More frequent and intense climate extremes, warming temperatures, and altered precipitation patterns have led to widespread, pervasive impacts on human health and well-being (IPCC, 2022). Climate change affects health directly through exposures to heat, floods, and other weather events, and indirectly through exacerbated health threats, such as higher levels of air pollutants, degraded water quality, and increased populations of disease vectors (Balbus et al., 2013; Ebi et al., 2018; NIH, 2022).

In California and across the US, heat causes more reported deaths per year on average than any other weather hazard (NOAA, 2021). In addition to emergency room visits and hospitalizations due to heat-related illness, other impacts are evident in California. Reports of occupational heat-related illnesses are increasing, especially among wildland firefighters and farmworkers. As drought and elevated temperatures fuel wildfires across the state, the threat of exposure to hazardous smoke has increased in recent years for many communities. Warming temperatures and changes in precipitation patterns have altered the seasonality, distribution, and behavior of insects that act as vectors of infectious disease, such as the *Culex* mosquito, the vector of West Nile virus. The number of West Nile virus cases have increased in California during periods of above-normal temperatures and drought conditions. Warming temperatures, drought, aridity, windstorms, and wildfires, contribute to the proliferation of the Valley Fever fungus and the dissemination of its spores, leading to a rise in the number of cases.

Climate change is often described as a threat multiplier. Communities in California confronted by multiple climate hazards must also deal with the challenges posed by environmental pollution, poorly maintained infrastructure, poverty, and other economic and institutional factors. Low-income communities, rural communities, communities of color and Tribes are often disproportionately impacted by such compounding vulnerabilities. The same communities also generally have less capacity and resources to prepare for, adapt to, or recover from the impacts of climate change. To address this gap, the State [Adaptation Strategy] aims to strengthen climate resilience in the most climate-vulnerable communities in California. Similarly, in recognition that the burden of extreme heat falls disproportionately on the most vulnerable of populations in the state, the State's [Extreme Heat Action Plan] commits to near-term actions to accelerate readiness and protect such communities.

INDICATORS: IMPACTS ON HUMAN HEALTH

Heat-related deaths and illnesses *(updated)*
Occupational heat-related illness *(new)*
Valley fever (Coccidioidomycosis) *(new)*
Vector-borne diseases *(updated)*
Wildfire smoke *(new)*

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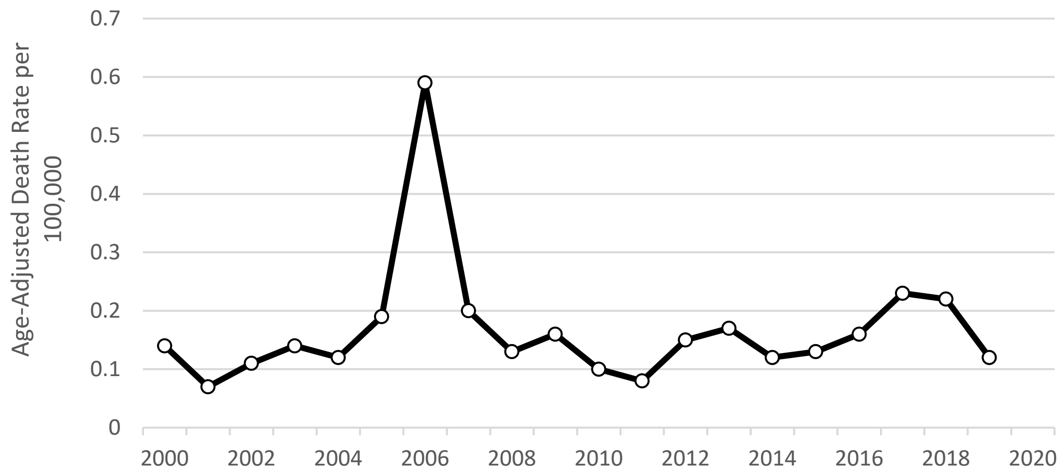
HEAT-RELATED DEATHS AND ILLNESSES

Deaths and illnesses from heat exposure are often unrecognized, misdiagnosed and thus, severely underreported. In 2006, when summertime temperatures were especially high, the reported number of deaths attributed to heat was much higher than any other year. Reported deaths and emergency department visits were also elevated in 2017, another notably warm year.

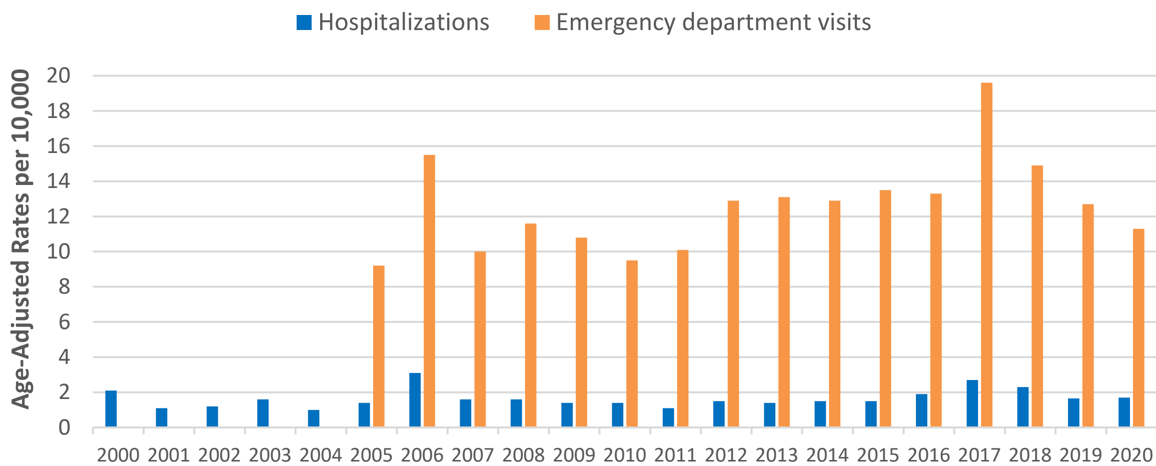
Figure 1. Heat-related deaths in California*



Source: Data set compiled by Tracking California (2021), using data from the Center for Health Statistics

** Reported deaths in May to September due to heat exposure as a main or contributing cause.*

Figure 2. Heat-related illness in California*



Source: Data set compiled by Tracking California (2022), using data from the data from the Office of Statewide Health Planning and Development

** Reported hospitalizations and emergency department visits in May to September. Data for emergency department visits were not available until 2005.*

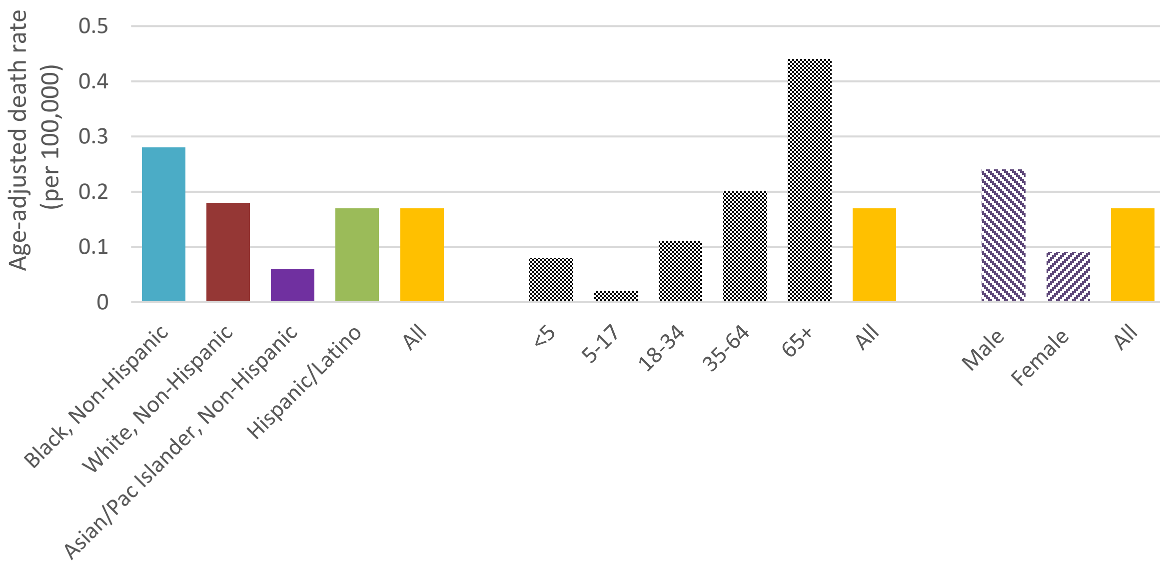
What does the indicator show?

The association between exposure to high temperatures and illness or deaths is well established. The classical case definition of heat illnesses includes ailments such as heat rash, heat cramps, heat exhaustion, and heat stroke. However, because of the stress that elevated ambient temperatures can exert on the body, heat exposure can produce health effects and exacerbate a broad range of health conditions (see below under *Why is this indicator important)*. Health records may not capture heat-related illness if exposure to excess heat is not explicitly documented. Consequently, health cases related to heat are often unrecognized and misdiagnosed. For example, a study of about 300 populous counties across the US estimated that the annual number of deaths attributable to heat was substantially larger than previous estimates reported by the Centers for Disease Control (CDC) and others (Weinberger et al., 2020). A substantial number of deaths occurred at only moderately hot temperatures. While recognizing that lack of consistency in the identification and recording of heat-related death and illness underestimates impacts (Berko et al., 2014), tracking the number of deaths and illnesses attributed either wholly or in part to heat illnesses can provide an indication of the trend in health impacts related to climate change.

Figure 1 presents annual age-adjusted death rates in California for diagnoses specifically attributed to heat, either as a primary or underlying cause, from 1999 to 2019. Figure 2 shows both heat-related hospitalizations (2000 to 2018) and heat-related emergency department (ED) visits (2005 to 2018) in California. No trend is evident for heat-attributed deaths or hospitalizations in California; rates were highest in 2006 (for deaths) and 2017 (for emergency department visits), when summertime temperatures were especially high. The mortality data, and to a lesser extent hospitalization data, do capture the impact of extended heat waves on health over large geographical areas. Emergency department visits show a statistically increasing trend, as expected with the warming temperatures associated with climate change.

Examining these indicators among specific demographics points to greater susceptibility to heat illnesses among adults aged 65 and older, males, and non-Hispanic Blacks. These groups have higher rates of identified heat-related deaths, emergency department visits and hospitalizations than those in other comparable demographic groups (Figures 3 and 4).

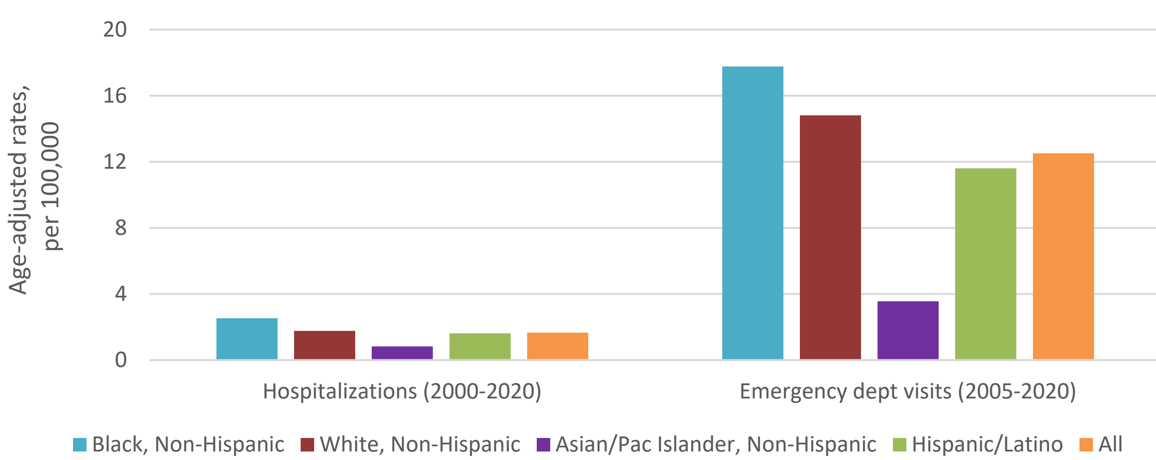
Figure 3. Heat-related death rates in California, by race, age and gender (2000-2019)



Source: Data set compiled by Tracking California (2021), using data from the Center for Health Statistics

** Reported deaths in May to September due to heat exposure as a main or contributing cause.*

Figure 4. Heat-related illness, by race



Source: Data set compiled by Tracking California (2022), using data from the data from the Office of Statewide Health Planning and Development

**Includes death with heat identified as a primary or underlying cause.*

Why is this indicator important?

Heat causes more reported deaths per year on average in the United States than any other weather hazard, yet heat-related illnesses and deaths are generally preventable (Luber et al., 2014; NOAA, 2021). A comprehensive analysis of heat-related deaths in the US by the CDC found an average of 702 deaths occurred annually during 2004-2018 (Vaidyanathan et al., 2020). CDC noted that understanding patterns of heat-related deaths (for example, by race or ethnicity, age, or income level) is critical to developing more effective surveillance and intervention strategies. Their *Heat and Health Tracker* provides local heat and health information for communities to better prepare for and respond to extreme heat events.

