PONDEROSA PINE FOREST RETREAT

Ponderosa pine forests in the Sierra Nevada have retreated uphill since the mid-1930s.

Update to 2018 Report

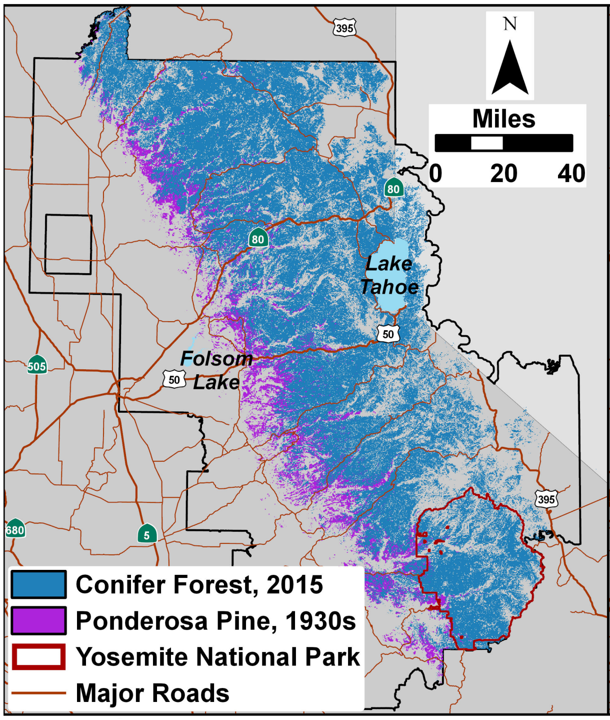
Ponderosa pine in California's Sierra Nevada occupies the western lower edge of the montane conifer forest. As noted in the 2018 indicator report, the death of adult trees and the inability of seedlings to survive unfavorable conditions are driving the upslope retreat of the lower edge of the ponderosa pine in this area. During the 2012-2016 drought, tree mortality in these mountains was concentrated in the lower half of the elevations of the conifer belt, particularly in the southern Sierra.

Recent studies have advanced the understanding of factors affecting conifer mortality, particularly the role of moisture deficit. One study using field measurements and remote sensing products linked tree die-off across the Sierra Nevada to the drying of the deep rooting zone (Goulden and Bales, 2019). This loss of soil moisture in 5 to 15 meter depths is due to a combination of drought, heat and increased evaporative demand. It occurred in dense forests where fire suppression practices have been in place since at least 1980. Conifer mortality was highest in the Southern Sierra and at elevations below 2,300 meters. Another study documented a retreat in the lower edge of ponderosa pine in 90 sites across the western United States (Davis et al., 2019). Using tree ring analysis from 2,935 trees in the footprints of 33 wildfires, the study focused on factors that limit the regeneration of trees after a fire, including vapor pressure deficit, soil moisture and maximum surface temperatures. Climate conditions in the last 20 years in dry sites were found to be "increasingly unsuitable for regeneration."

The studies that follow present findings relating drought conditions to western pine beetle (WPB) infestations, and forest structure (the size and density of trees, which often reflect the influence of forest management). A study of ponderosa pine in the Sierra Nevada Mountains focused on interactions between broad-scale environmental factors (climatic water deficit, a measure of water stress associated with hotter, drier conditions) and local-scale host tree size (Koontz et al., 2021). Using drones to map 450,000 trees at 32 dry sites at around 1,000 meter elevation, the authors found that sites with larger, denser ponderosa pine trees (which facilitated WPB colonization and expansion) amplified tree mortality rates in hot, dry conditions. Similarly, field observations in the southern and central Sierra Nevada showed that mortality rates increased with size, density and proportion of ponderosa pine trees, and with climatic water deficit (Restiano et al., 2019). In contrast, another study in the southern Sierra Nevada found that while ponderosa pine mortality in the first two years of the 2012-2016 drought was high, large trees that survived were thereafter more stable (Pile et al., 2019). These recent mortality events, in combination with a number of large wildfires that have traversed the lower edge of montane conifers, have likely contributed to ongoing upslope retreat of ponderosa pine.

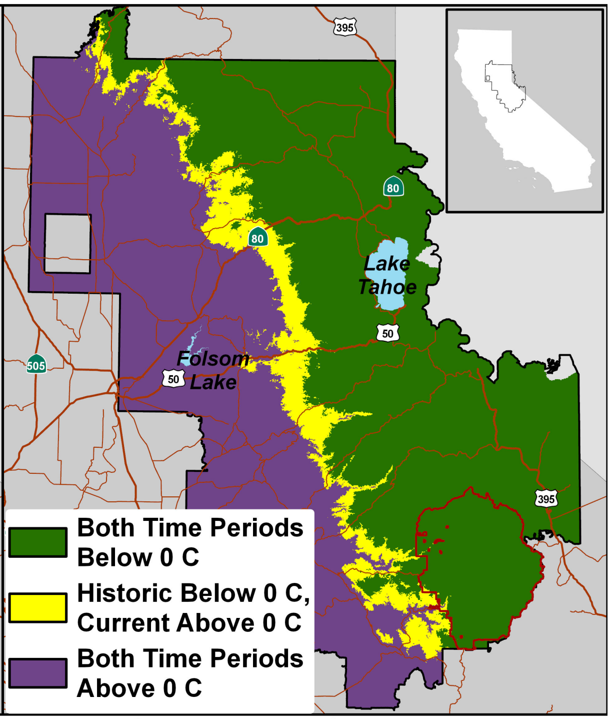
The sections below are unchanged from the 2018 report.

