National Weather Service, “Natural Hazard Statistics,” 2017, http://www.nws.noaa.gov/om/hazstats/resources/weather_fatalities.pdf

26 Brian Stone, J. Vargo, and D. Habeeb, “Managing Climate Change in Cities: Will Climate Action Plans Work?" *Landscape and Urban Planning*, vol. 107, no. 3, 2012, p. 263–271, http://www.urbanclimate.gatech.edu/pubs/StoneVargoHabeeb2012.pdf.

27 Rupa Basu, “High Ambient Temperature and Mortality: A Review of Epidemiologic Studies from 2001 to 2008,” *Environmental Health*, vol. 8, no. 40, September 16, 2009, p. 1–13, https://ehjournal.biomedcentral.com/track/pdf/10.1186/1476-069X-8-40.

28 Allison Crimmins et al., “Impacts of Climate Change on Human Health in the United States: A Scientific Assessment,” U.S. Global Change Research Program, 2016, p. 6, http://dx.doi.org/10.7930/J0R49NQX.

29 Rupa Basu and J.M. Samet, “Relation between Elevated Ambient Temperature and Mortality: A Review of the Epidemiologic Evidence,” *Epidemiologic Reviews*, vol. 24, no. 2, December 1, 2002, p. 190–202, https://academic.oup.com/epirev/article/24/2/190/535042.

30 California Department of Public Health and Public Health Institute, “California Environmental Health Tracking Program,” http://www.cehtp.org/page/main, accessed October 6, 2018.

31 Rupa Basu, W.Y. Feng, and B. Ostro, “Characterizing Temperature and Mortality in Nine California Counties,” *Epidemiology*, vol. 19, 2008, p. 138–145, https://www.ncbi.nlm.nih.gov/pubmed/18091422.

32 Rochelle Green et al., “Effect of Temperature on Hospital Admissions in Nine California Counties,” *International Journal of Public Health*, vol. 55, 2010, p. 113–121, https://www.energy.ca.gov/2009publications/CEC-500-2009-037/CEC-500-2009-037-F.PDF.

33 Christine N. Manser et al., “Heat Waves, Incidence of Infectious Gastroenteritis, and Relapse Rates of Inflammatory Bowel Disease: A Retrospective Controlled Observational Study,” *American Journal of Gastroenterology*, vol. 108, 2013, p. 1,480–1,485, https://www.nature.com/articles/ajg2013186#s1.

34 Rupa Basu and B. Ostro, “A Multicounty Analysis Identifying the Populations Vulnerable to Mortality Associated with High Ambient Temperature in California,” *American Journal of Epidemiology*, vol. 168, no. 6, September 15, 2008, p. 632–637, https://www.ncbi.nlm.nih.gov/pubmed/18663214.

35 Rupa Basu et al., “Effect of High Ambient Temperature on Emergency Room Visits,” *Epidemiology*, vol. 23, no. 6, November 2012, p. 813–820, https://www.ncbi.nlm.nih.gov/pubmed/23007039.

36 Rupa Basu, F. Dominici, and J.M. Samet, “Temperature and Mortality Among the Elderly in the United States: A Comparison of Epidemiologic Methods,” *Epidemiology*, vol. 16, no. 1, 2005, p. 58–66, https://www.ncbi.nlm.nih.gov/pubmed/15613946.

37 T.J. Mathews and M.F. MacDorman, “Infant Mortality Statistics From the 2004 Period Linked Birth/Infant Death Data Set,” *National Vital Statistics Reports*, vol. 55, no. 14, 2007, p. 1–32, https://www.ncbi.nlm.nih.gov/pubmed/17569269.

38 Gabriel J. Escobar, R.H. Clark, and J.D. Greene, “Short-Term Outcomes of Infants Born at 35 and 36 Weeks Gestation: We Need to Ask More Questions,” *Seminars in Perinatology*, vol. 30, no. 1, 2006, p. 28–33, https://www.ncbi.nlm.nih.gov/pubmed/16549211.

39 Rupa Basu, B Malig, and B Ostro, “High Ambient Temperature and the Risk of Preterm Delivery,” *American Journal of Epidemiology*, vol. 172, no. 10, November 15, 2010, p. 1,108–1,117, https://www.ncbi.nlm.nih.gov/pubmed/20889619.

40 Adapted from Rupa Basu, B Malig, and B Ostro, “High Ambient Temperature and the Risk of Preterm Delivery,” *American Journal of Epidemiology*, vol. 172, no. 10, November 15, 2010, p. 1,108–1,117, https://www.ncbi.nlm.nih.gov/pubmed/20889619.

41 Lyle R. Turner et al., “Ambient Temperature and Cardiorespiratory Morbidity: Systematic Review and Meta-Analysis,” *Epidemiology*, vol. 23, 2012, p. 594–606, https://www.ncbi.nlm.nih.gov/pubmed/22531668.

42 Dung Tri Phung et al., “Ambient Temperature and Risk of Cardiovascular Hospitalization: An Updated Systematic Review and Meta-Analysis,” *Science of the Total Environment,* vol. 550, 2016, p. 1,084–1,102, https://www.sciencedirect.com/science/article/pii/S004896971630153X?via%3Dihub.

43 Kim Knowlton et al., “2006 California Heat Wave: Impacts on Hospitalizations and Emergency Department Visits,” *Environmental Health Perspectives,* vol. 117, 2009, p. 61–67, https://www.ncbi.nlm.nih.gov/pubmed/19165388.

44 Roger B. Trent, “Review of July 2006 Heat Wave-Related Fatalities in California,” California Department of Health Services Epidemiology and Prevention for Injury Control Branch, 2007, https://tools.niehs.nih.gov/cchhl/index.cfm/main/detail?reference_id=2359.

45 Thara Srinivasan, “Cost of Excess Hospitalizations and Emergency Department Visits for the 2006 California Heat Wave,” Natural Resources Defense Council, 2008, https://www.nrdc.org/sites/default/files/hea_08082601a.pdf.

46 Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, “Indicators of Climate Change in California,” 2018, https://oehha.ca.gov/media/downloads/climate-change/report/2018caindicatorsreportmay2018.pdf.

47 Kim Knowlton et al., "The 2006 California Heat Wave: Impacts on Hospitalizations and Emergency Department Visits," *Environmental Health Perspectives*, vol. 117, no. 1, 2009, p. 61-67, 2009, https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.11594?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%3dpubmed.

48 Kristen Guirguis et al., “Impact of Recent Heat Waves on Human Health in California,” *Journal of Applied Meterology and Climatology*, vol. 53, 2014, p. 3–19, https://journals.ametsoc.org/doi/10.1175/JAMC-D-13-0130.1.

49 Kristen Guirguis et al., “Impact of Recent Heat Waves on Human Health in California,” *Journal of Applied Meterology and Climatology*, vol. 53, 2014, p. 3–19, https://journals.ametsoc.org/doi/10.1175/JAMC-D-13-0130.1

50 Toki Sherbakov et al., “Ambient Temperature and Added Heat Wave Effects on Hospitalizations in California from 1999 to 2009,” *Environmental Research*, vol. 160, 2018, p. 83–90, https://www.ncbi.nlm.nih.gov/pubmed/28964966.

51 Paul English et al., “Public Health Impacts of Climate Change in California: Community Vulnerability Assessments and Adaptation Strategies,” Climate Change Public Health Impacts Assessment and Response Collaborative, California Department of Public Health Institute, 2007, https://www.energy.ca.gov/2008publications/DPH-1000-2008-014/DPH-1000-2008-014.PDF.

52 Alexander Gershunov and K. Guirguis, “California Heat Waves in the Present and Future,” *Geophysical Research Letters*, vol. 39, 2012, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2012GL052979.

53 Jeremy J. Hess, J.Z. McDowell, and G. Luber, “Integrating Climate Change Adaptation Into Public Health Practice: Using Adaptive Management to Increase Adaptive Capacity and Build Resilience,” *Environmental Health Perspectives*, vol. 120, 2012, p. 171–179, https://ehp.niehs.nih.gov/doi/10.1289/ehp.1103515.

54 Geoffrey Heal and J. Park, “Temperature Stress and the Direct Impact of Climate Change: A Review of an Emerging Literature,” *Review of Environmental Economics and Policy*, vol. 10, no. 2, 2016, p. 1–17, https://academic.oup.com/reep/article/10/2/347/1753081.

55 California Department of Public Health and Public Health Institute, “California Environmental Health Tracking Program,” http://www.cehtp.org/page/main, accessed October 6, 2018.

56 California Department of Public Health, “Climate Change and Health Vulnerability Indicators for California,” https://discovery.cdph.ca.gov/ohe/CCHVIz/, accessed October 6, 2018.

57 Janice Prudhomme and A. Neidhardt, “State of California Memorandum: Cal/OSHA Investigations of Heat Related Illnesses,” Department of Industrial Relations Division of Occupational Safety and Health, February 17, 2006, https://www.dir.ca.gov/dosh/heatillnessinvestigations-2005.pdf.

58 Abderrezak Bouchama et al., “Prognostic Factors in Heat Wave-Related Deaths: A Meta-Analysis,” *Archives of Internal Medicine*, vol. 167, 2007, p. 2,170–2,176, https://jamanetwork.com/journals/jamainternalmedicine/fullarticle/413470.

59 Megan L. Christenson, S.D. Geiger, and H.A. Anderson, “Heat-Related Fatalities in Wisconsin During the Summer of 2012,” *Wisconsin Medical Journal*, vol. 112, 2013, p. 219–23, https://www.wisconsinmedicalsociety.org/_WMS/publications/wmj/pdf/112/5/219.pdf.

60 Lisa A. Page et al., “Temperature-Related Deaths in People With Psychosis, Dementia and Substance Misuse,” *British Journal of Psychiatry*, vol. 200, 2012, p. 485-490, http://dx.doi.org/10.1192/bjp.bp.111.100404.

61 U.S. Environmental Protection Agency, “Reducing Urban Heat Islands: Compendium of Strategies,” October 2008, https://www.epa.gov/sites/production/files/2014-06/documents/basicscompendium.pdf.

62 Tim Oke, “Urban Energy Balance,” *Progress in Physical Geography,* vol. 12, no. 4, December 1, 1988, p. 471–508, https://journals.sagepub.com/doi/10.1177/030913338801200401.

