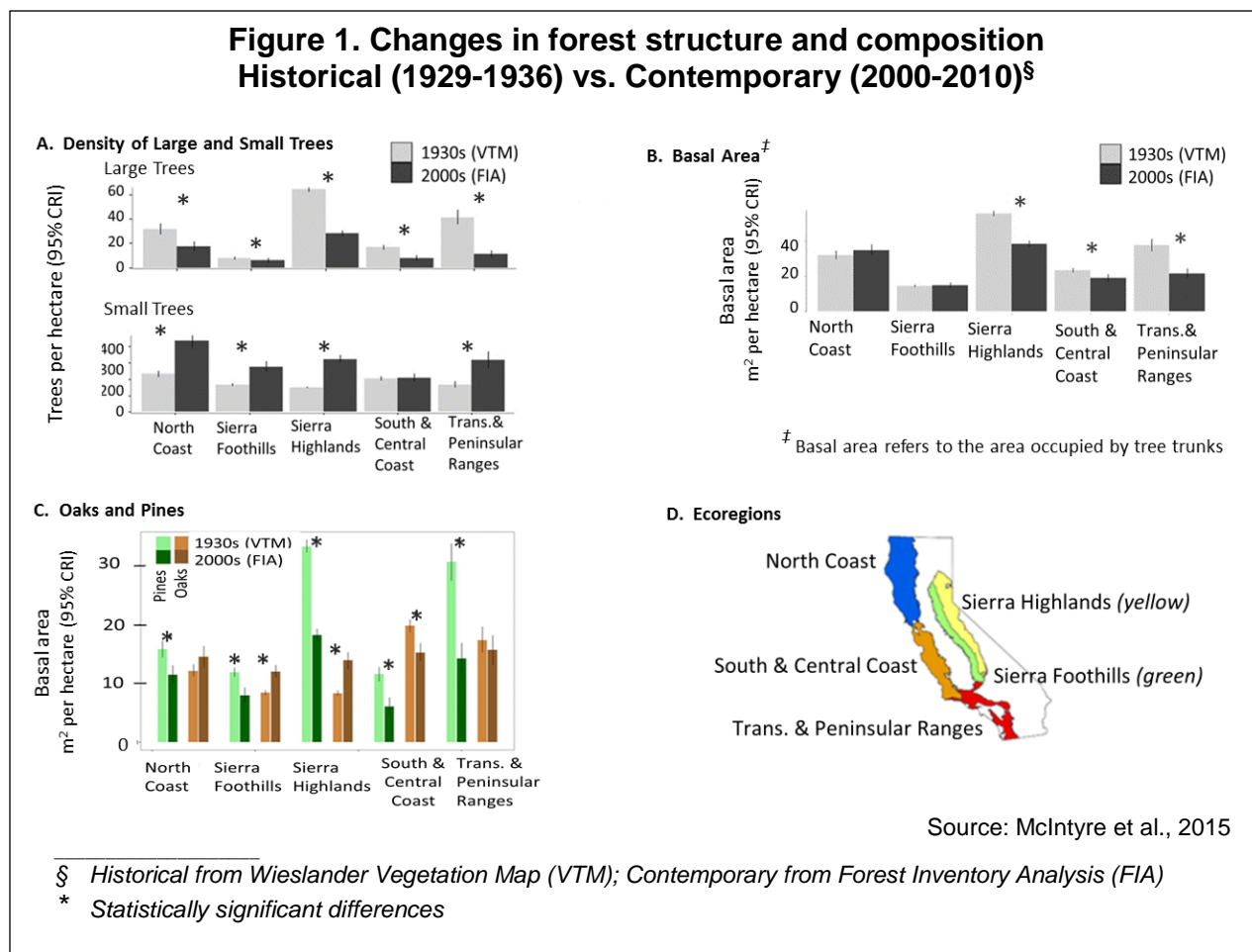


CHANGES IN FORESTS AND WOODLANDS

Compared to 80 years ago, California's forests today have more small trees, fewer large trees, and less biomass. The areas occupied by pines have decreased in all regions studied, while the areas occupied by oaks have increased in the Sierra Nevada but have decreased in the South and Central Coast. These changes are associated with decreased water availability driven by warmer temperatures.