Figure 1
Ponderosa Pine Forest Retreat in the Sierra Nevada Mountains since 1934



Source: Thorne et al., 2008 (updated 2017)

Figure 2
Change in Winter Freeze Line
The change in winter temperatures between 1921-1950 and 1988-2015



Source: Thorne et al., 2015

What does the indicator show?

The lower edge of the conifer-dominated forests of the Sierra Nevada has been retreating upslope over the past eight decades. The dark blue areas in Figure 1 are the regions that still are dominated by the Sierran conifer forests, including the well-known forests leading up to the Lake Tahoe Basin. The area in purple was historically occupied by ponderosa pine (*Pinus ponderosa*), the pine that extends the lowest of the group of conifers making up the mixed conifer forests of the Sierra Nevada Mountains (Thorne et al., 2008). This lower edge is contracting along a 186-mile long front, which is consistent with predicted forest response to future climate change (Lenihan et al., 2003) – that is, an expansion of broadleaf-dominated forests in this elevation zone, with the accompanying loss of conifer-dominated forests.

Figure 2 shows the change in winter nighttime freezing temperatures (that is, minimum temperatures during December, January and February) (adapted from Thorne et al., 2015) over the past several decades. Winter nighttime temperatures were historically below freezing in the 4015-square kilometer (km^2) area in yellow, but are currently above 0°C on average. The purple region to the west represents the area where winter average minimum temperatures have always exceeded 0°C, while the green region to the east is the area that had, and on average still has, freezing winter nighttime temperatures.

The area that no longer has freezing nighttime winter temperatures (the yellow area in Figure 2) occupies elevations from 476 to 1861 meters (m). These elevations fall within those from which ponderosa pine has retreated — between 92 and 2310 m (shown in purple in Figure 1).

Why is this indicator important?

Since plant species are adapted to environmental conditions, changes in the distribution of dominant plants can be both an indicator of, and a response to, climate change. As conditions warm, species are generally expected to move towards the poles and to higher elevations. At the lower edge of the Sierra Nevada Mountains' conifer forests, there has been a transition to oak-dominated and chaparral vegetation concurrent with the uphill retreat of ponderosa pines.

The shift in vegetation from needle-leafed to broad-leafed trees and chaparral is a significant change, with consequences for the species of this region. Birds, mammals and other species that rely on acorns and oaks for food and habitat will find more of this type of habitat available, while species that depend on pine nuts and pine trees will find fewer resources. Increasing temperatures and the change to oak-dominated ecosystems means these areas will dry out more quickly due to both increased plant evaporative demand (Goulden and Bales, 2014) and earlier onset to the summer seasonal drought (see *Snow-water content and Snowmelt runoff* indicators). The vegetation transformation may also lead to more frequent wildfires (see *Wildfires* indicator). Moreover, the temperature of microenvironments will also be different, due to the differing amount of shade and the physical structure of the trees and shrubs making up the majority of the area.

The upslope retreat of conifers is a clear biological signal that conditions are changing. Since the snowpack of the Sierra Nevada is a vitally important resource for people, plants and animals, and the lower edge of the snowpack is also associated with the conifer belt, the upslope retreat of conifers may be a visible measure for monitoring what regions of the Sierra can still support a snowpack.

What factors influence this indicator?

The Sierra Nevada foothills have a Mediterranean climate that includes a summer seasonal drought, and the mixed conifer forests found higher upslope do not often occur in this zone. As temperatures warm, these drought-dominated conditions are moving upslope, as evidenced by the upslope movement of the freezeline. This change in the freezeline means that, should a rare winter storm drop snow in the yellow zone, it will likely melt within a few days, and not accumulate in a snowpack. In turn, this means that the countdown to summer drought conditions starts from the last precipitation event of the year, since there is no stored water in a snowpack to be released through melting. Therefore, summer drought conditions begin earlier, as also evidenced by the advancing spring snow melt, which has been documented throughout the western United States (Stewart et al., 2005) and in the Sierra Nevada (see *Snowmelt runoff* indicator). The uphill retreat of the ponderosa pines in the Sierra Nevada roughly corresponds to the upward migration of the freezeline shown in Figure 2.

Vegetation changes occurring along elevation gradients are linked to changes in climate as well as many other factors such as species competition, topographic conditions, and land use (Macias-Fauria and Johnson, 2013). The discovery of tree seedlings recently established in alpine areas above the tree line suggests that those trees had found some suitable condition and moved upslope into the area. This phenomenon is a leading edge dynamic — that is, successful establishment of seedlings at the advancing edge of a species' range. An increase or decrease in the area of a vegetation type within its elevational limits is reflective of the population changes among the dominant plant species of that type. At the retreating, lower end of a species' range, as shown here, change is likely driven by mortality of adults, along with the inability of seedlings to survive under unfavorable conditions.