63 Marc L. Imhoff et al., “Remote Sensing of Urban Heat Island Effect Across Biomes in the Continental USA,” *Remote Sensing of Environment,* vol. 114, 2010, p. 504–513, https://www.coolrooftoolkit.org/wp-content/uploads/2012/04/Imhoff-Remote-Sensing-of-UHI-biomes-in-US-2010.pdf.

64 Hashem Akbari, “Energy Saving Potentials and Air Quality Benefits of Urban Heat Island Mitigation,” Lawrence Berkeley National Laboratory, U.S. Department of Energy Office of Scientific and Technical Information, 2005, https://www.osti.gov/servlets/purl/860475.

65 Marie S. O’Neill and K.L. Ebi, “Temperature Extremes and Health: Impacts of Climate Variability and Change in the United States,” *Journal of Occupational and Environmental Medicine*, vol. 51, 2009, p. 13–25, https://www.ncbi.nlm.nih.gov/pubmed/19136869.

66 Joyce Klein Rosenthal, “Evaluating the Impact of the Urban Heat island on Public Health: Spatial and Social Determinants of Heat-Related Mortality in New York City,” Columbia University Academic Commons, 2010, https://academiccommons.columbia.edu/doi/10.7916/D8JD53WX.

67 Brian Stone, J.J. Hess, and H. Frumkin, “Urban Form and Extreme Heat Events: Are Sprawling Cities More Vulnerable to Climate Change Than Compact Cities?” *Environmental Health Perspectives,* vol. 118, no. 10, 2010, p. 1,425–1,428, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2957923/.

68 Jennifer Vanos et al., “Assessing the Health Impacts of Urban Heat Island Reduction Strategies in the Cities of Baltimore, Los Angeles, and New York,” Global Cool Cities Alliance, July 3, 2104, http://www.coolrooftoolkit.org/wp-content/uploads/2014/07/Three-City-Heat-Health-Report-FINAL.pdf.

69 Haider Taha et al., “Modeling and Observations to Detect Neighborhood-Scale Heat Islands and Inform Effective Countermeasures in Los Angeles,” California’s Fourth Climate Change Assessment, California Energy Commission, publication no. CCCA4–CEC–2018–007, 2018, http://climateassessment.ca.gov/techreports/docs/20180827-Energy_CCCA4-CEC-2018-007.pdf.

70 Haider Taha, et al., “Air-Temperature Response to Neighborhood-Scale Variations in Albedo and Canopy Cover in the Real World: Fine-Resolution Meteorological Modeling and Mobile Temperature Observations in the Los Angeles Climate Archipelago,” *Climate*, vol. 6, no. 53, 2018, http://www.mdpi.com/2225-1154/6/2/53.

71 California Environmental Protection Agency, “Urban Heat Island Index for California,” https://calepa.ca.gov/climate/urban-heat-island-index-for-california/, accessed October 8, 2018.

72 Tom H. Brikowski, Y. Lotan, and M.S. Pearle, “Climate-Related Increase in the Prevalence of Urolithiasis in the United States,” *Proceedings of the National Academy of Sciences*, vol. 105, no. 28, July 2008, p. 9,841–9,846, http://www.pnas.org/content/105/28/9841.

73 Christopher S. Saigal, G. Joyce, and A.R. Timilsina, Urologic Diseases in America Project, “Direct and Indirect Costs of Nephrolithiasis in an Employed Population: Opportunity for Disease Management?” *Kidney International*, vol. 68, 2005, p. 1,808–1,814, https://www.ncbi.nlm.nih.gov/pubmed/16164658.

74 Tom H. Brikowski, Y. Lotan, and M.S. Pearle, “Climate-Related Increase in the Prevalence of Urolithiasis in the United States,” *Proceedings of the National Academy of Sciences*, vol. 105, no. 28, July 2008, p. 9,841–9,846, http://www.pnas.org/content/105/28/9841.

75 Bart Ostro, S. Rauch, and S. Green, “Quantifying the Health Impacts of Future Changes in Temperature in California,” *Environmental Research*, vol. 111, 2011, p. 1,258–1,264, https://www.ncbi.nlm.nih.gov/pubmed/21975126.

76 Katherine Hayhoe et al., “Emissions Pathways, Climate Change, and Impacts on California,” *Proceedings of the National Academy of Sciences*, vol. 101, 2004, p. 12,422–12,427, http://www.pnas.org/content/101/34/12422.

77 Nebojsa Nakićenović et al., *IPCC Special Report on Emissions Scenarios* (Cambridge and New York: Cambridge University Press), 2000, https://www.ipcc.ch/pdf/special-reports/emissions_scenarios.pdf.

78 Deborah M. Drechsler et al., “Public Health-Related Impacts of Climate Change in California,” California Climate Change Center, December 1, 2005, p. 17, https://escholarship.org/uc/item/9gq3j11r.

79 Alan Barreca et al., “Adapting to Climate Change: The Remarkable Decline in the U.S. Temperature-Mortality Relationship Over the 20th Century,” National Bureau of Economic Research paper, 2013, https://doi.org/10.3386/w18692.

80 Bart Ostro et al., “Effects of Temperature and Use of Air Conditioning on Hospitalizations,” *American Journal of Epidemiology*, vol. 172, no. 9, November 1, 2010, p. 1,053–1,061, https://academic.oup.com/aje/article/172/9/1053/147649.

81 Bart Ostro et al., “Quantifying the Health Impacts of Future Changes in Temperature in California,” *Environmental Research*, vol. 111, 2011, p. 1,258–1,264, https://www.ncbi.nlm.nih.gov/pubmed/21975126.

82 Kristin Guirguis et al., “Heat, Disparities, and Health Outcomes in San Diego County’s Diverse Climate Zones,” *GeoHealth*, May 23, 2018, https://doi.org/10.1029/2017GH000127.

83 Kate L. Bassil and D. Cole, “Effectiveness of Public Health Interventions in Reducing Morbidity and Mortality During Heat Episodes: A Structured Review,” *International Journal of Environmental Research and Public Health,* vol. 7, no. 3, 2010, p. 991–1001, https://doi.org/10.3390/ijerph7030991.

84 Alexander Gershunov and K. Guirguis, “California Heat Waves in the Present and Future," *Geophysical Research Letters*, vol. 39, 2012, https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2012GL052979.

85 Jennifer L. Peel, et al., “Impact of nitrogen and climate change interactions on ambient air pollution and human health,” *Biogeochemistry*, vol. 114, 2013, p. 121-134, https://link.springer.com/content/pdf/10.1007%2Fs10533-012-9782-4.pdf.

86 Jerry M. Melillo, T. Richmond, and G.W. Yohe, eds., “Climate Change Impacts in the United States: Third National Climate Assessment,” U.S. Global Change Research Program, 2014, p. 222, https://data.globalchange.gov/report/nca3; Arlene M. Fiore et al., “Global Air Quality and Climate,” *Chemical Society Reviews*, vol. 41, no. 19, October 7, 2012, p. 6,663–6,683, https://www.ncbi.nlm.nih.gov/pubmed/22868337.

87 Haider Taha, S. Douglas, and J. Haney, “Analysis of Energy Efficiency and Air Quality in the South Coast Air Basin–Phase II,” Lawrence Berkeley Laboratory Report LBL–35728, Berkeley, 1994, https://cloudfront.escholarship.org/dist/prd/content/qt62r7628p/qt62r7628p.pdf?t=p0i3z3.

88 Cizao Ren et al., “Ozone Modifies Associations Between Temperature and Cardiovascular Mortality: Analysis of the NMMAPS Data,” *Occupational and Environmental Medicine*, vol. 65, 2008, p. 255–260, https://oem.bmj.com/content/65/4/255.long.

89 Deborah M. Drechsler, “Climate Change and Public Health in California,“ California Climate Change Center, August 2009, CEC–500–2009–034–F, http://www.energy.ca.gov/2009publications/CEC-500-2009-034/CEC-500-2009-034-F.PDF.

90 Jane V. Hall and V. Brajer, “Health and Related Economic Benefits of Attaining Healthful Air in the San Joaquin Valley,” Fullerton: California State University Institute for Economic and Environmental Studies, 2006, https://www.arb.ca.gov/lists/sip111512/4-csuf_hall_report_benefits_attaining_healthful_air_s_j_v_032906.pdf.

91 Ibid.

92 Mai A. Ngo et al., “Airborne Particles in the San Joaquin Valley May Affect Human Health,” *California Agriculture*, vol. 64, no. 1, 2010, p. 12–16, http://calag.ucanr.edu/Archive/?article=ca.v064n01p12.

93 Donald R. Blake et al., “Volatile Organic Compound Emissions From Dairy Farming and Their Effect on San Joaquin Valley Air Quality,” *Proceedings of the 2009 American Geophysical Union Joint Assembly*, 2009, http://adsabs.harvard.edu/abs/2009AGUSM.A21C..04B.

94 Lisa Kresge and R. Strochlic, “Clearing the Air: Mitigating the Impact of Dairies on Fresno County’s Air Quality and Public Health,” California Institute for Rural Studies, 2007, https://www.cirsinc.org/publications/category/9-food-systems?download=4:clearing-the-air-mitigating-the-impact-of-dairies-on-fresno-countys-air-quality-and-public-health.

95 California Air Resources Board, “Staff Report: Public Hearing to Consider Amendments to the Ambient Air Quality Standards for Particulate Matter and Sulfates,” California Environmental Protection Agency, May 3, 2002, https://www.arb.ca.gov/carbis/research/aaqs/std-rs/pm-final/ch1-6.pdf.

96 California Air Resources Board, “Review of the California Ambient Air Quality Standard for Ozone,” California Environmental Protection Agency, 2005; California Air Resources Board, “Draft Emission Reduction Plan for Ports and International Goods Movement in California,” California Environmental Protection Agency, 2005, https://www.arb.ca.gov/planning/gmerp/gmerp.htm.

97 The World Bank, “Air Pollution Deaths Cost Global Economy US$225 Billion,” press release, September 8, 2016, http://www.worldbank.org/en/news/press-release/2016/09/08/air-pollution-deaths-cost-global-economy-225-billion.

98 Meredith Milet, “Asthma Prevalence in California: A Surveillance Report,” California Department of Public Health, Environmental Health Investigations Branch, January 2017, https://www.cdph.ca.gov/Programs/CCDPHP/DEODC/EHIB/CPE/CDPH%20Document%20Library/Asthma_in_California_2013.pdf.