Assessing how heat-related deaths and illnesses change with time provides a specific measure of how climate change-related temperature shifts are impacting human health. As noted above, the cases identified will represent only a small selection of heat-related health effects. Higher temperatures have been linked with increased deaths from all non-accidental causes, and more specifically cardiovascular and respiratory causes (Basu and Malig, 2011; Song et al., 2017). Heat waves and generally higher temperature exposures in California are related to increased health care usage for a wide range of diagnoses including electrolyte imbalance, diabetes, renal, cardiovascular and respiratory diseases (Basu et al., 2012; Guirguis et al., 2014; Green et al., 2010; Knowlton et al., 2009; Malig et al., 2019; Sherbakov et al., 2018). Increases in apparent temperature (measure of ambient temperature adjusted for relative humidity) have also been linked with adverse birth outcomes such as preterm birth, stillbirth, and low birth weight (Bekkar et al., 2020). Additionally, hotter temperatures may increase emergency department visits for mental health-related outcomes, such as for psychiatric conditions and self-harming or aggressive behaviors (Basu et al., 2017b; Liu et al., 2020; Thompson et al., 2018).

Tracking heat-related illnesses and deaths provides critical information for developing adaptation plans and evaluating their successes, especially in relation to heat waves. State and local policies, plans, and programs focusing on heat are already in place in some locations. These may include heat wave early warning and surveillance (observation) systems, accessible cooling centers, public education campaigns on preventing heat-related illnesses, and worker heat-safety regulations. The use of air conditioning has been associated with significant reductions in heat-related hospital visits in California (Ostro et al., 2010). However, during periods of high heat, there is likely to be a greater risk of brownouts or blackouts from overuse of gas and electricity.

Periods of warmer temperatures and heat waves are expected to rise in frequency, duration, and intensity over the next century (IPCC, 2021; Luber et al., 2014). In California, annual average maximum daily temperatures are projected to increase by about 4.4 to 5.8 degrees Fahrenheit (°F) by mid-century, and by about 5.6 to 8.8°F by the end of the century (Bedsworth et al., 2018). These projections suggest an increasing public health burden from heat-related deaths and illnesses.

What factors influence this indicator?

Heat-related illnesses are affected by characteristics of the heat exposure, such as frequency, intensity and duration. Other factors relate to the exposed individuals themselves, such as age, health status, and the degree to which protective measures against heat are taken by individuals and instituted through policy on a broader population-level.

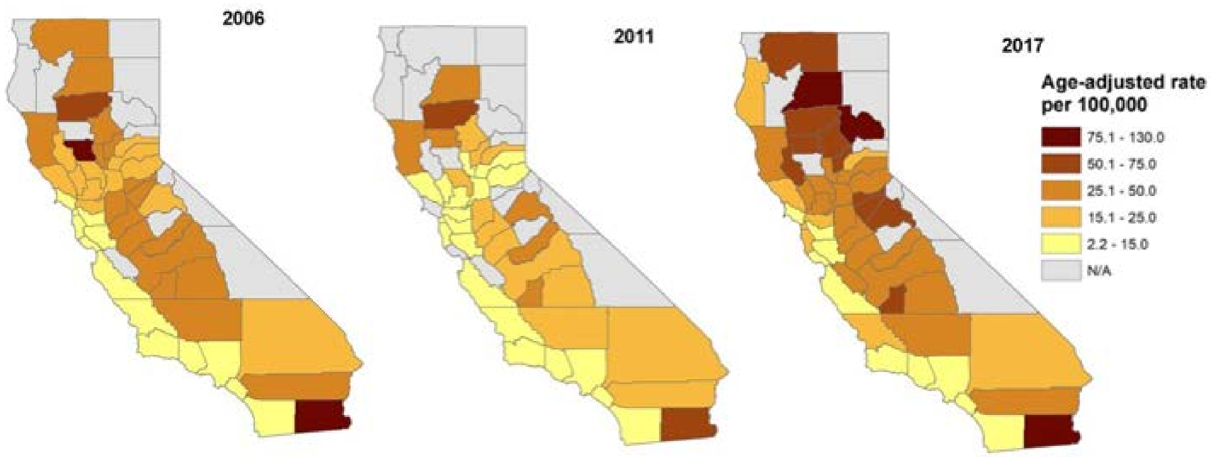
High temperatures and heat waves can impact air quality and pose a threat to public health (Nolte et al., 2018; O'Lenick et al., 2019). Heat can accelerate the formation of ground-level ozone and also trap ozone, particulate matter and other harmful air pollutants. Exposure to these pollutants has been linked to adverse respiratory, cardiovascular, mental health, and reproductive outcomes (Bekkar et al., 2020; Nguyen et al., 2021; US EPA 2019). Air pollution may also work in synergy with extremely high temperatures to increase adverse cardiovascular, respiratory and other health effects (Anenberg et al., 2020).

As shown in Figures 1 and 2, heat-related illnesses and deaths in 2006 peaked during the prolonged heat wave that occurred from July 16 to 26 (Knowlton et al., 2009; Margolis et al., 2008). Average apparent temperatures ranged from 81°F to 100°F, which is 4°F greater than the average statewide temperatures in July. The Central Valley region had the highest number of uninterrupted hot days ever recorded, with each day reaching 100°F and greater. Multiple locations in California broke records for the highest number of uninterrupted days over 100°F ever recorded: 11 in Sacramento; 12 in Modesto; and 21 in Woodland Hills near Los Angeles (Kozlowski and Edwards, 2007). In 2017, California experienced record summer heat, with numerous daytime and nighttime heat waves and record high temperatures (DWR, 2018). Death Valley set a new record for highest average monthly temperature in July with a value of 107.4°F. In Redding, the temperature topped 100°F a record 72 times. Statewide, the June/July/August average temperature was also a record high.

Specific characteristics of prolonged heat events may influence the degree to which heat-related health effects are felt. Higher night-time temperatures during heat waves may incur greater effects by preventing respite from high daytime temperatures (Gershunov et al., 2009). Heat waves accompanied by high humidity are especially dangerous, as the humidity prevents sweat from evaporating to cool down the body. Studies report that even short periods of high temperatures are associated with health impacts (Gasparinni and Armstrong 2011; Sherbakov et al., 2018).

Studies of California heat waves found that health impacts were greatest in the Central Valley and along the coast (Guirguis et al., 2014; Knowlton et al., 2009). Coastal populations tend to be less acclimated to higher temperatures and have lower rates of air conditioner ownership. Buildings, dark paved surfaces, lack of vegetation and trees, and heat emitted from vehicles and air conditioners cause cities to generate and retain heat, a phenomenon known as the "urban heat island effect" (CDPH 2007). Thus, urban residents may experience more heat than people who live in surrounding suburban and rural areas. Figure 5 shows emergency department visit rates across California in 2006 (extended summer heat wave), 2011 (a cool summer season), and 2017 (exceptionally hot summer). Note the distinction between 2006 vs 2017 and which counties are most impacted.

Figure 5. Emergency department visits by county due to heat illness in 2006, 2011 and 2017*



Source: Tracking California 2021

** Maps present age-adjusted rates for emergency department visits by county during two unusually hot summer years (2006 and 2017) and a relatively cool summer (2011).*

As noted above, certain demographic groups may be more vulnerable to heat illness (adults aged 65 and older, males, and non-Hispanic Blacks). Other factors that can increase susceptibility to temperature are young age (5 years and under), pre-existing health conditions (such as heart or lung disease) or certain medications or substances (Ebi et al., 2018; Gronlund et al., 2018; Vaidyanathan et al, 2020). Furthermore, socially isolated people, the poor, and those who have difficulty accessing medical care likely face increased risks during hot weather (Basu and Ostro, 2008; Luber et al., 2014). Pregnant women may be more likely to suffer adverse birth outcomes with heat exposure (Bekkar et al., 2020).

Those engaged in vigorous physical activity, such as workers in construction, firefighting, and agriculture are also at risk. Over the past two decades, reported heat-related illnesses have increased in California (see *Occupational heat-related illness* indicator). In contrast, occupational heat-related deaths has not been well studied. An analysis of worker death rates in the United States from 2000-2010 reported a rate of 0.24 deaths per 1 million workers in California (Gubernot et al. 2016). Compared to the states with the ten highest rates (Mississippi had the highest, at 1.05 per 1 million workers), California's rate is relatively low, likely due to the promulgation in 2005 of the state's enforceable regulation for prevention of heat illness in outdoor workers.

As adaptation measures are implemented and become more effective, the impacts of higher temperatures on heat illness rates may be mitigated. Measures – both planned and already under way –by state and local government and other entities include early warning and surveillance systems, access to air conditioning through cooling centers or through grants, and public outreach and education, particularly those targeting vulnerable populations. The state's priorities and goals addressing the risks posed by warming temperatures and other climate change impacts are outlined in California's Climate Adaptation Strategy.

Technical considerations

Data characteristics

Heat-related hospitalizations and emergency department visits were identified for the months of May to September by the California Environmental Health Tracking Program (CEHTP, recently renamed "Tracking California"). Tracking California is a program of the Public Health Institute, in partnership with the California Department of Public Health. Cases were included when heat stress was explicitly listed as the primary diagnosis or any other diagnosis. Heat-related diseases were identified using International Classification of Diseases (ICD-9 for 2000-2015, ICD-10 for 2015-2018) codes for: heat stroke and sunstroke; heat syncope; heat cramps; heat exhaustion; heat fatigue; heat edema; other specified heat effects; unspecified effects of heat and light; and exposure to excessive natural heat or sunlight. Causes that were due to a man-made source of heat were excluded. Hospitalization data were available for the years 2000 to 2018, and data on emergency department visits for the years 2005 to 2018.

CEHTP also identified heat-related deaths for the months of May to September, from 2000 to 2019, using ICD-10 codes for the following as the main or contributing causes of death: heat stroke and sun stroke; heat syncope; heat cramps; heat exhaustion; heat fatigue; heat edema; other specified heat effects; unspecified effects of heat and light; and exposure to excessive natural heat; and sunlight. As with the illness dataset, deaths due to a man-made source of heat were excluded. More information about data and methods, including rate calculations, can be found at the Tracking California website.

Strengths and limitations of the data

As noted earlier, the available data on heat-related illnesses and death likely underestimates the full health impact of exposure to heat. Heat-related health effects can manifest in a number of clinical outcomes, and people with chronic health problems are more susceptible to the effects of heat than healthy individuals. Heat-related illnesses and deaths are often misclassified or unrecognized.

The number of heat-related deaths from coroners' reports rely on deaths coded as "heat-related" without universally applied classification of these diseases, and often require knowledge of the circumstances around death to be communicated by other parties. Consequently, few deaths are recorded on death certificates as being heat-related and heat is rarely listed as a main cause of deaths that occur in hospitals or emergency rooms, even when exposure to heat is a contributing factor (English et al., 2009). It is likely that there were three to four times as many deaths in the July 2006 heat wave than were actually reported (Ostro et al., 2009; Joe et al., 2016). Recent studies of annual heat-related deaths in the US explain how the number of deaths is substantially larger than what has been previously reported (Weinberger et al., 2020; Vaidyanathan et al., 2020).

Non-fatal endpoints may similarly be undercounted, as it is often difficult to determine that an illness is heat-related when it involves other organ systems, and there is no standardized training among healthcare providers who make the determination (Madrigano et al., 2015). For example, during the 2006 California heat wave, over 16,000 excess emergency department visits and 1,100 excess hospitalizations were observed. These were much larger than the 2,134 ED visits and 538 hospitalizations officially identified as heat-related, so the majority of cases were not explicitly diagnosed as heat illnesses (Knowlton et al., 2009).

For hospitalizations and emergency department visits, the change in usage of ICD-9-CM to ICD-10-CM in the 4th quarter of 2015 may have resulted in differences in classification of heat-related visits that impact observed patterns in those indicators.

Despite these known limitations, heat-related emergency department visits, hospitalizations and deaths can be used to document changes over place and time, monitor vulnerable areas, and evaluate the results of local climate-adaptation strategies. They are tracked at the national level as part of the National Environmental Public Health Tracking Network, allowing comparisons across states. This tracking provides a better understanding of risks to specific groups, and helps with designing interventions and communication efforts (CDC, 2021).

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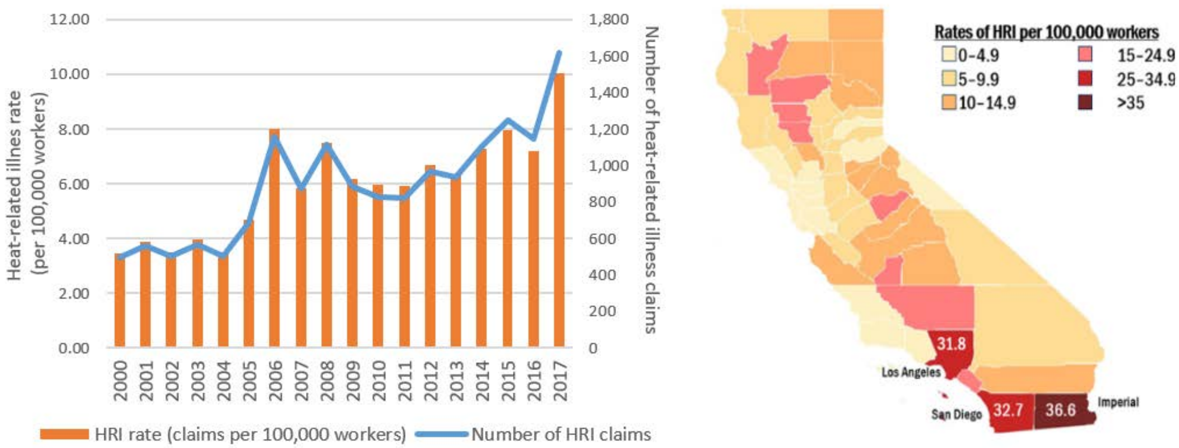
OCCUPATIONAL HEAT-RELATED ILLNESS

Heat-related illnesses reported by California workers have increased from 2000 to 2017.