What does this indicator show?

The structure and composition of California's forests have changed, and this is associated with climate change related water availability. This indicator consists of three metrics tracking changes in the structure and composition of forests across five regions in California. These metrics are based on a comparison of data from a 1930s survey of the state's vegetation (documented in the Wieslander Vegetation Type Map, or VTM) with data from surveys conducted between 2000 to 2010 (as part of the US Forest Service's Forest Inventory Analysis, or FIA) (McIntyre et al., 2015). Forest structure refers to the distribution of small, medium, and large-sized trees, while species composition refers to the diversity of tree species present.

Figure 1A displays the first metric, which shows changes in the density of large and small trees. Large trees are defined as greater than (>) 61 centimeters (cm), or



>24 inches (in), in diameter at a height of 4.5 feet (“diameter at breast height,” or dbh), and small trees are defined as 10–30 cm, or 4–12 in, dbh. Decreases in large tree density were observed in all regions studied (top row). The greatest decrease occurred in the Transverse and Peninsular ranges of Southern California, where large tree density in the contemporary period was less than 30 percent of the density in the historical dataset (40.8 vs. 10.6 trees per hectare (trees/ha)). Declines of about 50 percent in large tree densities were observed in the Sierra Nevada highlands (64.3 vs. 28.03 trees/ha), the Coast Ranges of southern and central California (16.6 vs. 7.5 trees/ha), and northern California (30.6 vs. 16.7 trees/ha). Declines in large trees were lowest in the Sierra Nevada foothills (7.6 vs. 5.7 trees/ha), the region where large tree densities are lowest.

From the historical to the contemporary period, densities of small trees increased over two-fold within the Sierra Nevada highlands (149 vs. 315 trees/ha), and over 50 percent in the Sierra Nevada foothills (165 vs. 268 trees/ha), the North Coast region (229 vs. 412 trees/ha) and the Transverse and Peninsular ranges (165 vs. 301 trees/ha) (Figure 1, bottom row). The density of small trees was unchanged in the South and Central Coast Region (200 vs. 197 trees/ha). Patterns of change for intermediate-sized trees (31–60 cm or 12–24 in dbh) were variable across the two time periods (not shown).

Figure 1B illustrates the second metric, which shows changes in basal area — the amount of area occupied by tree trunks within a given area (here expressed in units square meters per hectare (m²/ha)). Basal area, which reflects biomass, decreased in three of the five regions: up to 40 percent in the Transverse and Peninsular Ranges Region (37.8 vs. 21.6 m²/ha, 30 percent in the Sierra Nevada Highlands Region (55.9 vs. 38.5 m²/ha), and 18 percent in the South and Central Coast Region (23.3 vs. 19.0 m²/ha). In the North Coast and Sierra Nevada Foothills Regions, the reductions in basal area due to large tree declines were balanced by increases in smaller size classes, hence no decline in overall basal area was observed.

The third metric is displayed in Figure 1C, which compares historical and contemporary basal area occupied by pines and oaks. Changes in the relative abundance of these tree species represent changes in forest composition. Pines have declined in all regions, whereas oaks increased in two Sierra Nevada regions but decreased in the South and Central Coastal ranges.

Why is this indicator important?

The pine and oak-dominated forests and woodlands of California provide ecosystem benefits such as erosion control, water provision and carbon sequestration, as well as wildlife habitat, timber, and opportunities for recreation. Changes in forest structure and tree species composition can impact these functions.