99 Bart Ostro et al., “Effects of Fine Particle Components on Respiratory Hospital Admissions in Children,” *Environmental Health Perspectives*, vol. 117, 2009, p. 475–480, https://www.ncbi.nlm.nih.gov/pubmed/19337525.

100 Rob McConnell et al., “Asthma in Exercising Children Exposed to Ozone: A Cohort Study,” *Lancet*, vol. 359, 2002, p. 386–91, https://www.ncbi.nlm.nih.gov/pubmed/11844508; Study areas included Alpine, Atascadero, Lake Elsinore, Lake Gregory, Lancaster, Lompoc, Long Beach, Mira Loma, Riverside, San Dimas, Santa Maria, and Upland.

101 Jennifer L. Peel et al., “Impact of Nitrogen and Climate Change Interactions on Ambient Air Pollution and Human Health,” *Biogeochemistry*, vol. 114, 2013, p. 121–134, https://link.springer.com/content/pdf/10.1007%2Fs10533-012-9782-4.pdf.

102 Jerry M. Melillo, T. Richmond, and G.W. Yohe, eds., “Climate Change Impacts in the United States: Third National Climate Assessment,” U.S. Global Change Research Program, 2014, p. 222, https://data.globalchange.gov/report/nca3.

103 Arlene M. Fiore et al., “Global Air Quality and Climate,” *Chemical Society Reviews*, vol. 41, no. 19, October 7, 2012, p. 6,663–6,683, https://www.ncbi.nlm.nih.gov/pubmed/22868337.

104 Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, “Indicators of Climate Change in California,” 2018, https://oehha.ca.gov/climate-change/report/2018-report-indicators-climate-change-california.

105 Benjamin Bryant and A. Westerling, “Potential Effects of Climate Change on Residential Wildfire Risk in California,” California Energy Commission, 2009, CEC–500–2009–048–F, https://www.energy.ca.gov/2009publications/CEC-500-2009-048/CEC-500-2009-048-D.PDF

106 Anthony Westerling et al., “Climate Change, Growth, and California Wildfire,” California Climate Change Center, March 2009, draft paper, CEC–500–2009–046–D, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.386.1728&rep=rep1&type=pdf.

107 Matthew D. Hurteau et al., “Projected Effects of Climate and Development on California Wildfire Emissions through 2100,” *Environmental Science and Technology*, vol. 48, 2014, p. 2,298–2,304, http://fire.ca.gov/fcat/downloads/Hurteau%20et%20al%202014%20CA%20emissions.pdf.

108 California Building Resilence Against Climate Effects, 2018, https://www.cdph.ca.gov/Programs/OHE/Pages/CalBRACE.aspx.

109 U.S. Environmental Protection Agency et al., “Wildfire Smoke, A Guide for Public Health Officials,” May 2016, https://www3.epa.gov/airnow/wildfire_may2016.pdf.

110 Allison Crimmins et al., "Impacts of Climate Change on Human Health in the United States: A Scientific Assessment," U.S. Global Change Research Program, 2016, p. 1-312, http://dx.doi.org/10.7930/J0R49NQX.

111 U.S. Environmental Protection Agency et al., "Wildfire Smoke, A Guide for Public Health Officials," May 2016, https://www3.epa.gov/airnow/wildfire_may2016.pdf.

112 Zachary S. Wettstein et al., “Cardiovascular and Cerebrovascular Emergency Department Visits Associated With Wildfire Smoke Exposure in California in 2015,” *Journal of the American Heart Association*, vol. 7, April 11, 2018, https://www.ahajournals.org/doi/pdf/10.1161/JAHA.117.007492; The study collected data from May 1–September 30, 2015, from the Great Basin valleys, Lake County, Lake Tahoe, mountain counties, north coast, northeast plateau, Sacramento Valley, and San Joaquin Valley.

113 Justine A. Hutchinson et al., “San Diego 2007 Wildfires and Medi-Cal Emergency Department Presentations, Inpatient Hospitalizations, and Outpatient Visits: An Observational Study of Smoke Exposure Periods and a Bidirectional Case-Crossover Analysis,” *PLOS Medicine*, vol. 15, no. 7, 2018, p. e1002601, https://journals.plos.org/plosmedicine/article?id=10.1371/journal.pmed.1002601.

114 Ralph J. Delfino et al., “Relationship of Respiratory and Cardiovascular Hospital Admissions to the Southern California Wildfires of 2003,” *Occupational and Environmental Medicine*, vol. 66, 2009, p. 189–197, http://oem.bmj.com/content/66/3/189; Study areas included Los Angeles, Orange, Riverside, San Bernardino, San Diego, and Ventura counties.

115 Nino Künzli et al., “Health Effects of the 2003 Southern California Wildfires in Children,” *American Journal of Respiratory and Critical Care Medicine*, vol. 174, 2006, p.1,221–1,228, https://www.ncbi.nlm.nih.gov/pubmed/16946126.

116 Louise Bedsworth et al., “Summary Report from Tribal and Indigenous Communities within California, California’s Fourth Climate Change Assessment,” 2018, http://www.climateassessment.ca.gov/state/docs/20180928-TribalCommunitySummary.pdf.

117 Joshua A. Mott et al., “Wildland Forest Fire Smoke: Health Effects and Intervention Evaluation, Hoopa, California, 1999,” *Western Journal of Medicine*, vol. 176, no. 3, 2002, p. 157–162, https://www.ncbi.nlm.nih.gov/pubmed/12016236.

118 Dennis Shusterman, J.Z. Kaplan, and C. Canabarro, “Immediate Health Effects of an Urban Wildfire,” *Western Journal of Medicine*, vol. 158, 1993, p. 133–138, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1021964/pdf/westjmed00078-0031.pdf.

119 J. Morris and A. Cronquist, letter to Dr. Victorio Vaz, Arizona Department of Health Services, regarding preliminary findings on evaluation of community impact of evacuation and smoke exposure due to Rodeo–Chediski fire, August 30, 2002, https://www.azdhs.gov/documents/preparedness/epidemiology-disease-control/environmental-toxicology/rodeo_chedeski_assmnt.pdf.

120 Nancy E. Rosenstein et al., “Risk Factors for Severe Pulmonary and Disseminated Coccidioidomycosis: Kern County, California, 1995–96,” *Clinical Infectious Diseases*, vol. 32, no. 5, March 1, 2001, p. 708–15, https://academic.oup.com/cid/article/32/5/708/358336.

121 E. Durry et al., "Coccidioidomycosis in Tulare County, California, 1991: Reemergence of an Endemic Disease," *Journal of Medical and Veterinary Mycology*, vol. 35, no. 5, September–October 1997, p. 321–6, https://www.ncbi.nlm.nih.gov/pubmed/9402524; Nancy F. Crum et al., "Coccidioidomycosis: A Descriptive Survey of a Reemerging Disease: Clinical Characteristics and Current Controversies," *Medicine*, vol. 83, no. 3, 2004, p. 149–75, https://www.ncbi.nlm.nih.gov/pubmed/15118543.

122 Christopher W. Woods et al., "Coccidioidomycosis in Human Immunodeficiency Virus-Infected Persons in Arizona, 1994–97: Incidence, Risk Factors, and Prevention," *Journal of Infectious Diseases*, vol. 181, no. 4, April 2000, p. 1428–34, https://academic.oup.com/jid/article/181/4/1428/863152.

123 Janis E. Blair and J.L. Logan, "Coccidioidomycosis in Solid Organ Transplantation," *Clinical Infectious Diseases,* vol. 33, no. 9, November 1, 2001, p. 1,536–44, https://academic.oup.com/cid/article/33/9/1536/1746139; Laurie Bergstrom et al., "Increased Risk of Coccidioidomycosis in Patients Treated With Tumor Necrosis Factor Alpha Antagonists," *Arthritis and Rheumatism*, vol. 50, no. 6, June 2004, p. 1959–66, https://onlinelibrary.wiley.com/doi/abs/10.1002/art.20454; Robert S. Bercovitch et al., "Coccidioidomycosis During Pregnancy: A Review and Recommendations for Management," *Clinical Infectious Diseases*, vol. 53, no. 4, August 2011, p. 363–8, https://academic.oup.com/cid/article/53/4/363/446649.

124 California Department of Public Health Office of Public Affairs, "Increase in Reported Valley Fever Cases in California in 2017," https://www.cdph.ca.gov/Programs/OPA/Pages/NR17-080.aspx, accessed March 1, 2018.

125 Gail Sondermeyer et al., "Notes from the Field: Increase in Coccidioidomycosis – California, 2016," *Morbidity and Mortality Weekly Report*, vo. 66, no. 31, August 11, 2017, p. 833-834, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5687785/.

126 California Department of Public Health, "Epidemiologic Summary of Coccidioidomycosis in California, 2009–12," 2012, https://www.cdph.ca.gov/Programs/CID/DCDC/CDPH%20Document%20Library/CocciEpiSummary09-12.pdf.

127 Public Health Institute, "Infectious Disease, Climate Change and Health," Center for Climate Change and Health, 2016, http://climatehealthconnect.org/wp-content/uploads/2016/09/InfectiousDisease.pdf.

128 Lynnette Zelezny et al., "Impact of the Drought in the San Joaquin Valley of California," Fresno State Academics, 2015, http://www.fresnostate.edu/academics/drought/documents/Fresno%20State_Drought%20Study_Minus%20Executive%20Summary_FINAL.pdf.

129 Jason Wilken et al., "Coccidioidomycosis Among Workers Constructing Solar Power Farms, California, 2011–14," *Emerging Infectious Diseases*, vol. 21, no. 11, 2015, https://wwwnc.cdc.gov/eid/article/21/11/15-0129_article.

130 Katherine M. Shea et al., "Climate Change and Allergic Disease," *Journal of Allergy and Clinical Immunology*, vol. 122, no. 3, 2008, p. 443–453, http://www.jacionline.org/article/S0091-6749(08)01181-0/fulltext.