Figure 1 Occupational heat-related illnesses in California, 2000-2017



Source: Workers' Compensation Information System data, California Department of Industrial Relations (Heinzerling et al., 2020)

What does the indicator show?

Exposures to high temperatures while at work can lead to a range of heat-related illnesses (HRI). Figure 1 presents annual rates of occupational HRI per 100,000 California workers from 2000 to 2017 based on an analysis of workers' compensation claims data. HRI cases were identified from claims that listed heat as the cause of injury or that specified heat-related illness key words (e.g., "heat stroke") or disease codes. Occupational HRI rates started to climb in 2005, reached about 8 cases per 100,000 workers in 2006, and in 2017 saw the highest number of cases (1616), with a rate of 10.1 cases per 100,000 workers. Occupational HRI rates over six-year periods also increased over time: the rate from 2012 to 2017 was two times greater than the rate from 2000 to 2005.

The map in Figure 1 shows worker HRI rates by county from 2000-2017. HRI rates were calculated by dividing the total number of cases over the study period by the total number of workers and multiplying by 100,000 to yield rates per 100,000 workers. Imperial County had the highest rate of 36.6 per 100,000 workers, followed by San Diego and Los Angeles counties, with rates of 32.7 and 31.8 per 100,000 workers, respectively. Orange, Kern, Kings, Mariposa, Trinity, Tehama, Glen, and Colusa counties (shaded pink) reported HRI rates of 15 to 25 per 100,000 workers.

Why is this indicator important?

The link between heat exposure and adverse health outcomes in workers is well documented across the globe (Fatimaa et al., 2021). HRIs are a broad spectrum of diseases, ranging from headaches, dizziness, cramps, rapid heartbeat, and disorientation to more serious outcomes including heat stroke (Gubernot et al., 2014). In many cases employees have little control over their work environment and limited ability to adapt when faced with extreme heat conditions. Workers who are socially isolated and economically disadvantaged, have chronic illnesses, or have no health insurance are especially vulnerable to HRI; these workers are often from communities of color. HRI is a preventable occupational illness, with well-established strategies to protect workers (Heinzerling et al., 2020). While there is no federal workplace standard that protects workers from heat exposures and related illnesses, California's Division of Occupational Safety and Health (Cal/OSHA) enacts and enforces its own workplace standards for public and private sector employees. In 2005, in response to a series of heat-related farmworker deaths, California enacted an HRI prevention standard for outdoor workers, requiring employers to provide employees with HRI training and access to water, shade, and rest (https://www.dir.ca.gov/title8/3395.html). In spite of prevention and mitigation efforts, occupational HRI continues to increase in California.

As climate change increases, average daily temperatures and the frequency and intensity of extreme heat events, occupational HRIs, and deaths are projected to rise (ILO, 2019). A study of rising heat exposure and health risk faced by U.S. crop workers estimates that climate change at its current pace will double occupational HRI by the middle of the century (Tigchelaar et al., 2020). As more and more workers are placed at risk, additional strategies and interventions will be needed to protect workers from HRI.

The effects of rising temperatures on workers are impacting global employment sectors and economies. Borg et al. (2021) reviewed 20 studies to estimate the past and potential future global economic burden of workplace heat exposure. They estimated substantial heat stress-related expenses from lost productivity, decreased work efficiency, and healthcare costs and highlighted the need for workplace heat management policies to minimize future economic burden. A study of workplace heat-related injuries in California estimated financial costs at between $525 and $875 million per year, considering health care expenditures, lost wages and productivity, and disability claims (Park et al., 2021).

Exposure to elevated workplace temperatures may also exacerbate trends in labor market inequality. Park et al. (2021) report that lower wage workers are more likely to live and work in places with greater heat exposure and experience larger increases in risk on hotter days. People in the state's lowest household income tier are approximately five times more likely to be affected by HRI or injuries on the job than those in the top income tier. Moreover, workplace injuries for low-income workers can lead to large direct health care costs and persistent wage impacts that affect subsequent earnings trajectories.

What factors influence this indicator?

California has been experiencing higher temperatures and extreme heat events, particularly since the 1980s (see *Annual air temperature and Extreme heat events* indicators). These warming trends coincide with increasing reports of worker HRI, as shown in Figure 1. In 2006 there was an uptick in HRI cases that coincided with a prolonged heat wave in California.

Excessive heat during work restricts a worker's physical functions and leads to loss of productivity (ILO, 2019). Workplace temperatures above 75-79 degrees Fahrenheit (˚F) are associated with reduced labor productivity. At 91-93˚F, a worker operating at moderate work intensity loses 50 percent of his or her work capacity. In California, a comparison of workers' compensation claims with local weather data from 2001 to 2018 showed that on days with a high temperature above 90˚F, workers have a 6 to 9 percent greater risk of injuries than on days with high temperatures of 50 to 60˚F (Park et al., 2021). When temperatures top 100˚F, the risk of injuries increases by 10 to 15 percent.

Workers who perform exertional tasks or work outdoors are particularly vulnerable to HRI (Heinzerling et al., 2020). Between 2000 and 2017, most of the 15,996 HRI cases in California identified from workers' compensation data occurred in summer months. July had the highest number of cases (4199 cases; 26.3 percent), followed by August (3161 cases; 19.8 percent), and June (2915 cases; 18.2 percent). Certain demographic groups were found to be at higher risk of occupational HRI: rates among men were 2.3 times higher than among women, and rates were highest among young workers (the highest age group was 16-24 years). Younger people may be at higher risk of HRI because they tend to work in industries or occupations with higher risk of HRI, may be more likely to undertake more physically demanding work, and may also lack work experience and adequate acclimatization to hotter temperatures. Relatively high HRI rates for temporary employees in service industries suggested they may be particularly vulnerable to occupational health threats.

Rates of occupational HRI also varied by industry and occupation. The occupational group with both the highest number of cases and highest HRI rate was *protective services*, which includes police and firefighters, with 3380 total cases and an HRI rate of 57 per 100,000 workers (Heinzerling et al., 2020). When exposed to high ambient temperatures, the body depends on evaporative cooling and is susceptible to anything that restricts evaporation, such as personal protective equipment or clothing (Gubernot et al., 2014). Firefighting presents significant challenges for heat illness prevention, given the high heat exposure and exertion involved and heavy personal protective equipment required (West et al., 2020). Risk of HRI in this group, especially among wildland firefighters, is likely to continue to increase as wildfires become larger and more severe and as the fire seasons lengthen (see *Wildfires* indicator).

The *crop production* industry, which includes most types of farming, reported 1335 total HRI cases with a rate of 41 per 100,000 workers. The majority of farmworkers in California are migrant workers, work long days during the summer season, and have limited control over their work schedule and job tasks (ILO, 2019). The common payment system is based on the amount of produce harvested, which discourages workers from taking breaks to eat, drink water, or rest. A study of heat strain in California farmworkers found increased odds of acute kidney injury after a day of work, especially in female workers paid by amount harvested (Moyce et al., 2017).

In a California Heat Illness Prevention Study, core body temperature (CBT) increase and work rate (monitored using a personal accelerometer) over a work shift were used to monitor HRI risk in 587 farmworkers throughout the state (Langer et al., 2021).

Almost seven percent of workers were at higher risk of HRI based on elevated CBT. With an estimated 829,000 farmworkers in California, this translates to about 58,000 workers at risk of elevated CBT. Despite consuming more water compared to less active workers, those at risk became dehydrated (15.7% of men and 3.3% of women). The study concluded that risk of HRI was exacerbated by work rate and environmental temperature despite farms following Cal/OSHA HRI regulations (described above).

Technical considerations

Data characteristics

Workers who experienced HRI were identified through the California Workers' Compensation Information System (WCIS) electronic database managed by the California Department of Industrial Relations (Heinzerling et al., 2020). Since 2000, California has required workers' compensation claims administrators to report to WCIS any claim resulting in more than one day of lost work time or requiring treatment beyond first aid. Claims were considered HRI cases if they included specific WCIS heat-related cause of injury codes (e.g., temperature extremes); if they contained certain HRI key-words in the injury description (e.g., "heat stroke"); or if their billing data contained an International Classification of Diseases (ICD) (Ninth or Tenth revision) code indicating heat illness. All claims with date of injury from January 1, 2000 to December 31, 2017 meeting these criteria were extracted from WCIS in January 2018. Claims meeting only ICD criteria were manually reviewed, and only those deemed to be heat-related based on the injury description were included as HRI cases.

HRI cases were categorized by sex and age group, month and year of injury, county of injury (using ZIP code), industry, and occupation. WCIS reports do not include worker race, ethnicity, or medical comorbidities. Employment denominators used in rate calculations for all variables except county were obtained from the National Institute for Occupational Safety and Health (NIOSH) Employed Labor Force tool, which estimates total numbers of workers based on the U.S. Census Current Population Survey and includes all non-institutionalized civilian workers aged 16 and older. Employment denominators by county were obtained from the California Employment Development Department.

Strengths and limitations of the data

There is limited public health surveillance of occupational HRI in the United States. The primary source of this information in most states comes from the Bureau of Labor Statistics Survey of Occupational Injuries and Illnesses (BLS SOII). These data, based on self-reporting from a small sample of employers nationwide, underestimate the true number of occupational illnesses and injuries. Numbers of HRI cases identified using California's WCIS database, shown in Figure 1, are higher than those from other sources, such as BLS SOII. They are, however, still likely to be underestimates, as they do not include other types of illnesses and injuries where heat may have been a contributing factor, and occupational illnesses are not always reflected in workers' compensation data (Heinzerling et al., 2020).

Rates of reporting may also differ by industry and occupation. Those in certain occupations may be unaware of workers' compensation eligibility. Occupational groups that are particularly vulnerable to employer reprisal, such as farmworkers, may be less likely to report illnesses or injuries and file workers' compensation claims.

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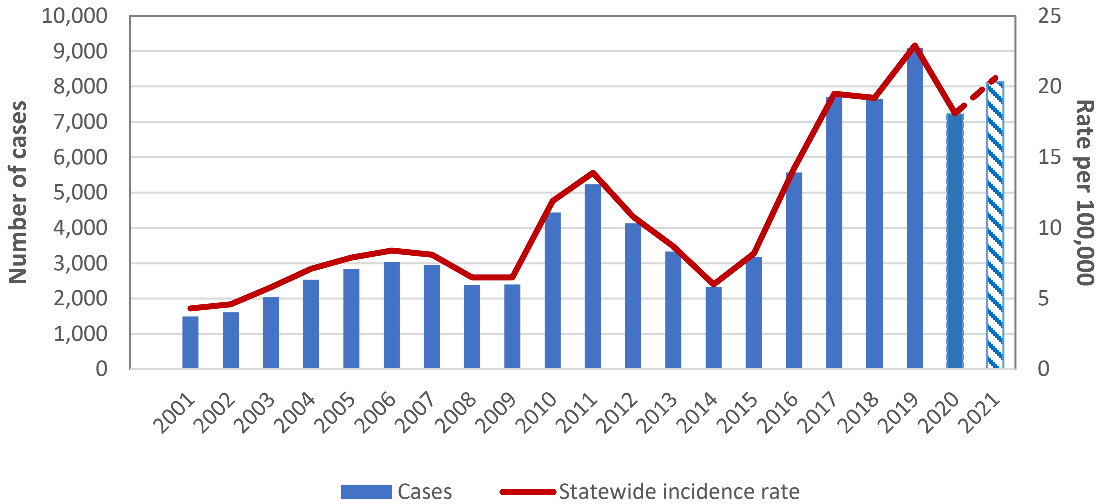
VALLEY FEVER (COCCIDIOIDOMYCOSIS)

The incidence of Coccidioidomycosis, commonly known as Valley fever, has increased over the past 20 years. Valley fever is caused by inhaling spores of the Coccidioides fungus that is endemic in the soil in parts of southwestern United States, including California. The fungus usually infects the lungs, causing respiratory symptoms.

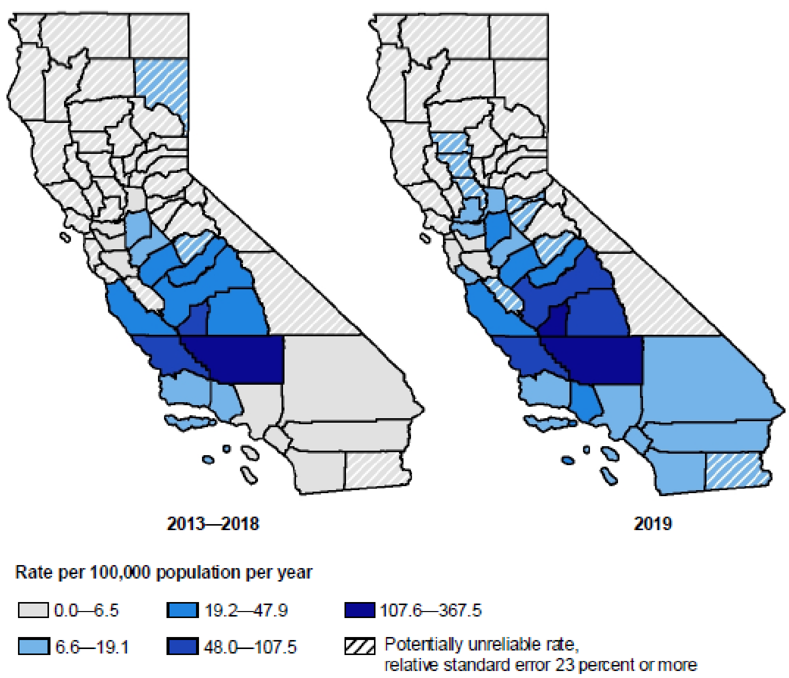
Figure 1. Valley fever cases and incidence rates by year of estimated illness onset in California (2001-2021*)



Source: CDPH 2020a; CDPH 2022a,b

**Note: 2021 values are provisional.*

Figure 2. Coccidioidomycosis, annual incidence rate by county, California, 2013-2019



Source: CDPH 2020a

What does the indicator show?

