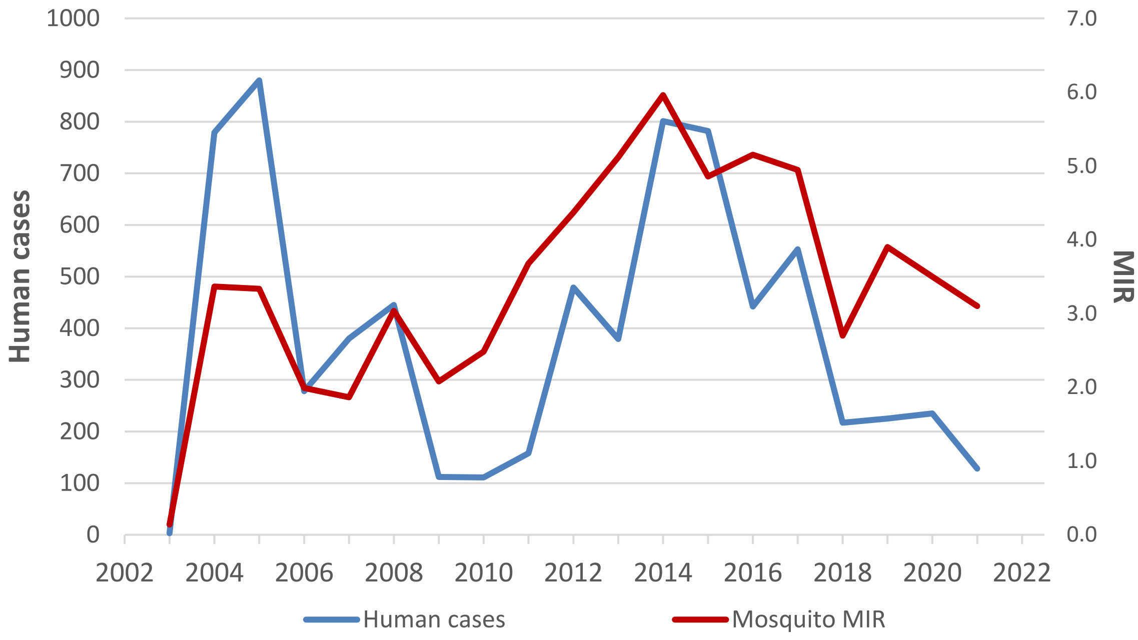
VECTOR-BORNE DISEASES

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

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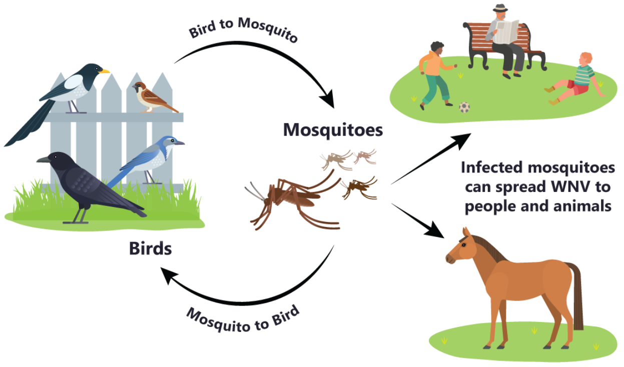
[1] **Cases** – reported human infection (neuroinvasive and nonneuroinvasive cases; does not include asymptomatic blood bank positive individuals). Infections are substantially underreported, especially the less severe, often undetected cases.

[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).

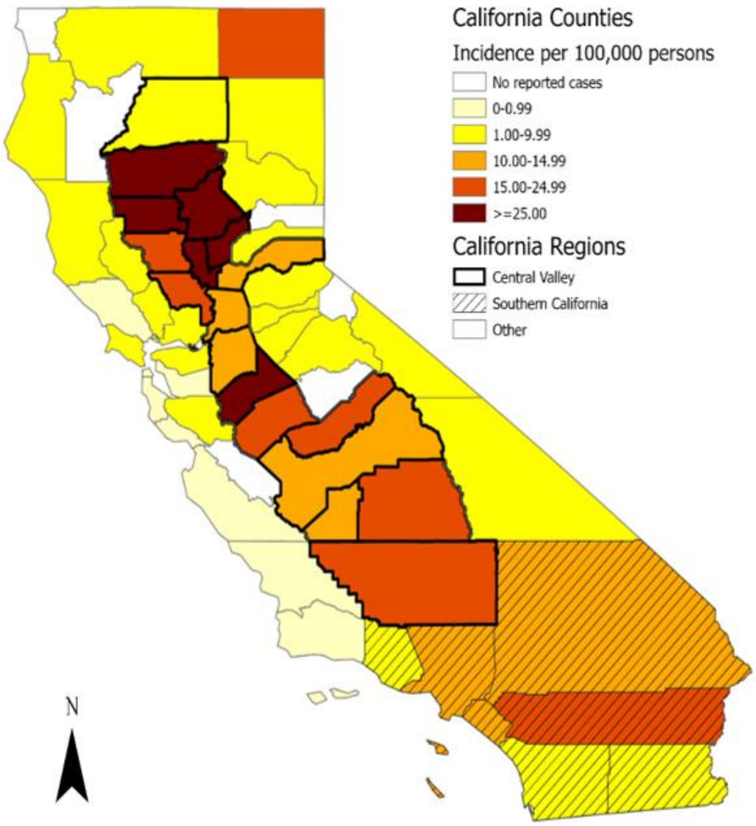
WNVs human cases in Figure 1 show no clear trend, varying from year to year over the 18-year period shown. The number of cases peaked in 2004-2005, and in 2014-2015. WNV cases are driven in part by the MIR which measures the level of WNV infection in *Culex* mosquitoes. The MIR typically increases as 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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