131 Lorenzo Cecchi et al., "Projections of the Effects of Climate Change on Allergic Asthma: Contribution of Aerobiology," *Allergy*, vol. 65, 2010, p. 1,073–1,081, https://www.ncbi.nlm.nih.gov/pubmed/20560904; Gennaro D'Amato, G. Liccardi, and G. Frenguelli, "Thunderstorm-Asthma and Pollen Allergy," *Allergy*, vol. 62, 2007, p. 11–16, https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1398-9995.2006.01271.x.

132 Lewis Ziska et al., "Recent warming by latitude associated with increased length of ragweed pollen season in central North America," *Proceedings of the National Academy of Sciences*, vol. 108, no. 10, March 8, 2011, p. 4,248-4,251, http://www.pnas.org/content/pnas/108/10/4248.full.pdf.

133 Ronson Zhang et al., "Development of a Regional-Scale Pollen Emission and Transport Modeling Framework for Investigating the Impact of Climate Change on Allergic Airway Disease," *Biogeosciences*, vol. 11, no. 6, 2014, p. 1,461–78, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4021721/pdf/nihms-580693.pdf.

134 Anne E. Kelly and M.L. Goulden, "Rapid Shifts in Plant Distribution With Recent Climate Change," *Proceedings of the National Academy of Sciences*, vol. 105, no. 33, August 2008, p. 11,823–11,826, http://www.pnas.org/content/105/33/11823.long.

135 U.S. Global Change Research Project, "National Climate Assessment: Climate Change Impacts in the United States," U.S. government, 2014, https://nca2014.globalchange.gov/.

136 Harvey W. Kaufman et al., "Largest Study of Allergy Testing in the United States," Quest Diagnostics Health Trends, 2011, http://www.questdiagnostics.com/dms/Documents/Other/2011_QD_AllergyReport.pdf.

137 Michael D. Mastrandrea et al., "Current and Future Impacts of Extreme Events in California," California Climate Change Center report, August 2009, http://www.energy.ca.gov/2009publications/CEC-500-2009-026/CEC-500-2009-026-F.PDF.

138 Allison Crimmins et al., "Impacts of Climate Change on Human Health in the United States: A Scientific Assessment," U.S. Global Change Research Program, 2016, p. 102, http://dx.doi.org/10.7930/J0R49NQX.

139 Derrick Hambly et al., "Projected Implications of Climate Change for Road Safety in Greater Vancouver," *Climatic Change*, vol. 116, no. 3–4, 2011, p. 613–629, https://link.springer.com/article/10.1007%2Fs10584-012-0499-0.

140 Kenneth R. Bradbury et al., "Source and Transport of Human Enteric Viruses in Deep Municipal Water Supply Wells," *Environmental Science and Technology,* vol. 47, 2013, p. 4,096-4,103, https://pubs.acs.org/doi/10.1021/es400509b.

141 Patrick Drayna et al., "Association Between Rainfall and Pediatric Emergency Department Visits for Acute Gastrointestinal Illness," *Environmental Health Perspectives*, vol. 118, 2010, p. 1,439–1,443, https://ehp.niehs.nih.gov/doi/10.1289/ehp.0901671.

142 Frank C. Curriero et al., "Association Between Extreme Precipitation and Waterborne Disease Outbreaks in the United States, 1948–94," *American Journal of Public Health*, vol. 91, no. 8, 2001, p. 1,194–1,199, https://www.ncbi.nlm.nih.gov/pubmed/11499103.

143 E. Durry et al., "Coccidioidomycosis in Tulare County, California, 1991: Reemergence of an Endemic Disease," *Journal of Medical and Veterinary Mycology*, vol. 35, no. 5, September 1, 1997, p. 321–326, https://academic.oup.com/mmy/article/35/5/321/1031274.

144 Seth B. Shonkoff et al., "Environmental Health and Equity Impacts from Climate Change and Mitigation Policies in California: A Review of the Literature," California Climate Change Center, 2009, https://www.energy.ca.gov/2009publications/CEC-500-2009-038/CEC-500-2009-038-D.PDF

145 Michael D. Mastrandrea et al., "Current and Future Impacts of Extreme Events in California," California Climate Change Center, 2009, https://www.energy.ca.gov/2009publications/CEC-500-2009-026/CEC-500-2009-026-F.PDF

146 U.S. Centers for Disease Control and Preventions, "NCHHSTP Social Determinants of Health," https://www.cdc.gov/nchhstp/socialdeterminants/definitions.html, accessed September 15, 2018.

147 Judith Rodin, *Resilience Dividend: Being Strong in a World Where Things Go Wrong*. (Public Affairs, 2014), https://www.publicaffairsbooks.com/titles/judith-rodin/the-resilience-dividend/9781610394710/.

148 U.S. National Research Council, *Disaster Resilience: A National Imperative*. (Washington, DC: National Academies Press, 2012), p. 1-244, https://www.nap.edu/catalog/13457/disaster-resilience-a-national-imperative.

149 Nick Watts et al., "Health and Climate Change: Policy Responses to Protect Public Health," *Lancet*, vol. 386, no. 10006, November 7, 2015, p. 1,861–1,914, https://www.thelancet.com/action/showPdf?pii=S0140-6736%2815%2960854-6.

150 "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation," special report of working groups I and II of the Intergovernmental Panel on Climate Change, 2012, p. 582, https://www.ipcc.ch/pdf/special-reports/srex/SREX_Full_Report.pdf.

151 Randall R. Bovbjerg and J. Hadley, "Why Health Insurance Is Important," Health Policy Briefs, Urban Institute, Washington, D.C., 2007, https://www.urban.org/sites/default/files/publication/46826/411569-Why-Health-Insurance-Is-Important.PDF

152 Paul Fronstin, "California's Uninsured: As Coverage Grows, Millions Go Without," California Health Care Foundation, November 14, 2017, https://www.chcf.org/publication/californias-uninsured-as-coverage-grows-millions-go-without/.

153 Rebecca J. Eisen et al., "Spatial Patterns of Lyme Disease Risk in California Based on Disease Incidence Data and Modeling of Vector-Tick Exposure," *American Journal of Tropical Medicine and Hygiene*, vol. 75, 2006, p. 669–676, https://pdfs.semanticscholar.org/c6cf/cbeb4c7d3c3d1b33bf9431fd8908ad172cc0.pdf.

154 Infectious Diseases Branch, Division of Communicable Disease Control, Center for Infectious Diseases, "2016 Annual Report, Vector-borne Disease Section," California Department of Public Health, 2016, https://www.cdph.ca.gov/Programs/CID/DCDC/CDPH%20Document%20Library/VBDSAnnualReport16.pdf.

155 Institute of Medicine Committee on Emerging Microbial Threats to Health, *Emerging Infections: Microbial Threats to Health in the United States* (Washington, D.C.: National Academies Press, 1992), https://www.ncbi.nlm.nih.gov/pubmed/25121245.

156 Brandee L. Stone, Y. Tourand, and C.A. Brissette, "Brave New Worlds: Expanding Universe of Lyme Disease," *Vector-Borne and Zoonotic Diseases*, vol. 17, 2017, p. 619–29, https://www.ncbi.nlm.nih.gov/pubmed/28727515.

157 Nicholas H. Ogden et al., "Estimated Effects of Projected Climate Change on the Basic Reproductive Number of the Lyme Disease Vector *Ixodes Scapularis*," *Environmental Health Perspectives*, 2014, https://www.ncbi.nlm.nih.gov/pubmed/24627295.

158 Rebecca J. Eisen et al., "A Spatially Explicit Model of Acarological Risk of Exposure to *Borrelia Burgdorferi*-Infected *Ixodes Pacificus* Nymphs in Northwestern California Based on Woodland Type, Temperature, and Water Vapor," *Ticks and Tick-Borne Diseases*, vol. 1, 2010, p. 35–43, https://www.ncbi.nlm.nih.gov/pubmed/20532183.

159 Rebecca J. Eisen et al., "Environmentally Related Variability in Risk of Exposure to Lyme Disease Spirochetes in Northern California: Effect of Climatic Conditions and Habitat Type," *Environmental Entomology*, vol. 32, no. 5, October 2003, p. 1,010–1,018, https://academic.oup.com/ee/article-abstract/32/5/1010/338210?redirectedFrom=fulltext.

160 Daniel J. Salkeld et al., "Disease Risk and Landscape Attributes of Tick-Borne *Borrelia* Pathogens in the San Francisco Bay Area, California," *PLOS One*, vol. 10, no. 8, 2015, http://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0134812&type=printable; Study areas included Marin, Napa, San Mateo, Santa Clara, Santa Cruz, and Sonoma counties.

161 Kerry Padgett et al., "Large-Scale Spatial Risk and Comparative Prevalence of *Borrelia Miyamotoi* and *Borrelia Burgdorferi* Sensu Lato in *Ixodes Pacificus*," *PLOS One*, vol. 9, 2014, https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0110853.

162 Sarah A. Billeter et al., "Species Composition and Temporal Distribution of Adult Ixodid Ticks and Prevalence of *Borrelia Burgdorferi* Sensu Lato and *Rickettsia* Species in Orange County," *Journal of Vector Ecology,* vol. 42, 2017, p. 189–192, https://onlinelibrary.wiley.com/doi/abs/10.1111/jvec.12255.

163 Edward B. Hayes and D.J. Gubler, "West Nile Virus: Epidemiology and Clinical Features of an Emerging Epidemic in the United States," *Annual Review of Medicine*, vol. 57, 2006, p. 181–94, https://pdfs.semanticscholar.org/7a48/9a70f71e1d7290faa47814d9a685df17c3a1.pdf.

164 William K. Reisen, Y. Fang, and V.M. Martinez, "Effects of Temperature on the Transmission of West Nile Virus by *Culex Tarsalis* (Diptera: Culicidae)," *Journal of Medical Entomology*, vol. 43, 2006, p. 309–317, https://www.ncbi.nlm.nih.gov/pubmed/16619616.

165 California Department of Public Health, UC Davis Arbovirus Research and Training, and Mosquito and Vector Control Association of California, "Latest West Nile Virus Activity in California," http://www.westnile.ca.gov/, accessed August 18, 2018.

166 Lynnette Zelezny et al., "Impact of the Drought in the San Joaquin Valley of California," Fresno State Academics, 2015, http://www.fresnostate.edu/academics/drought/documents/Fresno%20State_Drought%20Study_Minus%20Executive%20Summary_FINAL.pdf.