Figure 1 presents the number cases of Valley fever reported in California each year, from 2001 through 2021, along with the statewide incidence rate. The annual incidence of reported cases of Valley fever has increased almost fivefold from 2001 (with a rate of 4.3 cases per 100,000 population) to 2021 (rate of 20.6, based on preliminary data). The number of new cases reported in 2019 is the highest reported in a given year since reporting began in 1995.

Figure 2 compares the change in Valley Fever rates from 2013-2018 and 2019, with a number of new counties reflecting substantial increase in cases in 2019. Regionally, Valley fever incidence has consistently been highest in the counties of Fresno, Kern, Kings, Madera, Merced, Monterey, San Luis Obispo, and Tulare. Kern County historically had the highest number of new cases, with 338 cases reported in 2019 (CDPH, 2020b). A recent regional analysis of surveillance data from 2000 to 2018 suggested that, despite the consistent high rates of Valley fever in the Southern San Joaquin Valley, the largest increases in incidence have occurred outside of that region, primarily in Northern San Joaquin Valley, Central Coast, and Southern Coast regions (Sondermeyer Cooksey et al, 2020).

The California Department of Public Health (CDPH) has an established surveillance system to track Valley fever cases and has been collecting individual case data since 1995 (Tabnak et al., 2017). Because Valley fever may occur as a chronic condition and be reported more than once, only the first report of the onset of illness is counted (CDPH, 2020). Valley fever is likely underdiagnosed and under-reported, as symptoms are similar to many other respiratory illnesses, such as influenza, COVID-19, or bacterial pneumonia.

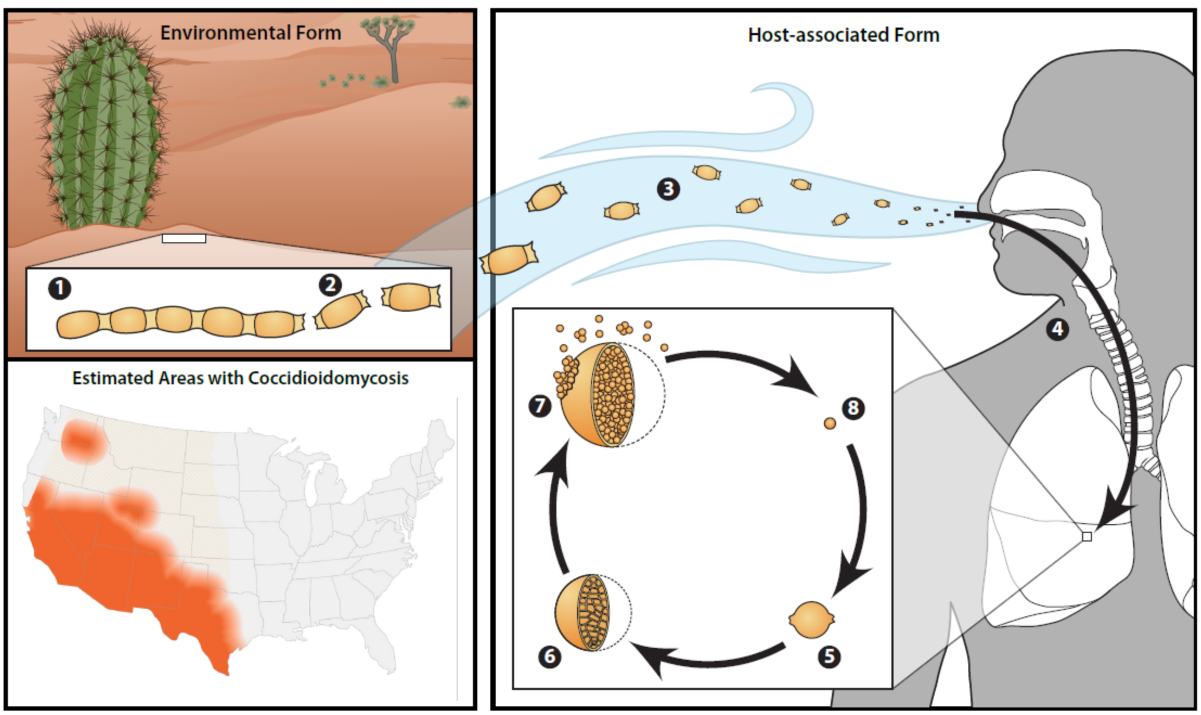
Why is this indicator important?

Approximately 97% of coccidioidomycosis cases in the United States are reported from California and Arizona. The disease usually manifests as a mild self-limited respiratory illness or pneumonia. While most people recover fully, experiencing only mild symptoms, up to five percent exhibit more serious health consequences, including severe respiratory, disseminated disease - where the infection has spread from the lungs to the skin, bones and central nervous system, or meningitis (Ampel et al., 2010; CDPH, 2015). Severe Valley fever can lead to hospitalization, and in the most severe cases, death. Even in those with milder disease, days lost to low productivity and poor health create significant burdens for the patients and the economy at large. Those of Black or Filipino background, pregnant women, older adults, and people with weakened immune systems are at increased risk for severe disease (CDPH, 2020).

Robust CDPH surveillance of Valley fever over the last couple of decades indicates an increase in disease burden. Each year in California, around 80 deaths and over 1,000 hospitalizations are attributed to Valley fever. It is not transmitted directly from person to person, but rather from the direct inhalation of fungal spores. Pets and other animals can also be infected (CDPH, 2020).

Two species of the soil-dwelling *Coccidioides* fungus cause coccidioidomycosis: *C. immitis*, which is found primarily in California, and *C. posadasii*, which is found primarily in Arizona, other parts of the southwestern United States as well as Central and South America (CDPH, 2015; Tintelnot et al., 2007). The life cycle of the fungus is illustrated in Figure 3. Since there is no commercially available test to determine whether the fungus is growing in the soil in an area, the current understanding of the geographic risk for infection is largely based on human surveillance data. As mentioned above, most cases of Valley fever in California are reported in people who live in the Central Valley and Central Coast regions.

Figure 3. The life cycle of *Coccidioides*



Modified from: CDC, 2020

The *Coccidioides* fungus exists in different forms in the environment (left) and in the host (right). In the environment, the fungus exists as filaments or chains divided into cellular compartments (1). These compartments can fragment into spores called arthroconidia (2), which measure only 2-4 µm in diameter and are easily aerosolized when disturbed (3). Arthroconidia are inhaled by a susceptible host (4) and settle into the lungs, where they become spherules (5). Spherules divide internally until they are filled with endospores (6). When a spherule ruptures (7), the endospores are released and disseminate within surrounding tissue. Endospores are then able to develop into new spherules (6) and repeat the cycle. The map in the lower left shows where the Valley fever fungi live in the United States.

Population influx into endemic areas, increased construction and other soil-disturbing activities, and climatic changes that induce fungal proliferation and dissemination through air could be factors working in unison to increase Valley fever incidence in California. Tracking the incidence and geographic distribution of Valley fever therefore provides valuable information to inform public health decisions, particularly given projected changes in climate-related factors. There is currently no vaccine to prevent Valley fever, but antifungal medications are available for treatment, particularly for severe disease (CDPH, 2015). Understanding the dynamics among climatic, ecological niche, lifestyle and demographic factors could help control the spread of the disease (Pearson et al., 2019). Informing people whether their occupation, residence or travel destination could expose them to the spores could help in preventing disease propagation or help identify early disease symptoms before they get worse, disseminate in the body, or even lead to death. Fact sheets and other information help communicate the potential association between high wind events, like the Santa Anas, wildfire and Valley fever infection (CDPH, 2013; Ventura County DPH, 2018).

Valley fever presents an ongoing and increasing public health burden in California. Since mild cases are less likely to be diagnosed and reported, incidence data likely reflect cases with moderate or severe illness. Hence, impact on the economy and health costs are also grossly underestimated (Thompson et al., 2015). A study estimated that lifetime costs in 2017 from Valley fever in California were $94,000 per hospitalized person – with $58,000 in direct costs (including diagnosis, treatment, and follow-up) and $36,000 in indirect costs (including productivity losses) – totaling $700 million for the state (Wilson et al., 2019). At the same time, severe infections have costly implications: from 2000 to 2011, patients hospitalized with Valley fever in California spent a median of six days receiving care at a median charge of $6,800 per day ($55,062 per stay). For the same time period, the total charge for all Valley fever-associated hospitalizations in the state was $2.2 billion (Sondermeyer et al., 2013).

What factors influence this indicator?

People are more likely to get Valley fever if they live, work, or visit in areas where the fungus grows in the soil or is in airborne dust. The majority of outbreaks in California have been associated with dirt-disturbing work settings, including construction, military, archeologic sites, wildland firefighting, and correctional institutions, where high attack rates have been seen even among relatively young people. Drought, aridity, dust storms and wildfires – all related to climate change in California and projected to increase in frequency and severity over the years (Abatzoglou et al., 2016; Cook et al., 2015; Prein et al., 2016; Seager et al., 2007; Tong et al., 2017) – could directly or indirectly affect fungal proliferation and spore dissemination, and eventual human and animal infection with Valley fever. These and other climate-related phenomena can work together to spread *Coccidioides* infection to people who live beyond the historically-endemic Central Valley (Pearson et al., 2019). Valley fever cases have been increasing, although not linearly, likely due to the complex interaction between various climatic and environmental factors that impact *Coccidioides,* changes in work or recreational travel patterns that influence exposure, changes in population susceptibility, and testing and reporting practices.

Geography, drought and precipitation

"Valley" in Valley fever refers to the disease being endemic to the Central Valley of California where most cases in the state have been consistently reported. However, over the last decade, increasing cases have been detected in surrounding counties and even more northerly locations, like eastern Washington State (Johnson et al., 2016). The geographic niches within California that are hospitable to *Coccidioides* also appear to be expanding, as evidenced by increasing rates of Valley fever outside of the Central Valley, particularly in the Northern San Joaquin Valley and Central Coast (Sondermeyer et al., 2020). Central Coast counties like Monterey and Santa Barbara, where numerous large fires have recently occurred, are seeing more cases, particularly among firefighters who participate in ground-disrupting fire prevention activities (Bubnash 2017; Laws, et al., 2021; Wilson 2017). There is also some evidence indicating cases are increasing in geographic range around Los Angeles County. One study found that compared with 2000 through 2003, 19 of 24 health districts in Los Angeles County had a 100% to 1,500% increase in overall cases during 2008–2011 (Guevara et al., 2015). Although the reasons for these increases are likely multifactorial, drought and aridity and other climatic changes likely play a major role. In the Antelope Valley, a high desert area containing parts of San Bernardino, Los Angeles, and eastern Kern County, researchers found the fungal pathogen in 40% of soil samples; they also found an association between the incidence of Valley fever and both land use and particulate matter of 10 micrometer (μm) or less in air (Colson et al., 2017).

Drought desiccates soil, creating dust and coarse particulate matter in endemic areas containing *Coccidioides* spores, which escape deeper into the soil (Gorris et al., 2018). Because the *Coccidioides* fungus is quite hardy, it can become dormant deep in parched soil whereas other organisms would have succumbed to drought and lack of nutrients. When rain and more ideal conditions return, the dormant fungus becomes active, growing in soil and often multiplying in larger numbers than usual since competing organisms have become less plentiful (Coates and Fox, 2018; Fisher et al., 2000; Kirkland and Fierer, 1996; Zender et al., 2006). Then, when dry, hot conditions return, infections fragments called arthroconidia (refer to Figure 3) can be released into air when soil is disturbed (Gorris et al., 2018; Johnson et al., 2014; Lewis et al., 2015).

Patterns of Valley fever incidence and drought have been consistently observed in California, with large increases occurring following periods of drought. After several years of drought, increased rainfall in California in early 2016 might have resulted in more favorable conditions for *Coccidioides* and, consequently, more infections (Benedict et al., 2019). In another study, both temperature and drought variability were positively correlated with Valley fever vulnerability based on case incidence in California from 2000 through 2014 (Shriber et al., 2017). Researchers have predicted that prolonged dryness and drought in the American Southwest will render much of the area west of the Rocky Mountains hospitable to *Coccidioides* (Gorris et al., 2019). In fact, scientists have designated Arizona cases as being related to the effects of climate change (Park et al., 2005); cases in Arizona far outnumber those of California. Evidence of the expanding geographic range of *Coccidiodes* indicate a need for safety precautions aimed to limit Valley fever transmission when proceeding with development in these areas.

Wind and dust storms

Increased winds linked to global climate change (Tong et al., 2017) could also be driving Valley fever infections. There is evidence that a dust storm in 1978 in the Central Valley carried the pathogen hundreds of miles, infecting individuals in Sacramento County, for example (Williams et al., 1979). Dust storms, particularly those attributed to Santa Ana winds that take place in the fall in Southern California, could also help spread the spores to farther locations. Santa Ana winds and the ensuing dust storm that occurred after the 1994 Northridge earthquake have been linked to distributing *Coccidioides* spores to local communities after the earthquake, triggering an outbreak in Simi Valley (Schneider et al., 1997). In Arizona, researchers found a moderate correlation (r = 0.51) between frequency of dust storms and Valley fever incidence in Maricopa County (Tong et al., 2017).