This rise in temperature and associated drying in the Sierra Nevada is not likely to kill adult ponderosa pine trees directly. This tree species is resistant to heat and drought, and a gradual warming may not kill the adult trees. However, if the seedling establishment conditions have changed enough, the sequence of events is likely to proceed as follows: 1) A disturbance occurs on a site; this can be a fire that kills the adult trees (fires are increasing throughout the western US (Westerling, 2016) and in California [see *Wildfires* indicator]), a logging clear cut or other land use change, or disturbances such as a bark beetle outbreak or a disease that affects the adult trees; 2) Subsequent to the adults being killed off, the seeds and seedlings are not able to survive long enough to allow a new stand of trees to establish. Seedlings may be susceptible to a number of causes of mortality: desiccation due to increased aridity; root competition for water by other species, particularly chaparral shrubs and non-native grasses; or increased fire frequency, which kills all the seedlings. Long-term vegetation plot studies corroborate the trend that this map analysis illustrates, by documenting an increase in seedling mortality in Sierra Nevada conifers (van Mantgem and Stephenson, 2007). The upslope retreat of ponderosa pine overlaps but is also slightly lower than the upslope movement of the freezeline, suggesting a lag time during which forest tree species are adjusting to the new climate conditions.

Technical considerations

Data characteristics

This indicator is based on a study that compared vegetation maps made in two time periods spanning 80 years: the Wieslander Vegetation Type Survey of the 1930s, and the California Department of Forestry and Fire Protection's 2015 landcover map (FRAP, 2015). The climate trend information depends on reconstructions of historical climate from weather stations in the study area. The climate data comparison uses 30-year averages of winter nighttime low temperature (1921-1950 for the historical period and 1986-2015 to represent the current time period). These temperature values are derived from the monthly Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly et al., 1997) 800-meter (m) data, downscaled to 270 m (Flint et al., 2013). The mean minimum monthly temperatures for December, January and February were combined to represent the winter quarter and the average of the 30 years used to track changes in winter freezing conditions.

The Wieslander Vegetation Type Mapping (VTM) project was a US Forest Service survey program that began in the late 1920s and ended in the early 1940s, and was meant to inventory the forests of California (Wieslander, 1935a and b). Directed by Albert Wieslander, project surveyors would ascend to ridge lines and draw the patterns of the vegetation they observed on topographic maps, coding the polygons they drew with symbols representing the dominant species in each mapped unit. Maps were drawn for about half of the state, including most of the Sierra Nevada Mountains, the Coast Ranges from the San Francisco Bay Area to the Mexican border, and scattered quadrangles in the far northwest of the state. They also surveyed over 16,000 vegetation plots, took over 3,000 landscape photographs, and left notes associated with each quadrangle surveyed. University groups have digitized the survey (Kelly et al., 2005 and 2016): UC Berkeley digitized the photographs and the vegetation plots; UC Davis digitized the vegetation maps (Thorne et al., 2006; Thorne and Le, 2016). The Sierra Nevada VTM maps used here were surveyed from 1934-1937, meaning that this dataset provides a potential for assessing change in vegetation over the past 80 years. The analysis presented here compares parts of the central and northern Sierra Nevada which were mapped in both time periods and comprise 25 30' quadrangles and 47,955 km^2 (11,849,939 acres; Figure 1).

The Wieslander maps were compared to a 2015 digital vegetation map. Because the level of spatial detail in each map was different, a 200-m grid was created for the study area. Vegetation types occupying the most area were identified within each grid cell (about 1,198,887 cells for this study), and assigned to that cell. Once the dominant vegetation from each time period was identified for each cell, those cells that had been listed as ponderosa pine forest but had become a non-conifer vegetation type, were identified, and the pattern of loss at the lower edge was revealed.

The VTM survey data are used in two other indicators in this report. In the *Subalpine forest density* indicator, vegetation plots were revisited to see how tree size and the composition of species of trees at a particular location have changed since the original VTM survey; and in the *Changes in forest and woodlands* indicator, plots from independent surveys were summarized to describe changes in forest structure and composition since the VTM survey.

Strengths and limitations of the data

Historical reconstructions, whether of climate or vegetation, are dependent on the quality of the data. In the case of the Wieslander maps, the historic maps upon which the vegetation was surveyed have spatial inaccuracies of up to ~300 m. Registration methods allow the historical base maps and digitized vegetation maps to be registered to contemporary topography with an average RMSE of 98 m. This permitted the comparison between times at 200 m grid resolution. The Wieslander Vegetation Type Map survey was one of the most complete and thorough efforts to document the forests of California. The use of these data is a unique opportunity. The general trend is consistent across the entire western flank of the Sierra Nevada, which also lends credence to the findings.

Generally, the high elevation zones of the Sierra Nevada are the least well represented by weather stations that were used in generating the monthly climate maps. This study reports phenomenon more than two-thirds of the way down from the peaks of the Sierra, an area where there are more weather stations. Hence, while the historical climate maps of California as a whole may have some areas of high uncertainty, the region reported here was fairly well documented.

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