167 Centers for Disease Control and Prevention, "West Nile Virus Disease Cases and Presumptive Viremic Blood Donors by State – United States, 2017," 2017, https://www.cdc.gov/westnile/resources/pdfs/data/WNV-Disease-Cases-and-PVDs-by-State-2017_08082018-P.pdf.

168 William K. Reisen, Y. Fang, and V.M. Martinez, "Effects of Temperature on the Transmission of West Nile Virus by *Culex Tarsalis* (Diptera: Culicidae)," *Journal of Medical Entomology*, vol. 43, 2006, p. 309–317, https://www.ncbi.nlm.nih.gov/pubmed/16619616; Study areas included Kern, Yolo, Shasta, San Bernardino, and Riverside counties.

169 Jonathan E. Soverow et al., "Infectious Disease in a Warming World: How Weather Influenced West Nile Virus in the United States (2001–05)," *Environmental Health Perspectives*, vol. 117, no. 7, July 2009, https://pdfs.semanticscholar.org/440c/5f2b198094fc602b356af90ff9d63725aba9.pdf?_ga=2.204162256.1785291815.1543260039-99192019.1543260039.

170 David J. Dohm, M. O'Guinn, and M.J. Turell, "Effect of Environmental Temperature on the Ability of *Culex Pipiens* (Diptera: Culicidae) to Transmit West Nile Virus," *Journal of Medical Entomology*, vol. 39, 2002, p. 221–225, https://www.ncbi.nlm.nih.gov/pubmed/11931261.

171 Jeffrey Shaman and J. Day, "Reproductive Phase Locking of Mosquito Populations in Response to Rainfall Frequency," *PLOS One*, vol. 3, March 2007, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0000331.

172 William J. Landesman et al., "Interannual Associations Between Precipitation and Human Incidence of West Nile Virus in the United States," *Vector-Borne and Zoonotic Diseases*, vol. 7, no. 3, 2007, p. 337–343, https://www.ncbi.nlm.nih.gov/pubmed/17867908.

173 Jayne M. Deichmeister and A. Telang, "Abundance of West Nile Virus Mosquito Vectors in Relation to Climate and Landscape Variables," *Journal of Vector Ecology*, vol. 36, no. 1, 2011, p. 75–85, https://www.ncbi.nlm.nih.gov/pubmed/21635644.

174 William K. Reisen et al., "Effects of Warm Winter Temperature on the Abundance and Gonotrophic Activity of *Culex* (Diptera: Culicidae) in California," *Journal of Medical Entomology*, vol. 47, no. 2, 2010, p. 230–237, https://www.ncbi.nlm.nih.gov/pubmed/20380305.

175 Cory W. Morin and A.C. Comrie, "Regional and Seasonal Response of a West Nile Virus Vector to Climate Change," *Proceedings of the National Academy of Sciences*, September 2013, http://www.pnas.org/content/110/39/15620.

176 William K. Reisen et al., "Effects of Warm Winter Temperature on the Abundance and Gonotrophic Activity of *Culex* (Diptera: Culicidae) in California," *Journal of Medical Entomology*, vol. 47, no. 2, 2010, p. 230–237, https://www.ncbi.nlm.nih.gov/pubmed/20380305.

177 Jose G. Velascosoltero, “Effects of Climate Variability on the Abundance of West Nile Virus Vectors in San Diego County,” San Diego State University, Summer 2012, http://sdsu-dspace.calstate.edu/bitstream/handle/10211.10/2613/Velascosoltero_Jose.pdf?sequence=1.

178 Brian D. Carroll, R.M. Takahashi, and W.K. Reisen, “West Nile Virus Activity in Kern County During 2006,” *Proceedings of the Mosquito Vector Control Association of California*, vol. 75, 2007, p. 17–22, http://www.mvcac.org/amg//wp-content/uploads/MVCAC-2007-Proceedings-Papers-Vol-75.pdf.

179 William K. Reisen et al., “Delinquent Mortgages, Neglected Swimming Pools, and West Nile Virus, California,” *Emerging Infectious Diseases*, vol. 14, no. 11, 2008, p. 1,747–1,749, https://dx.doi.org/10.3201/eid1411.080719.

180 Sara H. Paull et al., “Drought and Immunity Determine the Intensity of West Nile Virus Epidemics and Climate Change Impacts,” *Proceedings of the Royal Society B: Biological Sciences*, vol. 284, 2017, p. 1,848, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5310598/.

181 Lynnette Zelezny et al., “Impact of the Drought in the San Joaquin Valley of California,” Fresno State Academics, 2015, http://www.fresnostate.edu/academics/drought/documents/Fresno%20State_Drought%20Study_Minus%20Executive%20Summary_FINAL.pdf.

182 Counties that tested positive for West Nile virus activity (in human cases, mosquito samples, dead birds, or horses) in 2017 were Alameda, Butte, Calaveras, Colusa, Contra Costa, El Dorado, Fresno, Glenn, Humboldt, Imperial, Inyo, Kern, Kings, Lake, Lassen, Los Angeles, Madera, Marin, Merced, Monterey, Nevada, Orange, Placer, Plumas, Riverside, Sacramento, San Benito, San Bernardino, San Diego, San Francisco, San Joaquin, San Luis Obispo, San Mateo, Santa Barbara, Santa Clara, Santa Cruz, Shasta, Solano, Sonoma, Stanislaus, Sutter, Tehama, Tulare, Tuolumne, Ventura, Yolo, and Yuba; California Mosquito-borne Virus Surveillance and Response Program, “Latest West Nile Virus Activity in California,” http://www.westnile.ca.gov/case_counts.php?year=2017&option=print, accessed October 24, 2018; California West Nile Virus Statistics, University of California, San Diego and Scripps Institution of Oceanography, http://jsl6906.net/Clients/ScrippsWestNile/?type=factorsByYear&var=Maximum+Human+Cases&year=2017.

183 Division of Communicable Disease Control, “California Compendium of Plague Control: Vector-Borne Disease Section—Infectious Diseases Branch,” California Department of Public Health, https://www.cdph.ca.gov/Programs/CID/DCDC/CDPH%20Document%20Library/CAPlagueCompendium.pdf, accessed July 2, 2018.

184 Yoshinori Nakazawa et al., “Climate Change Effects on Plague and Tularemia in the United States,” *Vector-Borne and Zoonotic Diseases*, vol. 7, no. 4, Jan 2008, p. 529-540, https://www.liebertpub.com/doi/abs/10.1089/vbz.2007.0125.

185 Mary Danforth et al., "Investigation of and Response to 2 Plague Cases, Yosemite National Park, California, USA, 2015," *Emerging Infectious Diseases*, vol. 22, no. 12, 2016, p. 2,045-2,053, https://wwwnc.cdc.gov/eid/article/22/12/16-0560_article.

186 California Department of Public Health Division of Communicable Disease Control, “CDPH Update on Number of Dengue Infections in California, November 2, 2018,” https://www.cdph.ca.gov/Programs/CID/DCDC/CDPH%20Document%20Library/TravelAssociatedCasesofDengueVirusinCA.pdf, accessed November 9, 2018; Counties positive for infectivity include Fresno, Imperial, Kern, Kings, Los Angeles, Madera, Merced, Orange, San Bernardino, San Diego, and Tulare.

187 Melinda K. Butterworth, C.W. Morin, and A.C. Comrie, “Analysis of the Potential Impact of Climate Change on Dengue Transmission in the Southeastern United States,” *Environmental Health Perspectives*, vol. 125, 2017, p. 579–585, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5381975/.

188 Kim Knowlton, G. Solomon, and M. Rotkin-Ellman, “Mosquito-Borne Dengue Fever Threat Spreading in the Americas,” Natural Resources Defense Council issue paper, July 2009, https://www.nrdc.org/sites/default/files/dengue.pdf.

189 Felipe J. Colón-González et al., “Effects of Weather and Climate Change on Dengue,” *PLOS Neglected Tropical Diseases*, vol. 7, no. 11, 2013, http://journals.plos.org/plosntds/article?id=10.1371/journal.pntd.0002503.

190 Yoshinori Nakazawa et al., “Climate Change Effects on Plague and Tularemia in the United States,” *Vector-Borne and Zoonotic Diseases*, vol. 7, no. 4, Jan 2008, p. 529-540, https://www.liebertpub.com/doi/abs/10.1089/vbz.2007.0125.

191 Sheba K. Meymandi et al., “Prevalence of Chagas Disease in the Latin American-Born Population of Los Angeles,” *Clinical Infectious Diseases*, vol. 64, 2017, p. 1,182–1,188, https://www.ncbi.nlm.nih.gov/pubmed/28329123.

192 Jamie Deneris and N.A. Marshall, “Biological Characterization of a Strain of Trypanosoma Cruzi Chagas Isolated From a Human Case of Trypanosomiasis in California,” *American Journal of Tropical Medical Hygiene*, vol. 41, no. 4, 1989, p. 422–8, https://www.ncbi.nlm.nih.gov/pubmed/2508500.

193 Wei Song Hwang et al., “Infection Rates of *Triatoma Protracta* (Uhler) With *Trypanosoma Cruzi* in Southern California and Molecular Identification of Trypanosomes,” *American Journal of Tropical Medicine and Hygiene*, vol. 83, no. 5, November 2010, p. 1,020–1,022, https://doi.org/10.4269/ajtmh.2010.10-0167.

194 Sherwin F. Wood, “*Trypanosoma cruzi*: New Foci of Enzootic Chagas Disease in California,” *Experimental Parasitology*, vol. 38, 1975, p. 153–160, https://www.ncbi.nlm.nih.gov/pubmed/809291.

195 Lisa A. Shender et al., “Molecular Diversity of *Trypanosoma cruzi* Detected in the Vector *Triatoma protracta* from California,” *PLOS Neglected Tropical Diseases*, vol. 10, no. 1, 2016, https://doi.org/10.1371/journal.pntd.0004291.

196 Rebecca Click Lambert et al., “Potential for Emergence of Chagas Disease in the United States,” *Geospatial Health*, vol. 2, no. 2, 2008, p. 227-239, http://www.geospatialhealth.net/index.php/gh/article/view/246/246.

197 Charles H. Porter and F.H. Collins, “Susceptibility of *Anopheles hermsi* to *Plasmodium vivax,” American Journal of Tropical Medicine and Hygiene*, vol. 42, 1990, p. 414–416, https://www.ncbi.nlm.nih.gov/pubmed/2187365.