Wildfire

With the increasing risk of wildfires (see *Wildfires* indicator), research has begun investigating their potential influence on Valley fever. Anecdotal evidence and interviews with firefighters have provided insight into this relatively new area of research. Although these associations are not yet well understood and research is ongoing, wildfires can impact soil composition and ground cover. Firefighting can lead to soil disruption when firefighters create fire lines using hand tools for digging. These factors could impact the ability of *Coccidioides* to proliferate and spores to be dispersed through the air. Santa Ana winds, which occur in the fall, coincide both with the seasonality of Valley fever and when fire danger is also highest, particularly in coastal Central and Southern California. Valley fever outbreaks have occurred among wildland firefighters, particularly among those involved in soil disruptive activities used to contain wildfires (Laws et al., 2021).

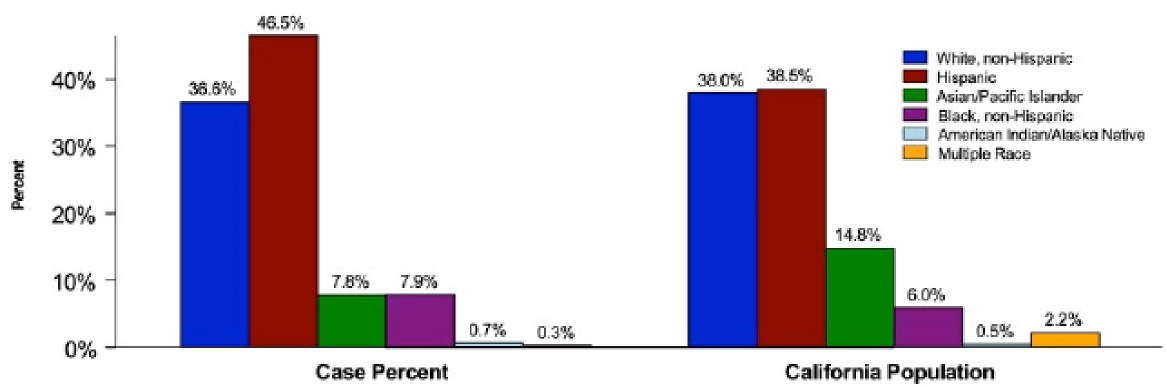
Seasonality

The number of Valley fever cases have generally shown an uptick during the late summer and fall seasons in California since disease surveillance attempts began in the 1940s, indicating possible associations with season, temperature, precipitation, and/or wind (Smith et al., 1946). With climate change experts predicting an earlier start to summer and a later beginning for fall/winter (Wang et al., 2021), there is the potential for an extension of Valley fever season, leaving residents and summer visitors in endemic areas more vulnerable to infection for longer periods of time. Although most people become immune to the pathogen after a primary illness, newcomers moving into endemic areas and children born to current residents remain susceptible to infection. However, surveillance data indicate that people who have lived in highly-endemic areas for years without becoming sick can develop symptoms, which are sometimes very severe. Compromised immunity, due to age or comorbidities, can lead to relapse (CDPH, 2018).

Vulnerable Populations

Different population groups in the state face additional risk of exposure to *Coccidioides* (e.g., outdoor workers) and of severe disease if infected (e.g., pregnant women, those 65 and older, and immunocompromised persons, including those who have diabetes) (Bercovitch et al., 2011; CDPH, 2018; Johnson et al., 2014; Nguyen et al., 2013). Black persons are consistently reported to have the highest rates of Valley fever throughout California and are known to have increased risk for severe and disseminated disease and hospitalization. Additionally, a higher proportion of Hispanics are reported among Valley fever cases than would be expected based on the California population. Racial-ethnic disparities (see Figure 4) in Valley fever cases are not well understood and are likely due to a variety of factors including occupation, genetics, and other factors, including the differential distribution of underlying health conditions across racial or ethnic groups.

Figure 4. Coccidioidomycosis, cases and population by race/ethnicity, 2013-2019



Source: CDPH 2020

34.5% (n=13363) of reported incidents of Coccidioidomycosis did not identify race/ethnicity and 5.6% (n=2176) of reported incidents identified as “other” race/ethnicity and are not included in the Case Percent calculation. Information presented with a large percentage of missing data should be interpreted with caution.

Outbreaks among incarcerated individuals imprisoned in endemic areas have been ongoing during the last twenty years. Many of these individuals have no previous exposure to Valley fever. In one outbreak, exposure stemmed from fugitive dust from building construction near where prisoners were housed or engaging in outdoor physical activity; despite mitigation efforts, such as planting vegetation, high Valley fever attack rates continued (Wheeler et al., 2015). (“Attack rate” refers to the proportion of persons in a population who experience an acute health event during a limited period, such as during an outbreak.) Black race was found to be a risk factor for disseminated disease.

Prisons include a continual rotation of new inmates who are likely immunologically naïve to Valley fever infection. California prisons house a disproportionately larger black population (Lofstrom et al., 2020), a group also identified as bearing a disproportionately poor health outcome burden from Valley fever. Again, many incarcerated individuals engage in wildland firefighting, putting them at greater risk.

Technical considerations

Data characteristics

California regulations require local health officers to report cases of Valley fever to CDPH. Up until 2019, a case was defined as a person who had laboratory and clinical evidence of infection that satisfied the most recent surveillance case definition published by the Council of State and Territorial Epidemiologists (CSTE). Effective January 1, 2019, CDPH changed its Valley fever case definition to require only laboratory confirmation of disease (CDPH, 2018). CDPH accepts all cases determined by the local health department as confirmed.

Strengths and limitations of the data

The number of reported cases of Valley fever shown in Figure 1 are likely to underestimate the true magnitude of the disease. Factors that may contribute to under-reporting include ill persons not seeking health care, misdiagnoses, failure to order diagnostic tests, and limited reporting by clinicians and laboratories. Asymptomatic or minor cases are likely not diagnosed and not reported and Valley fever is likely often misdiagnosed since it presents like many other respiratory illnesses such as influenza, COVID-19, and bacterial pneumonia. Factors that may enhance disease reporting include increased exposure and disease severity, recent media or public attention, and active surveillance activities. Surveillance data include serious cases, which are more visible and have been increasing, and are less likely to identify those with fewer symptoms but still lead to missed worked days and illness. Increased surveillance could explain some of the increased number of cases, though not all.

Because race/ethnicity information was missing or incomplete for 34.5 percent of all 2013-2019 cases (shown in Figure 4), incidence rates by race/ethnicity were not calculated for this indicator. However, the proportion of cases representing race/ethnicity categories are presented alongside statewide averages for these categories during the seven-year surveillance period. Nonetheless, race/ethnicity information based on a high percentage of missing data should be interpreted with caution. Data presented in this indicator may differ from previously published data due to delays inherent to case reporting, laboratory reporting, and epidemiologic investigation.

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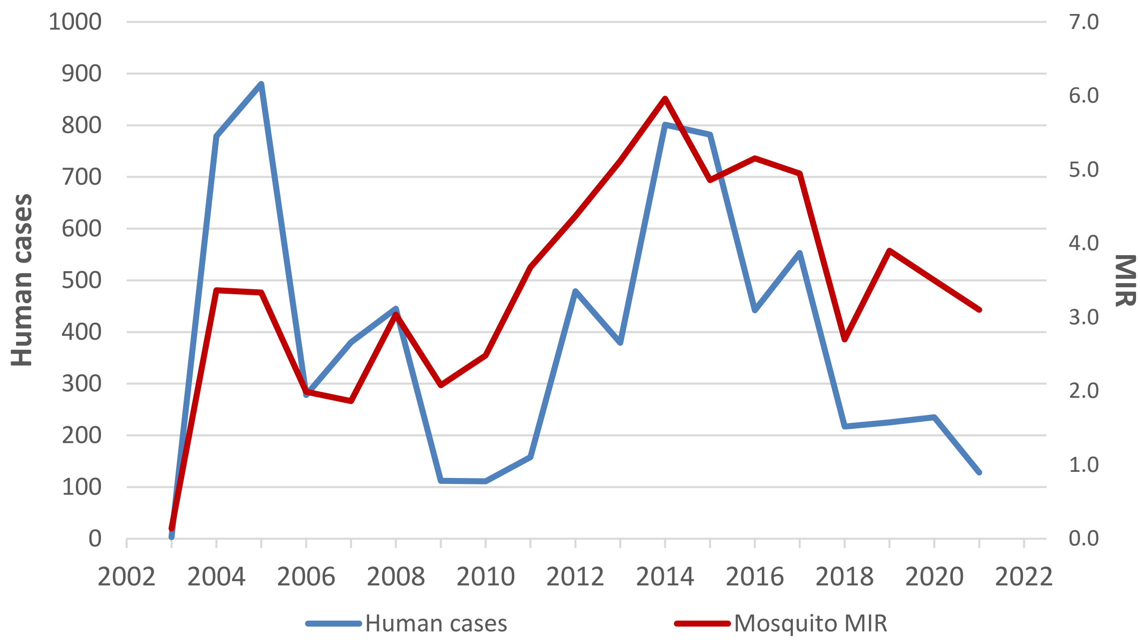
VECTOR-BORNE DISEASES

Warming temperatures and changes in precipitation affect vector-borne disease patterns in California through impacts on the vector, such as mosquitoes or ticks, the pathogen, and animal reservoirs. West Nile virus poses the greatest mosquito-borne disease threat to California residents and visitors. Higher temperatures shorten the development time of mosquito vectors and the viral (pathogen) incubation period in the mosquito, resulting in a greater number of infected mosquitoes.

Figure 1. Human West Nile virus cases[1] and mosquito minimum infection rates (MIR)[2] in California, 2003-2021



Source: CDPH 2021a

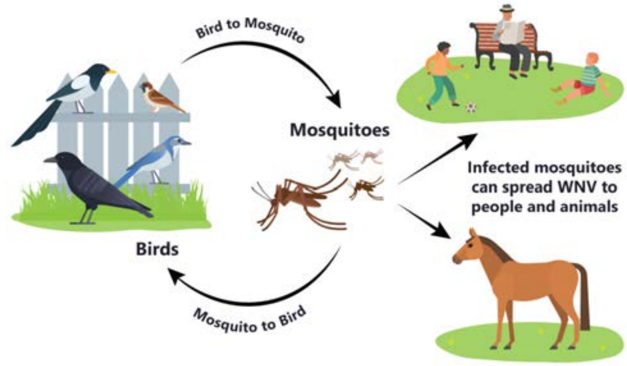
[1] **Cases** – reported human infection (neuroinvasive and nonneuroinvasive cases; does not include asymptomatic blood bank positive individuals). Infections are substantially underreported, especially the less severe, often undetected cases.

[2] **MIR** – number of positive mosquito samples divided by the total number of mosquitoes tested multiplied by 1,000. (A sample is a group of ≤ 50 trapped female mosquitoes that is used for virus testing.)

What does the indicator show?

Vector-borne diseases are caused by pathogens transmitted by living organisms, such as mosquitoes and ticks. Of the 15 mosquito-borne viruses known to occur in California, West Nile virus (WNV) in particular continues to seriously impact the health of humans, horses, and wild birds throughout the state (CDPH, 2020; CDPH, 2021a). Figure 1 shows human cases of WNV and mosquito minimum infection rates (MIR) (see *Technical Considerations*) reported in California during 2003-2020. The MIR is a standardized measure of WNV prevalence; the word "minimum" indicates that at least one infected mosquito in a pool may be detected. Figure 2 shows how WNV is transmitted to humans and animals.

Figure 2. West Nile Virus Transmission Cycle



Source: CDPH, 2020

In California, most vector-borne diseases are caused by viruses, bacteria, or other pathogens spread from animal reservoirs to incidental humans and domestic animal hosts. West Nile virus is an arthropod-borne virus, or arbovirus, which is the largest class of vector-borne human pathogens (NAS, 2016). *West Nile virus is most commonly spread by the bite of an infected mosquito* (CDPH, 2021a).

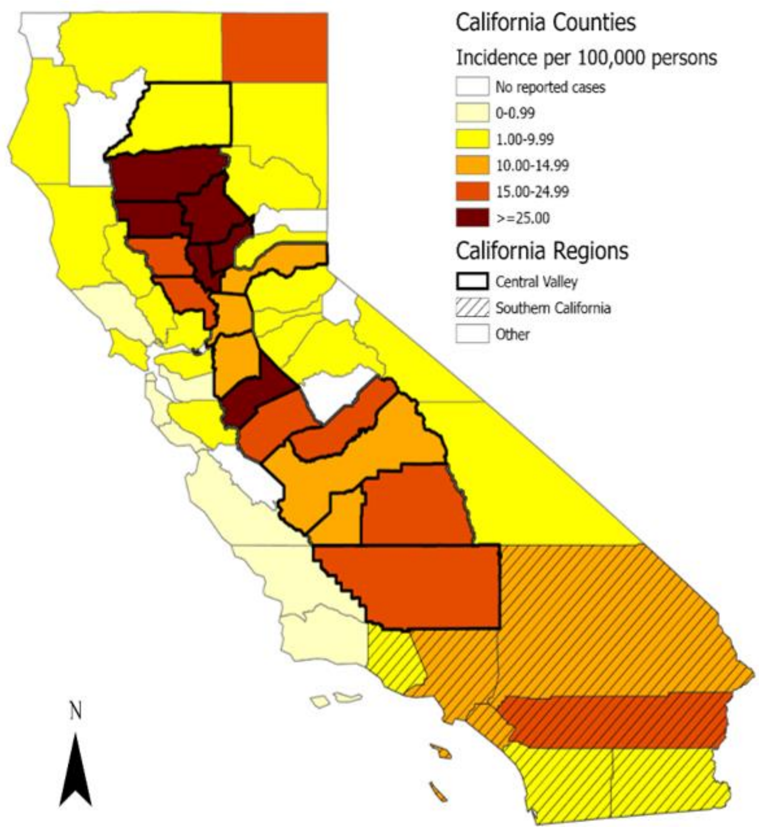
WNVs human cases in Figure 1 show no clear trend, varying from year to year over the 18-year period shown. The number of cases peaked in 2004-2005, and in 2014-2015. WNV cases are driven in part by the MIR which measures the level of WNV infection in *Culex* mosquitoes. The MIR typically increases as temperatures rise due to the shortened incubation period in the mosquito vector and more frequent feeding on hosts by the mosquito (see *What factors influence this indicator?*). MIR is used along with mosquito abundance levels at county or agency scales to evaluate human risk and plan for seasonal response as outlined in the California Mosquito-Borne Virus Surveillance and Response Plan (CDPH, 2021a). In areas of the state where there are no human WNV cases reported, and where mosquito testing is conducted, the mosquito MIR can provide a measure of annual risk.