198 Centers for Disease Control and Prevention, “Transmission of *Plasmodium vivax* Malaria–San Diego County, California, 1988 and 1989,” *Morbidity and Mortality Weekly Report*, vol. 39, no. 6, p. 91-94, https://www.cdc.gov/mmwr/preview/mmwrhtml/00001559.htm.

199 Rosemary Brunetti, R.F. Fritz, and H.C. Hollister, “An Outbreak of Malaria in California, 1952–53,” *American Journal of Tropical Medicine and Hygiene*, vol. 3, no. 5, 1954, p. 779–88.

200 Yvonne A. Maldonado et al., “Transmission of *Plasmodium vivax* Malaria in San Diego County, 1986,” *American Journal of Tropical Medicine and Hygiene*, 1990, https://www.ncbi.nlm.nih.gov/pubmed/1967916.

201 Cyril Caminade et al., “Impact of Climate Change on Global Malaria Distribution,” *Proceedings of the National Academy of Sciences*, vol. 111, no. 9, March 2014, p. 3,286–3,291, http://www.pnas.org/content/111/9/3286.

202 R.A. Murray et al., “Epidemiological Aspects of the 1984 St. Louis Encephalitis Epidemic in Southern California,” *Proceedings of the California Mosquito Vector Control Association*, vol. 53, 1985, p. 5–9, http://agris.fao.org/agris-search/search.do?recordID=US8745053.

203 William Carlisle Reeves and W.M Hammon, “Epidemiology of the Arthropod-Borne Viral Encephalitides in Kern County, 1943–1952,” Berkeley: University of California School of Public Health, vol. 4, 1962, https://www.ncbi.nlm.nih.gov/pubmed/14491029.

204 William K. Reisen et al., “Effect of Temperature on the Transmission of Western Equine Encephalomyelitis and St. Louis Encephalitis Viruses by *Culex tarsalis* (Diptera:Culicidae),” *Journal of Medical Entomology*, vol. 30, 1993, p. 151–160, https://academic.oup.com/jme/article-abstract/30/1/151/2221253.

205 William Carlisle Reeves et al., “Potential Effect of Global Warming on Mosquito-Borne Arboviruses,” *Journal of Medical Entomology*, vol. 31, 1994, p. 323–332, https://www.ncbi.nlm.nih.gov/pubmed/8057305.

206 William Carlisle Reeves and W.M. Hammon, “Epidemiology of the Arthropod-Borne Viral Encephalitides in Kern County, 1943–52,” Berkeley: University of California School of Public Health, vol. 4, 1962, https://www.ncbi.nlm.nih.gov/pubmed/14491029.

207 Kelly A. Reynolds, K.D. Mena, and C.P. Gerba, “Risk of Waterborne Illness Via Drinking Water in the United States,” *Reviews of Environmental Contamination and Toxicology*, vol. 192, 2008, p. 117–158, https://link.springer.com/chapter/10.1007%2F978-0-387-71724-1_4.

208 Frank C. Curriero et al., “Association Between Extreme Precipitation and Waterborne Disease Outbreaks in the United States, 1948–1994,” *American Journal of Public Health*, vol. 91, 2001, p. 1,194–1,199, https://www.ncbi.nlm.nih.gov/pubmed/11499103.

209 Joan M. Brunkard et al., “Surveillance for Waterborne Disease Outbreaks Associated With Drinking Water—United States, 2007–08,” *Mortality and Morbidity Weekly Report Surveillance Summaries*, vol. 60, no. 12, 2011, p. 38–68, https://www.cdc.gov/mmwr/preview/mmwrhtml/ss6012a4.htm.

210 Jeffrey A. Soller et al., “Estimating the Primary Etiologic Agents in Recreational Freshwaters Impacted by Human Sources of Faecal Contamination,” *Water Research*, vol. 44, 2010, p. 4,736–4,747, https://www.ncbi.nlm.nih.gov/pubmed/20728915.

211 Woutrina A. Miller et al., “Climate and On-Farm Risk Factors Associated With *Giardia duodenalis* Cysts in Storm Runoff From California Coastal Dairies,” *Applied Environmental Microbiology*, vol. 73, 2007, p. 6,972– 6,979, https://www.ncbi.nlm.nih.gov/pubmed/17873066.

212 Heather Auld, D. MacIver, and J. Klaassen, “Heavy Rainfall and Waterborne Disease Outbreaks: Walkerton Example,” *Journal of Toxicology and Environmental Health*, vol. 67, no. 20-22, 2010, p. 1,879–1,887, https://www.tandfonline.com/doi/abs/10.1080/15287390490493475.

213 U.S. Environmental Protection Agency, “Protecting Water Quality from Urban Runoff,” EPA Publication 841-F-03-003, February 2003, https://www.epa.gov/sites/production/files/2015-10/documents/nps_urban-facts_final.pdf.

214 Ryan H. Dwight et al., "Influence of Variable Precipitation on Coastal Water Quality in Southern California," *Water Environment Research*, vol. 83, no. 12, 2011, p. 2,121–2,130, https://www.ncbi.nlm.nih.gov/pubmed/22368953.

215 Ryan H. Dwight et al., "Health Effects Associated with Recreational Coastal Water Use: Urban vs. Rural California," *American Journal of Public Health*, vol. 94, 2004, p. 565–7, https://www.ncbi.nlm.nih.gov/pubmed/15054006.

216 Ryan H. Dwight et al., "Estimating the Economic Burden From Illnesses Associated With Recreational Coastal Water Pollution—Case Study in Orange County," *Journal of Environmental Management*, 2005, https://www.sciencedirect.com/science/article/pii/S0301479705000289#aep-keywords-id8.

217 Suzan Given, L.H. Pendleton, and A.B. Boehm, "Regional Public Health Cost Estimates of Contaminated Coastal Waters Case Study of Gastroenteritis at Southern California Beaches," *Environmental Science and Technology*, vol. 40, 2006, p. 4,851–4,858, https://pubs.acs.org/doi/abs/10.1021/es060679s.

218 Ianis Delpla et al., "Impacts of Climate Change on Surface Water Quality in Relation to Drinking Water Production," *Environment International*, vol. 35, 2009, p.1,225–1,233, http://dx.doi.org/10.1016/j.envint.2009.07.001.

219 Stephanie K. Moore et al., "Impacts of Climate Variability and Future Climate Change on Harmful Algal Blooms and Human Health," *Environmental Health,* vol. 7, supplement 2, S4, 2008, p. 5, http://doi.org/10.1186/1476-069X-7-S2-S4.

220 Kirk Klausmeyer and K. Fitzgerald, "Where Does California's Water Come From? Land Conservation and the Watersheds That Supply California's Drinking Water," Nature Conservancy of California, October 2012, https://www.nature.org/media/california/california_drinking-water-sources-2012.pdf.

221 Joan F. Kenny et al., "Estimated Use of Water in the United States in 2005," *U.S. Geological Survey Circular,* vol. 1344, 2009, https://pubs.usgs.gov/circ/1344/pdf/c1344.pdf; U.S. Environmental Protection Agency, "Recommendations for Public Water Systems to Manage Cyanotoxins in Drinking Water," EPA 815–R–15–010, EPA Office of Water, June 2015, https://www.epa.gov/sites/production/files/2017-06/documents/cyanotoxin-management-drinking-water.pdf.

222 Lorraine C. Backer et al., "Recreational Exposure to Microcystins During Algal Blooms in Two California Lakes," *Toxicon*, vol. 55, no. 5, 2010, https://www.sciencedirect.com/science/article/pii/S0041010109003481.

223 City of Toledo Department of Public Utilities, "Microcystin Event Preliminary Summary," August 4, 2014, p. 73, https://toledo.oh.gov/media/2720/microcystin-test-results.pdf.

224 Elizabeth D. Hilborn et al., "Algal Bloom-Associated Disease Outbreaks Among Users of Freshwater Lakes–United States, 2009–10," *Mortality and Morbidity Weekly Report,* vol. 63, no. 1, 2014, p. 11–15, https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6301a3.htm.

225 Lora E. Fleming et al., "Review of Florida Red Tide and Human Health Effects," *Harmful Algae*, vol. 10, 2011, p. 224–233, http://dx.doi.org/10.1016/j.hal.2010.08.006.

226 My Water Quality, "Are Harmful Algal Blooms Affecting Our Waters?" California Water Quality Monitoring Council, http://www.mywaterquality.ca.gov/habs/, accessed August 26, 2018.

227 Rachel J Parsons et al., "Ocean Time-Series Reveals Recurring Seasonal Patterns of Virioplankton Dynamics in the Northwestern Sargasso Sea," *ISME Journal*, vol. 6, 2012, p. 273–284, https://www.nature.com/articles/ismej2011101.

228 Centers for Disease Control and Prevention, "Food and Waterborne Diarrheal Disease," https://www.cdc.gov/climateandhealth/effects/food_waterborne.htm, accessed September 3, 2018; Ryan M. McCabe et al., "An Unprecedented Coastwide Toxic Algal Bloom Linked to Anomalous Ocean Conditions," *Geophysical Research Letters*, vol. 43, no. 10, 2016, p. 366–376, https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016GL070023.

229 Luis E. Escobar et al., "A Global Map of Suitability for Coastal *Vibrio cholera* Under Current and Future Climate Conditions," *Acta Tropica*, vol. 149, September 2015, p. 202-211, https://www.sciencedirect.com/science/article/pii/S0001706X15300218.

230 U.S. Centers for Disease Control and Prevention, "Cholera—*Vibrio cholerae* Infection," https://www.cdc.gov/cholera/index.html, accessed October 20, 2018.

231 Allison Crimmins et al., "Impacts of Climate Change on Human Health in the United States: A Scientific Assessment," U.S. Global Change Research Program, 2016, p. 1-312, http://dx.doi.org/10.7930/J0R49NQX.

232 Michelle A. Hummel, M.S. Berry, and M.T. Stacey, "Sea Level Rise Impacts on Wastewater Treatment Systems Along the U.S. Coasts," *Earth's Future*, 2018, p. e312, https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2017EF000805.

233 Office of Environmental Health Hazard Assessment, CalEPA, "Indicators of Climate Change in California," 2018, https://oehha.ca.gov/media/downloads/climate-change/report/2018caindicatorsreportmay2018.pdf.

234 Groundwater Ambient Monitoring and Assessment, “Guide for Private Domestic Well Owners,” California State Water Resources Control Board, March 2015, https://www.waterboards.ca.gov/gama/docs/wellowner_guide.pdf.

235 U.S. Environmental Protection Agency, “Private Drinking Water Wells,” 2012, https://www.epa.gov/privatewells.

236 Groundwater Ambient Monitoring and Assessment, “Guide for Private Domestic Well Owners,” California State Water Resources Control Board, March 2015, https://www.waterboards.ca.gov/gama/docs/wellowner_guide.pdf.

237 Gunther F. Craun et al., “Causes of Outbreaks Associated With Drinking Water in the United States From 1971 to 2006,” *Clinical Microbiology Reviews,* vol. 23, 2010, p. 507–528, https://www.ncbi.nlm.nih.gov/pubmed/20610821.

238 Elizabeth D. Hilborn et al., “Surveillance for Waterborne Disease Outbreaks Associated With Drinking Water and Other Nonrecreational Water—United States, 2009–2010," *Morbidity and Mortality Weekly Report*, vol. 62, 2013, p. 714–720, https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6235a3.htm.

239 Kimberley F. Cann et al., “Extreme Water-Related Weather Events and Waterborne Disease,” *Epidemiology and Infection*, vol. 141, 2013, p. 671–86, http://dx.doi.org/10.1017/s0950268812001653.

240 Aris P. Georgakakos et al., “Climate Change Impacts in the United States: Third National Climate Assessment,” ch. 3, U.S. Global Change Research Program, Washington, D.C., 2014, p. 69–112, http://s3.amazonaws.com/nca2014/high/NCA3_Climate_Change_Impacts_in_the_United%20States_HighRes.pdf.

241 Joan B. Rose et al., “Climate Variability and Change in the United States: Potential Impacts on Water- and Foodborne Diseases Caused by Microbiologic Agents," *Environmental Health Perspectives*, vol. 109, no. 2, 2001, p. 211–221, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1240668/.

242 Iain R. Lake et al., “A Re-Evaluation of the Impact of Temperature and Climate Change on Foodborne Illness," *Epidemiology and Infection*, vol. 137, p. 1,538–1,547, http://dx.doi.org/10.1017/s0950268809002477.

243 Iain R. Lake and G.C. Barker, “Climate Change, Foodborne Pathogens and Illness in Higher-Income Countries,” *Current Environmental Health Reports*, vol. 5, no. 1, 2018, p. 187–196, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5876342/.

244 Ibid.

245 Junguo Liu et al., “A Global and Spatially Explicit Assessment of Climate Change Impacts on Crop Production and Consumptive Water Use,” *PLOS One*, vol. 8, no. 2, 2013, p. e57750, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3583897/; Allison Crimmins et al., “Impacts of Climate Change on Human Health in the United States: A Scientific Assessment,” U.S. Global Change Research Program, 2016, p. 1-312, http://dx.doi.org/10.7930/J0R49NQX.

246 Lynnette Zelezny et al., “Impact of the Drought in the San Joaquin Valley of California,” Fresno State Academics, 2015, http://www.fresnostate.edu/academics/drought/documents/Fresno%20State_Drought%20Study_Minus%20Executive%20Summary_FINAL.pdf.

247 California Department of Public Health, “Yearly Summaries of Selected General Communicable Diseases in California, 2011–16," California Department of Public Health, Center for Infectious Diseases, Division of Communicable Disease Control, Infectious Diseases Branch, Surveillance and Statistics Section, 2013, https://www.cdph.ca.gov/Programs/CID/DCDC/CDPH%20Document%20Library/YearlySummariesofSelectedCommDiseasesinCA2011-2016.pdf.

248 Lynnette Zelezny et al., “Impact of the Drought in the San Joaquin Valley of California,” Fresno State Academics, 2015, http://www.fresnostate.edu/academics/drought/documents/Fresno%20State_Drought%20Study_Minus%20Executive%20Summary_FINAL.pdf.

249 California Department of Public Health, “Yearly Summaries of Selected General Communicable Diseases in California, 2011–16, California Department of Public Health, Center for Infectious Diseases, Division of Communicable Disease Control, Infectious Diseases Branch, Surveillance and Statistics Section, 2013, https://www.cdph.ca.gov/Programs/CID/DCDC/CDPH%20Document%20Library/YearlySummariesofSelectedCommDiseasesinCA2011-2016.pdf.

250 Christopher Kilonzo et al., “Fecal Shedding of Zoonotic Foodborne Pathogens by Wild Rodents in a Major Agricultural Region of the Central California Coast,” *Applied Environmental Microbiology*, vol. 79, 2013, p. 6,337–6,344, http://aem.asm.org/content/79/20/6337.

251 Daniel Patrick Bebber, “Range-Expanding Pests and Pathogens in a Warming World,” *Annual Review of Phytopathology*, vol. 53, 2015, p. 335–356, http://dx.doi.org/10.1146/annurev-phyto-080614-120207.

252 Rosa A. Sanchez-Guillen et al., “Evolutionary Consequences of Climate-Induced Range Shifts in Insects,” *Biological Reviews*, July 6, 2015, http://dx.doi.org/10.1111/brv.12204.

253 Jorge A. Zavala et al., “Anthropogenic Increase in Carbon Dioxide Compromises Plant Defense Against Invasive Insects,” *Proceedings of the National Academy of Sciences*, vol. 105, 2008, p. 5,129–5,133, http://dx.doi.org/10.1073/pnas.0800568105.

254 Bridget F. O’Neill et al., “Leaf Temperature of Soybean Grown Under Elevated $CO_2$ increases *Aphis gycines* (Hemiptera: Aphididae) Population Growth,” *Insect Science*, vol. 18, 2011, p. 419–425, https://onlinelibrary.wiley.com/doi/full/10.1111/j.1744-7917.2011.01420.x.

255 Chi-Chung Chen and B.A. McCarl, “An Investigation of the Relationship Between Pesticide Usage and Climate Change,” *Climatic Change*, vol. 50, 2001, p. 475–487, https://link.springer.com/article/10.1023%2FA%3A1010655503471.

256 R. Sari Kovats et al., “Climate Variability and *Campylobacter* Infection: An International Study,” *International Journal of Biometeorology*, vol. 49, no. 4, March 2005, p. 207–214, https://www.ncbi.nlm.nih.gov/pubmed/15565278.

257 R. Sari Kovats et al., “Effect of Temperature on Food Poisoning: A Time Series Analysis of Salmonellosis in 10 European Countries,” *Epidemiology of Infection*, vol. 132, 2004, p. 443–453, https://www.ncbi.nlm.nih.gov/pubmed/15188714.

258 Rita R. Colwell and J. Patz, “Climate, Infectious Disease and Health: An Interdisciplinary Perspective,” American Academy of Microbiology, 1998, https://www.asm.org/index.php/colloquium-reports/item/4469-climate-infectious-disease-and-health-an-interdisciplinary-perspective.

259 Iain R. Lake, “Foodborne Disease and Climate Change in the United Kingdom,” *Environmental Health*, vol. 16, no. 117, 2017, p. 53–59, https://ehjournal.biomedcentral.com/articles/10.1186/s12940-017-0327-0.

260 Ahmet Koluman et al., “Food Safety and Climate Change: Seasonality and Emerging Foodborne Pathogens,” *Journal of Gastroenterology Research*, vol. 1, no. 1, 2017, p. 24–29, http://scholarlypages.org/Articles/gastroenterology/jgr-1-004.php?jid=gastroenterology.

261 National Ocean Service, “West Coast Harmful Algal Bloom,” National Oceanic and Atmospheric Administration, U.S. Department of Commerce, https://oceanservice.noaa.gov/news/sep15/westcoast-habs.html, accessed September 26, 2018.

262 National Centers for Coastal Ocean Science, “Upwelling and Coastal Land Use Patterns on the Development of HAB Hotspots Along the California Coast,” National Oceanic and Atmospheric Administration, U.S. Department of Commerce, https://coastalscience.noaa.gov/project/upwelling-coastal-land-use-patterns-development-hab-california/, accessed September 26, 2018.

263 Matthew Schwartz, “Harmful Algal Blooms Threaten Public Health and Economic Stability Along the West Coast,” Harvard University Graduate School of Arts and Sciences blog, http://sitn.hms.harvard.edu/flash/2015/harmful-algal-blooms-threaten-public-health-and-economic-stability-along-the-west-coast/, accessed September 26, 2018.

264 California Department of Public Health Division of Radiation Safety and Environmental Management, “Marine Biotoxin Monitoring Program,” https://www.cdph.ca.gov/Programs/CEH/DRSEM/Pages/EMB/Shellfish/Marine-Biotoxin-Monitoring-Program.aspx, accessed October 20, 2018.

265 Ocean Water Protection Program, “Shellfish Toxins/Quarantine Information,” Orange County Health Care Agency, https://ocbeachinfo.com/shellfish/, accessed September 15, 2018.

266 Mark Prado, “Bay Area Mussel Eater Gets Paralytic Shellfish Poisoning,” *Mercury News*, March 14, 2018, https://www.mercurynews.com/2018/03/14/bay-area-mussel-eater-gets-paralytic-shellfish-poisoning/.

267 World Food Summit, “Rome Declaration on World Food Security,” November 13–17, 1996, http://www.fao.org/docrep/003/w3613e/w3613e00.htm.

268 Molly E. Brown et al., “Climate Change, Global Food Security, and the U.S. Food System,” U.S. Global Change Research Program, 2015, p. 146, https://www.usda.gov/oce/climate_change/FoodSecurity2015Assessment/FullAssessment.pdf.

269 Allison Crimmins et al., “Impacts of Climate Change on Human Health in the United States: A Scientific Assessment,” U.S. Global Change Research Program, 2016, p. 1-312, http://dx.doi.org/10.7930/J0R49NQX.

270 Daniel R. Taub, B. Miller, and H. Allen, “Effects of Elevated $CO_2$ on the Protein Concentration of Food Crops: A Meta-Analysis,” *Global Change Biology*, vol. 14, 2008, p. 565–575, https://onlinelibrary.wiley.com/doi/full/10.1111/j.1365-2486.2007.01511.x.