First detected in the state in 2003 (when three human cases were reported), the majority of WNV infections are not reported. The more severe cases, which involve neurological symptoms, tend to be reported; however, for every neuroinvasive case reported, there is likely an additional 140 to 256 infections that go unreported (McDonald et al, 2019; Busch et al., 2006; Mostashari et al., 2001). Lack of health care, access to testing, or the mild symptoms associated with most infections are some of the reasons that cases are under-reported or undetected (CDPH, 2015; Lindsey et al., 2016). Though current data does not show a clear trend in the number of human WNV cases nor the MIR, long-term monitoring is important as a warming climate will increase the frequency and intensity of short term weather events that impact the activity of this virus.

Why is this indicator important?

For most Californians, WNV poses the greatest mosquito-borne disease threat (Snyder et al., 2020). Not all WNV infections result in disease: about 1 in 5 develop fever and flu-like symptoms;1 in 150 develop a serious, sometimes fatal neurological illness (CDC, 2021). Symptomatic infections may include fever, headache, body aches, nausea, vomiting, swollen lymph glands, skin rash, and in some cases fatigue or weakness that lasts for weeks or months. West Nile virus neuroinvasive disease cases can result in encephalitis or meningitis, with symptoms that may include high fever, neck stiffness, disorientation, tremors, numbness and paralysis, and coma, and in the most severe cases, death; approximately 10 percent of these severe cases are fatal (CDC, 2015).

Figure 3 West Nile neuroinvasive disease cumulative incidence by county, 2003–2018



Source: CDPH 2021a
(based on Snyder et al., 2020)

Figure 3 shows the cumulative incidence of WNV neuroinvasive disease during 2003-2018 for all California counties (data from Snyder et al., 2020). While for most years, densely populated southern California had the highest number of reported cases, the incidence per 100,000 was highest in the Central Valley (thick black outline) where MIR is also typically elevated (CDPH, 2021b). The high WNV incidence in the Central Valley reflects the historically high risk of mosquito-borne diseases in the region. Sparsely populated Glenn County, situated in the northern Central Valley, had the highest cumulative incidence of WNV neuroinvasive disease among all California counties. Temperature and precipitation patterns and the expansive tracts of land for rice-growing in Glenn and its neighboring counties are conducive to high mosquito production in the summer. Although the number of cases are fewer, the low populations in these counties result in higher incidence rates compared to more populated counties. Warm southern California counties (hatched areas) had the next highest reported incidence.Six counties have not reported any human WNV infections to date: Alpine, Del Norte, Mariposa, San Benito, Sierra, and Trinity. Surveillance for cases in these counties will provide insights into future changes in the distribution and occurrence of the virus in a warming climate.

Tracking vector-borne disease trends, such as WNV activity, is critical to understanding the impact of climate change on disease prevalence. Climate change will affect vector-borne disease transmission patterns because changes in temperature and precipitation can influence the seasonality, distribution, and prevalence of vector-borne diseases (USGCRP, 2016). In fact, due to their widespread occurrence and sensitivity to climatic factors, vector-borne diseases have been closely associated with climate change (Smith et al., 2014).

Through the ongoing surveillance carried out by the California Department of Public Health (CDPH) and local partner agencies, the state has the capacity and readiness to detect increasing WNV transmission risk by monitoring mosquito infection rates and human WNV cases in the face of climate change. The surveillance system also includes the testing of dead birds (animal reservoirs) and sentinel chickens (domestic animal hosts).

In addition to WNV, other mosquito-borne viruses that can cause significant illness are western equine encephalomyelitis virus (WEEV) and St. Louis encephalitis virus (SLEV) (Reisen and Coffey, 2014). Although WEEV has been detected only rarely in California in recent years (Bergren et al., 2014), SLEV re-emerged in California in 2015 after more than a decade without detection (White et al., 2016); human SLEV cases have been detected annually since 2016 (http://westnile.ca.gov). WEEV activity has been thought to decrease with increasing temperatures (Reeves et al., 1994), whereas SLEV activity and outbreaks have long been associated with elevated temperatures (Monath, 1980).

Two invasive mosquito species, *Aedes aegypti* (the yellow fever mosquito) and *Aedes albopictus* (the Asian tiger mosquito), detected within the last decade in many Central Valley and southern California counties, could potentially spread to other areas of the state (Metzger et al., 2017). (See map posted at: https://arcg.is/00j1P8). Both mosquitoes have the potential to transmit Zika, dengue, chikungunya, and yellow fever viruses, and like West Nile virus, spring-fall temperatures in much of California are suitable for efficient transmission of these viruses (Winokur et al., 2020). Although all detected human infections with these viruses in California through 2020 have been associated with travel, the presence of competent vectors adds to the potential risk of local mosquito-borne transmission, especially as these species become more widely established in the state (CDPH, 2021b). The emergence of new infectious diseases associated with invasive species can be influenced by a number of factors, including land use changes (e.g., urbanization), the introduction of new hosts, and climate change (NAS, 2016).

In addition to mosquito vectors, climate change will impact the prevalence of tick-borne pathogens in California. Lyme disease, the most commonly reported tick-borne disease, is transmitted by the western blacklegged tick (*Ixodes pacificus).* Western blacklegged tick abundance is limited by abiotic conditions during the summer dry season (Swei et al., 2011), which impact microclimates where certain life stages of ticks survive (Kilpatrick et al., 2017). Western blacklegged tick distribution is expected to expand, particularly on public lands, under various climate change models (Hahn et al., 2021). The influence of climate change on the abundance and distribution of insect vectors is discussed in the next section.

What factors influence this indicator?

Focused geographical analyses of WNV human cases in California and in other locations demonstrate that an increase in temperature and drought conditions are associated with an increase in WNV cases (Hernandez et al., 2019; Paull et al., 2017; Lockaby et al., 2016; Hartley et al., 2012). Record hot temperatures and extended drought in 2015 may have contributed to the high number of human WNV cases and highest ever fatal cases reported that year.

Above-normal temperatures are among the most consistent factors associated with WNV outbreaks (Hahn et al., 2015). Mild winters have been associated with increased WNV transmission possibly due, in part, to less mosquito and resident bird mortality. Warmer winter and spring seasons may also allow for transmission to start earlier. Such conditions also allow more time for virus amplification in bird-mosquito cycles, possibly increasing the potential for mosquitoes to transmit WNV to people*.* The effects of increased temperature are primarily through acceleration of physiological processes within mosquitoes, which results in faster larval development and shorter generation times, faster blood meal digestion and therefore more frequent mosquito biting, and shortening of the incubation period required for infected mosquitoes to transmit WNV (Hoover and Barker, 2016). Coastal cities that are currently at low risk for WNV due to cooler summer temperatures may see increasing MIRs and transmission risk as average summer temperatures rise.

A useful measure of the efficiency of transmission of a vector-borne pathogen is the number of bites or blood meals required by the vector before the pathogen can be transmitted. Investigators have studied the efficiency of transmission of mosquito-borne viruses when mosquitoes were incubated at different temperatures (Reisen et al., 2006; Danforth et al., 2015). They report that with increasing temperatures, fewer blood meals are required for transmission and there is a higher probability that the virus can be transmitted within a mosquito's lifetime. Similar data have been used to delineate the effective global distribution of different malaria parasites and how climate change may have altered this pattern (Chaves and Koenraadt, 2010; Parham and Michael, 2010).

Precipitation and associated hydrological impacts also influence the likelihood of WNV transmission. Expected shifts of winter precipitation from snow to rain at high elevations (see *Precipitation* indicator) will limit water storage and cause spring runoff to occur earlier and faster, which would result in increased mosquito habitat during wet years (DWR, 2017). Periods of elevated rainfall (for example, during El Nino events) can increase immature habitats for mosquitoes and increase population survival due to higher humidity (Linthicum et al., 2016).

Mosquitoes tend to thrive during periods of drought, especially in urban areas, due to changes in stormwater management practices. Under drought conditions, mosquitoes in urban areas can become more abundant due to stagnation of underground water in stormwater systems that would otherwise be flushed by rainfall. Runoff from landscape irrigation systems mixed with organic matter can create ideal mosquito habitat (Hoover and Barker, 2016). During a drought, more birds may move into suburban areas where water is more available, thereby bringing WNV hosts into contact with urban vectors (Reisen, 2013). Drought was found to be an important predictor of reported annual WNV neuroinvasive disease cases in California and nationwide (Paull et al., 2017). However, on smaller geographic scales, drought can reduce WNV transmission. Water use restrictions in urban and suburban areas can reduce larval habitat, thus lowering the risk of WNV transmission (Bhattachan et al., 2020).

Changes in temperature and precipitation may also alter the transmission risk of other vector-borne diseases, including hantavirus and tick-borne diseases like Lyme disease, by affecting the distribution and abundance of key species of vertebrate hosts and vectors (Carver et al., 2015; Ogden and Lindsay, 2016; Hahn et al., 2021). As discussed above, a changing climate may also create conditions favorable for invasive mosquito species to expand their geographic range into California (Ogden et al., 2014).

Prolonged hot and dry periods may reduce tick abundance and therefore decrease Lyme disease risk in some locations, although if relative humidity is maintained, an increase in temperature may increase the longevity of ticks (Eisen et al., 2003). In contrast, the distribution of one vector of Rocky Mountain spotted fever (RMSF), the brown dog tick (*Rhipicephalus sanguineus),* may expand with increased frequencies of El Nino Southern Oscillation (ENSO) events. This could cause an increase in RMSF cases (Fisman et al., 2016). The ongoing outbreak of RMSF in northern Mexico, which occasionally results in human cases in the United States through imported dogs or ticks, is a multifactorial problem involving climate and socioeconomic factors (Foley et al., 2019; Álvarez-Hernández et al., 2017). Recently, host preferences of *R. sanguineus* have been shown to be altered by temperature, notably with increased feeding of tropical lineages on humans at high temperatures (38°C) (Backus et al., 2021).

Extreme precipitation events often associated with ENSO events are thought to impact hantavirus activity by expanding rodent habitat, particularly in normally arid habitats adjacent to humans (Carver et al., 2015). Hantavirus prevalence in rodents, particularly in deer mice, continues to be monitored in California in locations where rodents and humans may come into contact. Although the 2012 hantavirus outbreak in

Yosemite National Park was associated with rodent habitat enrichment provided by cabin construction rather than with weather abnormalities, it was an example of how human hantavirus infection risk can increase when rodent densities are given the opportunity to increase (Nunez et al., 2014).

The devastating environmental impacts of wildfires may impact pathogen, vector, and host interactions, leading to changing risks of vector-borne disease in humans and other animals (Pascoe et al., 2020; MacDonald et al., 2018). Forested habitats support the tick and host populations necessary for maintenance and transmission of numerous tick-borne pathogens. One California study reported that wildfire may potentially increase risk of exposure to vector ticks in the first year following wildfire but that risk decreases substantially in following years due to tick population declines and loss of hosts from the system (MacDonald et al., 2018).

It is important to recognize the role of other anthropogenic factors influencing vector-borne disease transmission. These include changing ecosystems and land use, socio-economic status, human behavior, the status of public health infrastructure, and mosquito and vector control activities (USGCRP, 2018; Rochlin et al., 2016; Carney et al., 2011). In particular, WNV infections have been linked with local-level factors such as income, sanitation, and population density (Watts et al., 2021; Hernandez et al., 2019; Harrigan et al., 2010). People in low income communities may find it difficult to afford mosquito repellents, air conditioning, and property upkeep (to prevent or drain standing water). They may be less aware of WNV activity in their area, of symptoms associated with the disease, and of the need to get tested. Furthermore, inadequate waste water management, flood protection, sanitation, upkeep of infrastructure, and other hazard prevention efforts can create favorable conditions for mosquito breeding.

Technical considerations

Data characteristics

California has a comprehensive mosquito-borne disease surveillance program that has monitored mosquito abundance and mosquito-borne virus activity since 1969 (CDPH, 2021a). Statewide, diagnosis of human infection with WNV and other arboviruses is performed at the CDPH Health Viral and Rickettsial Disease Laboratory, nine local county public health laboratories, and multiple commercial laboratories. Arbovirus surveillance also includes monitoring virus activity in mosquitoes and wild birds that enzootically amplify the virus for purposes of providing warning of human disease risk.