271 Irakli Loladze, “Hidden Shift of the Ionome of Plants Exposed to Elevated $CO_2$ Depletes Minerals at the Base of Human Nutrition,” *eLife*, vol. 3, 2014, p. e02245, http://dx.doi.org/10.7554/eLife.02245.

272 Louise Bedsworth et al., “Statewide Summary Report. California’s Fourth Climate Change Assessment,” publication no. SUMCCCA4–2018–013, 2018, http://www.climateassessment.ca.gov/state/docs/20180827-StatewideSummary.pdf.

273 Allison Crimmins et al., “Impacts of Climate Change on Human Health in the United States: A Scientific Assessment,” U.S. Global Change Research Program, 2016, p. 1–312, http://dx.doi.org/10.7930/J0R49NQX.

274 Christina Greene, “Broadening Understandings of Drought—Climate Vulnerability of Farmworkers and Rural Communities in California (USA),” *Environmental Science and Policy*, vol. 89, November 2018, p. 283–291, https://www.sciencedirect.com/science/article/pii/S1462901118305100.

275 Jerry M. Melillo, T. Richmond, and G.W. Yohe, eds., “Climate Change Impacts in the United States: Third National Climate Assessment,” U.S. Global Change Research Program, 2014, https://nca2014.globalchange.gov/report/our-changing-climate/frost-free-season.

276 Ibid.

277 California Emergency Management Agency and California Natural Resources Agency, “California Adaptation Planning Guide,” July 2012, http://resources.ca.gov/docs/climate/APG_Defining_Local_and_Regional_Impacts.pdf.

278 Jerry M. Melillo, T. Richmond, and G.W. Yohe, eds., “Climate Change Impacts in the United States: Third National Climate Assessment,” U.S. Global Change Research Program, 2014, https://nca2014.globalchange.gov/report/our-changing-climate/frost-free-season.

279 Ibid.

280 David B. Lobell, K.N. Cahill, and C.B. Field, “Historical Effects of Temperature and Precipitation on California Crop Yields,” *Climatic Change*, vol. 81, no. 2, 2007, p. 187–203, https://doi.org/10.1007/s10584-006-9141-3.

281 David B. Lobell et al., “Impacts of Future Climate Change on California Perennial Crop Yields: Model Projections with Climate and Crop Uncertainties,” Lawrence Livermore National Laboratory, March 14, 2006, https://e-reports-ext.llnl.gov/pdf/329204.pdf.

282 California Department of Food and Agriculture, “California Agricultural Exports, 2016–17,” https://www.cdfa.ca.gov/statistics/PDFs/2017AgExports.pdf.

283 California Walnuts, “Walnut Industry,” https://walnuts.org/walnut-industry/, accessed August 1, 2018.

284 California Department of Food and Agriculture, “California Agricultural Exports, 2016–17,” https://www.cdfa.ca.gov/statistics/PDFs/2017AgExports.pdf.

285 David B. Lobell et al., “Impacts of Future Climate Change on California Perennial Crop Yields: Model Projections with Climate and Crop Uncertainties,” Lawrence Livermore National Laboratory, March 14, 2006, https://e-reports-ext.llnl.gov/pdf/329204.pdf.

286 Tapan B. Pathak et al., "Climate Change Trends and Impacts on California Agriculture: A Detailed Review," *Agronomy*, vol. 8, no. 25, 2018, https://www.mdpi.com/2073-4395/8/3/25/pdf.

287 David B. Lobell and C.B. Field, “California Perennial Crops in a Changing Climate,” *Climatic Change*, vol. 109, 2011, p. 317–333, https://link.springer.com/article/10.1007/s10584-011-0303-6.

288 Jerry Hatfield et al., “Climate Change Impacts in the United States: Third National Climate Assessment," ch. 6, Jerry Melillo, T.C. Richmond, and G.W. Yohe, eds., (Washington, D.C.: U.S. Global Change Research Program, 2014), p. 150–174, http://s3.amazonaws.com/nca2014/high/NCA3_Climate_Change_Impacts_in_the_United%20States_HighRes.pdf.

289 David Zilberman and S. Kaplan, “An Overview of California’s Agricultural Adaptation to Climate Change,” Foundation of Agricultural Economics, University of California, https://giannini.ucop.edu/publications/are-update/issues/2014/18/1/agricultural-adaptation/.

290 Joseph P. Reser and J.K. Swim, “Adapting to and Coping With the Threat and Impacts of Climate Change,” *American Psychologist*, vol. 66, 2011, p. 277–289, http://dx.doi.org/10.1037/a0023412.

291 Mike Ahern et al., “Global Health Impacts of Floods: Epidemiologic Evidence,” *Epidemiologic Reviews*, vol. 27, 2005, p. 36–46, https://www.ncbi.nlm.nih.gov/pubmed/15958425.

292 Anita L. Wenden, “Women and Climate Change: Vulnerabilities and Challenges,” *Climate Change and Human Well-being: Global Challenges and Opportunities*, Inka Weissbecker, ed. (New York: Springer–Verlag, 2011), p. 119–133, http://dx.doi.org/10.1007/978-1-4419-9742-5.

293 Carol S. North et al., “Course of PTSD, Major Depression, Substance Abuse, and Somatization After a Natural Disaster,” *Journal of Nervous and Mental Disease*, vol. 192, 2004, p. 823–829, https://www.ncbi.nlm.nih.gov/pubmed/15583503.

294 Ryan Larrance, M. Anastario, and L. Lawry, “Health Status Among Internally Displaced Persons in Louisiana and Mississippi Travel Trailer Parks,” *Annals of Emergency Medicine,* vol. 49, 2007, p. 590–601, https://www.ncbi.nlm.nih.gov/pubmed/17397967.

295 Ronald C. Kessler et al., “Trends in Mental Illness and Suicidality After Hurricane Katrina,” *Molecular Psychiatry*, vol. 13, 2008, p. 374–384, http://dx.doi.org/10.1038/sj.mp.4002119.

296 Allison Crimmins et al., “Impacts of Climate Change on Human Health in the United States: A Scientific Assessment,” U.S. Global Change Research Program, 2016, p. 229, http://dx.doi.org/10.7930/J0R49NQX.

297 Rupa Basu et al., "Examining the Association Between Apparent Temperature and Mental Health-Related Emergency Room Visits in California," *American Journal of Epidemiology*, vol. 187, 2018, p. 726–735, https://academic.oup.com/aje/article/187/4/726/4081578; The 16 climate zones used in the study included parts of Arcata, China Lake, El Centro, El Toro, Fresno, Los Angeles, Mount Shasta, Oakland, Pasadena, Red Bluff, Riverside, Sacramento, San Diego, Santa Maria, Santa Rosa, and Sunnyvale.

298 Allison Crimmins et al., "Impacts of Climate Change on Human Health in the United States: A Scientific Assessment," U.S. Global Change Research Program, 2016, p. 224, http://dx.doi.org/10.7930/J0R49NQX.

299 Fran H. Norris et al., "60,000 Disaster Victims Speak: Part I. An Empirical Review of the Empirical Literature, 1981–2001," *Psychiatry: Interpersonal and Biological Processes*, vol. 65, 2002, p. 207–39, http://dx.doi.org/10.1521/psyc.65.3.207.20173.

300 David M. Simpson, I. Weissbecker, and S.E. Sephton, "Extreme Weather-Related Events: Implications for Mental Health and Well-Being," *Climate Change and Human Well-being: Global Challenges and Opportunities,* Inka Weissbecker, ed. (New York: Springer–Verlag, 2011), p. 57–78, http://dx.doi.org/10.1007/978-1-4419-9742-5.

301 Daya J. Somasundaram and W. van de Put, "Management of Trauma in Special Populations After a Disaster," *Journal of Clinical Psychiatry*, vol. 67, 2006, p. 64–73, https://www.ncbi.nlm.nih.gov/pubmed/16602818.

302 Ulrich Ranft et al., "Long-Term Exposure to Traffic-Related Particulate Matter Impairs Cognitive Function in the Elderly," *Environmental Research*, vol. 109, 2009, p. 1,004–1,011, http://dx.doi.org/10.1016/j.envres.2009.08.003.

303 Cathryn Tonne et al., "Traffic-Related Air Pollution in Relation to Cognitive Function in Older Adults," *Epidemiology*, vol. 25, 2014, p. 674–681, https://www.ncbi.nlm.nih.gov/pubmed/25036434.

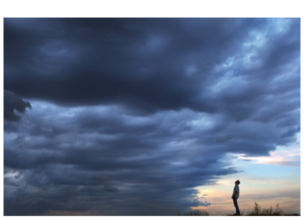
304 Greer Sullivan et al., "Preexisting Mental Illness and Risk for Developing a New Disorder After Hurricane Katrina," *Journal of Nervous and Mental Disease*, vol. 201, 2013, p. 161–166, https://www.ncbi.nlm.nih.gov/pubmed/23364127.

305 Alexander C. McFarlane and P. Papay, "Multiple Diagnoses in Post-Traumatic Stress Disorder in the Victims of a Natural Disaster," *Journal of Nervous and Mental Disease*, vol. 180, no. 8, August 1992, p. 498–504, https://www.ncbi.nlm.nih.gov/pubmed/1500931.

306 David M. Benedek, C. Fullerton, and R.J. Ursano, "First Responders: Mental Health Consequences of Natural and Human-Made Disasters for Public Health and Public Safety Workers," *Annual Review of Public Health*, vol. 28, 2007, p. 55–68, http://dx.doi.org/10.1146/annurev.publhealth.28.021406.144037.

307 California Department of Public Health Climate Change and Health Equity Program, "Climate Change and Health Equity," https://www.cdph.ca.gov/Programs/OHE/Pages/CCHEP.aspx, accessed October 25, 2018.

308 Hannah Nissan and D. Conway, "From Advocacy to Action: Projecting the Health Impacts of Climate Change," *PLOS Medicine*, vol. 15, no. 7, 2018, p. e1002624, https://doi.org/10.1371/journal.pmed.1002624.



Julianne McCall at the California Senate Office of Research (SOR) prepared this report at the request of Senator Ricardo Lara, November 2018. SOR is a nonpartisan office charged with serving the research needs of the California State Senate and assisting Senate members and committees with the development of effective public policy. The office was established by the Senate Rules Committee in 1969. For more information, please visit **http://sor.senate.ca.gov** or call **(916) 651-1500**.