Mosquito and dead bird testing is performed by the UC Davis Arbovirus Research and Training laboratory and several local vector control agencies. The mosquito surveillance program utilizes minimum infection rate to evaluate local virus activity patterns (CDPH 2021a). It is calculated as the number of WNV-positive mosquito pools divided by the total number of mosquitoes tested multiplied by 1,000. In addition to mosquito-borne diseases, CDPH works with local, state, and federal agencies, universities, the medical community and others in its efforts to monitor, prevent, and control rodent-, flea-, and tick-borne diseases.

The ability to use surveillance data effectively in real-time to support public-health and vector control decisions is a key part of California's efforts to mitigate the growing effects of climate change on vector-borne diseases, and California is a national leader in the development of such decision-support systems that are being used already to inform local and state policies. Public-facing data on WNV and other vector-borne pathogens are served via maps, reports, and other visualizations through CDPH's website. Statewide data on surveillance of vectors and vector-borne pathogens are managed, analyzed, and shared through the CalSurv data system, which is supported by funds from the State of California and housed at UC Davis through a partnership with CDPH and the Mosquito and Vector Control Association of California. The CalSurv system provides a wide range of tools for data entry, analysis, and visualization that are used by agencies throughout California on a daily basis. Maps showing CalSurv's data are available at https://maps.vectorsurv.org.

Strengths and limitations of the data

For human disease surveillance, local vector control agencies rely on the detection and reporting of confirmed cases to plan emergency mosquito control and prevention activities. However, human cases of mosquito-borne viruses are an insensitive surveillance measure because less severe fever cases are rarely diagnosed and most infected persons do not develop disease (CDPH, 2021a). For zoonotic pathogens that circulate in natural cycles between arthropod vectors and vertebrate hosts and may spill over to infect humans, testing of vectors or non-human hosts can provide valuable information about infection risk. In areas with robust mosquito testing, MIRs are useful indicators of WNV transmission risk and local vector control agencies can use MIRs to target mosquito control efforts. However, sampling effort and spatial coverage varies widely across the state, so the intensity of surveillance should be considered when comparing MIRs among counties and regions. Although 90 percent of California's population lives in an area with a vector control agency, not all agencies have the capacity to conduct robust mosquito surveillance and testing.

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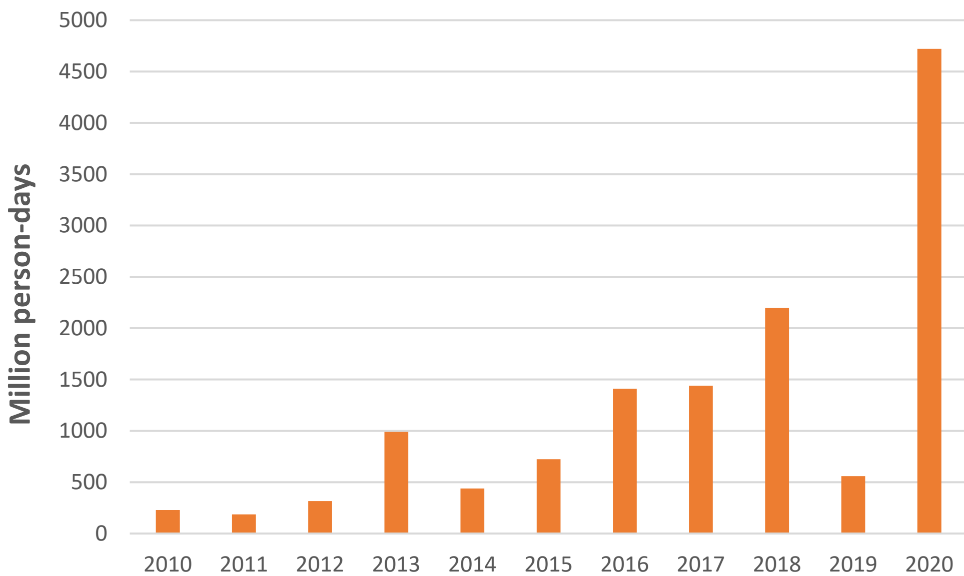
WILDFIRE SMOKE

Potential wildfire smoke exposures have been increasing in California since 2010, due to the increasing frequency, duration and severity of wildfires. This is reflected in the annual number of "person days" in areas where wildfire smoke is present.

Figure 1. Potential population exposures* to wildfire smoke, 2010-2020



Source: NOAA, 2021; US Census Bureau, 2010 (analysis based on Vargo, 2020)

** Graph presents the estimated number of people living in areas where smoke plumes were present multiplied by the number of days when the plumes were present in those areas.*

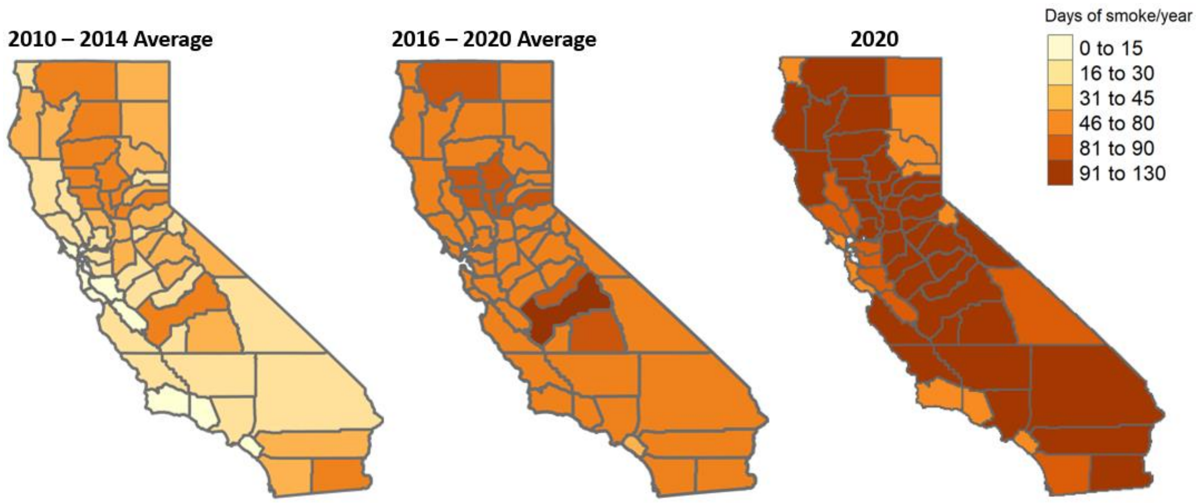
What does the indicator show?

Potential population exposures to wildfire smoke have been increasing in California since 2010, based on "person-days," a metric that is calculated as the number of persons living in the areas where wildfire smoke plumes were present multiplied by the number of days when smoke was present (Vargo, 2020); see Figure 1. Areas of wildfire smoke plumes are based on satellite imagery from the National Oceanic and Atmospheric Administration's Hazard Mapping System's Fire and Smoke Product (HMS Smoke) (NOAA, 2021).

The maps in Figure 2 show the number of days, by county, when wildfire smoke was present at different time periods. From 2010 to 2014, 11 California counties experienced at least 46 smoke days each year on average; three of these counties had 60 to 66 smoke days per year. The rest of the counties had 45 or less smoke days per year. From 2016 to 2020, 56 of the state's 58 counties experienced at least 46 smoke days each year on average: two counties had 34 and 45 smoke days per year, 46 counties had 46 to 80 smoke days per year, and ten had more than 80 smoke days per year. About 3.5 times more acres burned on average in the latter compared to the earlier five-year period, which includes a record-high 4.2 million acres burned across the state in

2020 (see *Wildfires* indicator). That year, smoke plumes were present in every county for at least 46 days; 36 counties had at least 91 smoke plume days.

Figure 2. Number of wildfire smoke days by California county



Source: NOAA, 2021 (analysis based on Vargo, 2020)

Maps present the number of days per county when smoke plumes were present. Left, average number of smoke days per year, 2010-2014. Middle, average number of smoke days per year, 2016-2020. Right, number of smoke days in 2020.

Why is this indicator important?

With the rise in the frequency and duration of wildfires in California, human and environmental exposures to harmful pollutants are also increasing. Wildfire smoke is a complex mixture that is determined by many factors unique to the burn site, such as the type of vegetation burned and weather conditions. A large portion of the resulting air pollutants consists of particulate matter, with a higher proportion of fine particulate matter (2.5 microns or less in diameter, or PM2.5) than typical ambient air pollution (Holm et al., 2021). PM2.5 can be inhaled into the deepest recesses of the lungs, enter the bloodstream, and affect the heart and other vital organs. Recent studies, including one in Southern California, suggest that wildfire particulate matter has greater carbon

Photo Credit: [Christopher Michel]

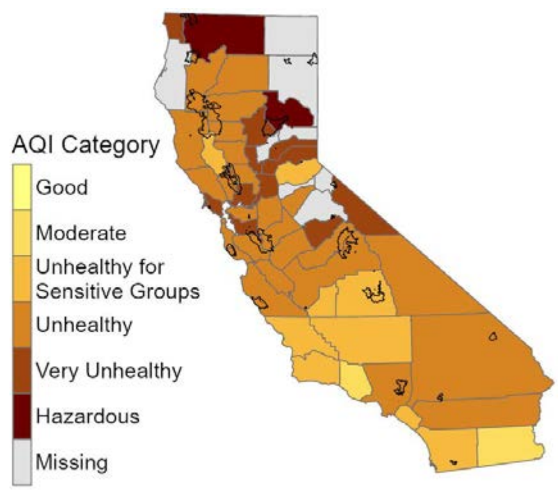
The San Francisco-Oakland Bay Bridge at noon on September 9, 2020 content and thus more potential to cause inflammation in the lungs than ambient PM2.5 (Aguilera, 2021a).

Other hazardous compounds in wildfire smoke include carbon monoxide, ozone precursor compounds, polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (Black et al., 2017). Some compounds are known human carcinogens (e.g., benzene, formaldehyde and certain PAHs). Wildfires that burn structures are reported to produce smoke that contains toxic heavy metals such as lead and zinc (CARB, 2021a).

Scientists observed that, between 2001 and 2020, wildfire emissions across the western United States led to widespread co-occurrence of high PM2.5 and ground-level ozone air concentrations (Kalashnikov et al., 2022). As summer and fall wildfires become larger and more severe, the co-occurrence of these air pollutants may pose a greater threat to public health.

Scientists are investigating the relationship between PM2.5 concentrations characterized using the HMS Smoke plume categories and those measured by ground-level monitors. Although the concentrations do not completely align and there is uncertainty in the relationship, studies have found that higher ground-level PM2.5 concentrations were more frequently observed during heavy smoke plume days (Fadadu et al., 2020). In 2015, a study in Central California found a weak, but statistically significant relationship between smoke plume locations and increased surface PM2.5 concentrations (Preisler et al., 2015). Another study found that unhealthy levels of PM2.5 were more likely to occur on days with smoke plumes than on clear days (Larsen et al., 2018). In short, satellite-detected smoke plumes often co-occur with an increase in PM2.5 concentrations but there is no real relationship between the different HMS smoke plume categories and a specific ground-level PM2.5 concentration.

Figure 3. Air quality (based on maximum daily PM2.5 concentrations) within California Counties, September 11-12, 2020



Source: US EPA, 2021b

** Map presents the Air Quality Index category based on EPA-defined PM2.5 concentration ranges[1] (µg/m^3, 24-hour average) found within each county between September 11 and 12, 2020. Black outlines indicate active fires perimeters during this period.*

Wildfire emissions can severely impact air quality both locally and beyond areas directly impacted by fires, as smoke and ash particles can travel many miles from the original fire location. The 2020 fire season was marked by several large wildfires burning at the same time, leading to unprecedented air quality impacts across the state. Maximum PM2.5 levels persisted in the "hazardous" range of the Air Quality Index (AQI)[1] for weeks in several areas of the state (CAL FIRE, 2021). September 11 to 12, 2020 had particularly bad air quality with most of the state experiencing an AQI of "unhealthy" or worse (Figure 3).

The November 2018 Camp Fire in Paradise provides a good example of the impact of wildfires on air quality in distant regions. Concentrations of PM2.5 reached 415 μg/m^3 in Chico (15 miles west), 228 μg/m^3 in Sacramento (over 80 miles south), and 134 μg/m^3 in San Jose (about 200 miles southwest) (CARB, 2021a). For comparison, the California Ambient Air Quality Standard (which is the same value as the National Ambient Air Quality Standard) is an annual average of 12.0 μg/m^3; an additional federal standard is a 24-hour average of 35 μg/m^3 (CARB, 2021b). These standards represent the maximum concentration of a pollutant in outdoor air that will not be harmful to human health. In addition to PM2.5, smoke up to 150 miles away from the Camp Fire was found to include lead, zinc, calcium, iron, and manganese (CARB, 2021b).

Wildfire smoke darkens the skies, reduces visibility, and poses a clear threat to public health. A large body of research has connected PM2.5 exposure, including wildfire-specific exposure, to respiratory and cardiovascular health outcomes (Chen et al., 2021; Reid et al., 2019). These include decreased lung function, asthma, chronic obstructive pulmonary disease, pneumonia, cardiac arrest, and congestive heart failure. Exposure to wildland smoke may have mental health impacts, particularly in episodes of chronic and persistent smoke events (Eisenman et al., 2021).

Studies have reported on wildfire smoke impacts on public health in California; examples include:

- In 2015, a year with an extensive wildfire season, smoke exposure was found to be associated with cardiovascular and cerebrovascular emergency department (ED) visits for adults in eight California air basins, particularly for those over aged 65 years (Wettstein et al., 2018).

- During the October 2017 Northern California wildfires, in nine San Francisco Bay Area counties, fire-related PM2.5 was most consistently linked to ED visits for respiratory disease, asthma, chronic lower respiratory disease and acute myocardial infarction (Malig et al., 2021).

- Between 2013 and 2018, a 14.6 percent increase in respiratory disease-related ED visits in Shasta County was observed in weeks where wildfire PM2.5 was

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[1] AQI categories are good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous; these correspond to 24-hour average PM2.5 concentrations (in micrograms per cubic meter of air or μg/m^3) of 0.0 to 12.0; 12.1 to 35.4; 35.5 to 55.4; 55.5 to 150.4; 150.5 to 250.5; or 250.5 and higher, respectively.

≥5.5 μg/m^3; a 27.0 percent increase occurred during the 2018 Carr Fire (Casey et al., 2021). Health costs related to fire-related air pollution from all California wildfires in 2018 were estimated at $32.2 billion (Wang et al., 2021).

Certain population subgroups are more susceptible to health impacts when exposed to wildfire smoke (US EPA, 2021b; Liu et al., 2017; Xi et al., 2020). These include people with cardiovascular disease, asthma or other respiratory diseases, and kidney disease. Older adults, children (18 years and younger) and pregnant people are also more vulnerable to the effects of wildfire smoke. During the 2020 wildfires, elevated PM2.5 levels were associated with increased risks of COVID-19 cases and deaths in many western US counties (Zhou, et al., 2021).

Children may be at an increased risk of negative respiratory effects from wildfire smoke due to their smaller airway size and developing lungs (Marabilli et al., 2009). A multi-country review of pediatric ED visits found an overall significant increase in respiratory symptoms and asthma hospitalizations within the first three days of exposure to wildfire smoke, particularly in children less than five years old (Henry et al, 2021). A California study found that exposure to wildfire-specific PM2.5 was associated with higher respiratory-related increases in pediatric hospitalizations compared to similar exposure to non-wildfire PM2.5 (Aguilera et al., 2021b). PM2.5 exposures are also associated with negative impacts on children's immune function, blood pressure and cardiovascular systems (Holm et al., 2021; Prunicki et al., 2021).

Studies suggest that maternal exposure to wildfire smoke during pregnancy is linked to reduced birth weight and preterm birth (Amjad et al., 2021). A California study estimated 6,974 excess preterm births as attributable to wildfire smoke exposure; this accounts for 3.7 percent of observed preterm births between 2006 and 2012 (Heft-Neal et al., 2021). Wildfire smoke exposure during pregnancy has also been associated with a variety of pregnancy complications, such as maternal gestational diabetes and hypertension (Park et al., 2021; Abdo et al., 2019).

Wildfire smoke effects can disproportionately fall on those in particular socioeconomic and occupational groups. People with lower income often have higher rates of respiratory conditions, fewer resources to employ measures that reduce smoke indoors (e.g., air conditioning or air purifiers) and less access to health care. Wildland firefighters (USDA, 2013; Black et al., 2017; Jung et al., 2021) are especially at risk due to unavoidable exposure to wildfire smoke. Some agricultural workers, already disproportionately affected by racial discrimination, exploitation, economic hardships, limited access to health care, language barriers, and fear of deportation, experience high levels of smoke exposure. During the December 2017 Thomas Fire, which burned over 280,000 acres in Santa Barbara and Ventura Counties, thousands of farmworkers continued working in the fields – most without respiratory protection – to prevent crop loss from smoke and ash (Mendez et al., 2020). This led to health impacts including coughing, headaches, difficulty breathing, nausea, and nosebleeds, as well as long-term effects such as respiratory illness. In addition, farmworkers are often exposed to other workplace hazards, such as pesticides and extreme heat.

As the extent of exposure to wildfire smoke increases and moves from periodic acute exposures to more chronic and long-term, it is important to track trends and patterns in potential population exposures to wildfire smoke. This information can be used to distribute health-relevant resources and communications to the most impacted areas and to assist in planning and preparation efforts. For example, the *US EPA Wildfire Smoke: A Guide for Public Health Officials* (Stone et al., 2019) recommends that health officials advise people to remain indoors during smoky conditions, use indoor air filtration systems, and wear respiratory protection when outside.

Wildfire smoke can increase business costs, affect job productivity, reduce earnings and impact tourism and outdoor recreation. Wildfires in recent years have deterred people from visiting the wine country and the Sierra Nevada region (Bauman et al., 2020; Wilson et al., 2020). Wildfire smoke and reduced visibility can elicit a sense of fear, require people to stay indoors, limit traffic to enable firefighting efforts, and ultimately cause tourists to cancel travel plans. A survey of people who visit the Sierra Nevada region reported that wildfire has significantly influenced past travel to the area and will most likely continue to do so in the future. Of those surveyed, 14 percent changed accommodations to avoid wildfire smoke. Outdoor workers in businesses serving tourists face reduced work hours due to visitor cancellations and uncertain work conditions on smoky days. Federal Occupational Safety and Health Administration (OSHA) standards have been proposed to adequately protect workers from wildfire smoke-related health risks (Layton, 2020).

In addition to impacts on human health and well-being, smoke and toxic gases released by wildfires can impact the health of wildlife and ecosystems. Adverse health impacts of wildfire smoke have been reported to contribute to changes in behavior, movement and vocalization in terrestrial and aquatic species (Sanderfoot et al., 2021). Smoke is known to damage the lungs of birds and increase their susceptibility to respiratory infection. Wildfires have increasingly coincided with fall bird migration, where low visibility caused by smoke can disrupt the navigation for migratory species and create difficulties in finding food sources (Sanderfoot and Holloway, 2017; Overton et al., 2021). Wildfire smoke can also negatively impact watersheds, where deposition of smoke and ash in streams can result in dramatic increases in nutrient concentrations and fluctuations of pH, potentially harming aquatic organisms (David et al., 2018).

What factors influence this indicator?

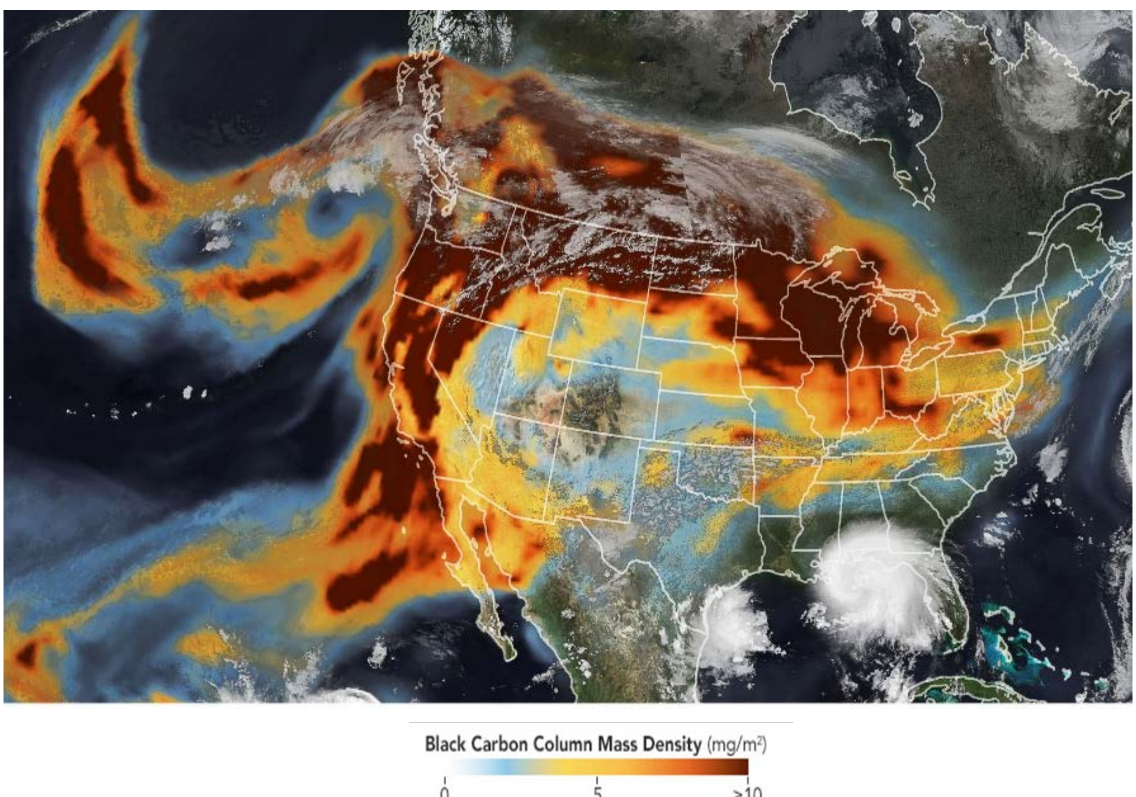
Wildfires are increasing in frequency, duration and severity due to conditions exacerbated by climate change, such as warmer temperatures, reduced precipitation and snowpack, and tree deaths (see *Wildfires* indicator; Goss et al., 2020). The fires are becoming more destructive as well, with 15 of the 20 most destructive wildfires in

California having occurred in the last ten years (Buis, 2021). Correspondingly, exposure to wildfire smoke across California has also increased substantially over time.

Particles from wildfire smoke stay suspended in the atmosphere and can be carried large distances from the source of the fire. The extent and duration of wildfire smoke are impacted by the size, severity, and duration of the source fires as well as wind and weather patterns (Sicard et al., 2019). The potential impact of human exposures is also dependent on the population density where the smoke travels.

In the summer of 2020, smoke from wildfires burning in California, Oregon and Washington drifted across northern states and reached the eastern US (Figure 4). However, the smoke did not have equally strong effects on air quality at ground level everywhere. While people living in communities near the fires in California and Oregon experienced very unhealthy air quality from September 14-16, surface air quality in the eastern US remained mostly good because the smoke was traveling high (above breathable space) in the atmosphere (NASA, 2020).

Figure 4. Satellite image of wildfire smoke plume across the continental United States (September 14, 2020)



Source: NASA, 2020

Jet stream winds transport black carbon across the United States from fires originating on the West Coast. [NASA Earth Observatory images by Joshua Stevens.]

Technical considerations

Data characteristics

Wildfire smoke plumes for years 2010–2020 are from HMS Smoke (NOAA, 2021). HMS Smoke uses visible imagery from satellites to generate smoke plumes associated with fires. Trained analysts manually validate and trace smoke plume locations from two Geostationary Operational Environmental Satellites (GOES). Visible imagery is available at one kilometer (km) spatial resolution. Aerosol Optical Depth information collected from GOES satellites, called the GOES Aerosol and Smoke Product (GASP), are used to provide an objective and quantitative estimate of smoke density. HMS Smoke layers for a specific day are created from several satellite passes, and so multiple plumes may exist over any single location on a given day. To resolve plumes to one observation for each day and location, a single day's plumes are treated as flattened layers so that the coverage of smoke plumes are defined by any HMS collection in that day. The sum of the individual days was used to derive the total smoke days per year.

Information on population was obtained from the 2010 US Census Centers of Population (US Census Bureau, 2010). The latitude and longitude fields from the "Centers of Population" file were used to create a spatial file of points and intersected with HMS Smoke plumes. The block group scale is the finest scale for which the "Centers of Population" exist, and they were used to best represent the locations where populations within Census tracts reside. To combine HMS Smoke plume information with US populations, a function written in R and implemented with RStudio was employed. The full script for processing can be accessed and amended and is available within Vargo et al. (2020).

A "person-days" metric is used to present the results and provides a way of estimating potential exposure, particularly for large areas with widely varying population densities. The use of person-days has been used previously in research to describe smoke plume exposures (Schweizer et al, 2019). Presentation of results as person-days may emphasize the burden of wildland fire smoke in densely populated areas where more people are present, even though potential PM2.5 levels may be higher or more frequent in less populated, rural areas.

AirData represents how the air quality is fluctuating at ground level. The US EPA hosts data from a collection of ground air quality monitors that is quality assured and controlled by state, local, and tribal agencies (US EPA 2021b). The data include daily PM2.5 concentrations for 164 stations throughout California. To give a snapshot of the worst-case scenario, the AQI categories based on the maximum observed PM2.5 concentration within each county are presented in the map in Figure 3. Daily averaged PM2.5 concentrations for each monitoring station were grouped by county, and the date with maximum PM2.5 concentrations for each county was noted (September 11, 2020). Some of the counties were missing data for September 11 so PM2.5 data for September 11^{th} though September 12^{th} were compiled.

Strengths and limitations of the data

HMS Smoke has many strengths: it is freely available, released in a timely manner, allows for daily calculations, it is available continuously across California, and can be used to compare locations across the state. In addition, HMS Smoke is particularly unique in that it gives fire-specific estimated smoke plumes (US EPA, 2021b). HMS Smoke has also been validated and shown to correlate with elevated PM2.5 concentrations measured by ground-level monitors (Preisler et al., 2015; Larsen et al., 2018; Fadadu et al., 2020).

The satellite imagery consists of visible bands and therefore is affected by cloud cover, is unable to differentiate land surface elevation or determine the height of smoke plumes. The HMS Smoke is also generated from satellite passes occurring during daylight hours, with no nighttime data. As mentioned above, presentation of results as person-days may emphasize the burden of wildland fire smoke on densely populated areas and understate the more frequent exposures occurring in rural areas.

AirData is freely available, allows for near daily calculations and is available from 1980 to the present. The sensors are located at near ground-level and are distributed throughout California (and the rest of the USA). Though the monitors are showing the air quality directly where people live, the monitors only represent air quality near where the monitors are located. The sensors are mostly located near more populated regions, leaving large spatial gaps in ground-level air quality. Furthermore, some stations do not have daily data available, which leads to gaps in daily time series analysis.

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References:

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