This indicator describes how forest conditions have changed relative to historical climate change by comparing the 80-year old VTM survey with modern-day observations. It shows that the state’s forests are transitioning from one set of species



to another. Since these changes may be a natural ecosystem response to warming and drying conditions, monitoring them provides valuable insight into future forest responses to climate change. There is evidence that wildfires at elevations up to about 5,000 feet where pines and oaks grow together can initiate this shift in species dominance by removing the dominant conifers (including pines but also other needle-leaved trees), allowing resident oaks and chaparral to establish and become the dominant vegetation. Another VTM-based study estimates that 13.5 million acres in California are at risk of this conversion (Goforth and Minnich, 2008). Decreases in large coniferous trees, including pines and firs in California montane (mountainous) forests have also been documented in other studies (van Mantgem and Stephenson, 2007; Dolanc et al., 2013; Lutz et al., 2009); furthermore, dieback of trees has been reported on all continents (Allen et al., 2015) and across the western USA (van Mantgem et al., 2009).

Despite a nearly 40 percent overall increase in tree density, the decline in large trees has resulted in about a 20 percent decline in basal area and associated biomass (not shown).

What factors influence this indicator?

Statewide, the decline in large trees and increases in the relative abundance of oaks compared to pines are associated with climatic water deficit (CWD), while changes in small tree densities are not (McIntyre et al, 2015). CWD is the cumulative annual excess of potential versus actual evapotranspiration of water from plants. It can be thought of as the amount of additional water that would have evaporated or been transpired by plants (beyond what was actually evaporated or transpired) if the water had been present in the soils for the plants to take up. CWD is a useful metric because it integrates plant water demand relative to soil moisture availability, and provides a measure of potential plant drought stress. Increases in CWD, which reflect decreases in soil moisture, are associated with a warming climate because increased air temperatures increase plant water demand (Thorne et al., 2015). CWD can be further increased if there is less precipitation under future conditions, and if snowpack melts sooner, leading to drier soils during summer months. CWD has been associated with patterns of forest mortality and vegetation distributions in a number of studies. Following four years of severe drought (2012-2015) in California, areas with high CWD experienced substantially more tree mortality than areas with low CWD (Young et al., 2017). Much of the mortality was caused by beetle attacks on trees weakened by the drought (see *Forest tree mortality* indicator).

The ratio of oak to pine basal area was correlated with estimates of CWD in the time periods of both forest surveys (McIntyre et al., 2015). In addition, the contemporary survey shows an increased relative dominance by oaks that was associated with increases in CWD. The paleological record is consistent with this: in the past 150,000 years, oaks dominated in warmer, drier interglacial periods, and pines in colder, more mesic (characterized by moderate or well-balanced supply of moisture) glacial periods (Heusser, 1992).



The changes in forest species composition and basal area described here are occurring in California forest and woodland areas at elevations that are subject to seasonal drought; these areas represent water-limited ecosystems throughout the low to mid-elevations of the state, from the southern coastal and transverse mountains to near the northern end of the foothills of the Sierra Nevada Mountains. Although there are several potential causes for these dynamics at lower elevations, hotter drought conditions are the lead environmental cause.

That conifer trees are potentially at higher climatic risk than broadleaf trees is supported by the findings of Lutz et al. (2010). The authors mapped the climate occupied by 17 Sierra Nevada tree species in Yosemite National Park relative to the entire range of climate conditions each species encounters in its geographic range. They found seven species, all except one of which is a conifer, occupy the arid end of their North American climate distributions: *Pseudotsuga menziesii*, *Pinus ponderosa*, *Calocedrus decurrens*, *Pinus lambertiana*, *Abies concolor*, *Abies magnifica*, and *Quercus kelloggii*.

Other factors potentially contributing to shifts in the oak: pine ratio include fire suppression, wildfires, and logging practices. Widespread fire suppression in the western USA has led to the buildup of forest litter and increased density of small trees, including the establishment of the highly flammable white fir (*Abies concolor*) — changes which have potentially contributed to the more frequent and larger wildfires today. Further, a warming climate is contributing to the increasing frequency and intensity of wildfires in the western US (Westerling et al., 2006) (see *Wildfires* indicator).

As noted above, wildfires can initiate the conversion of coniferous to broadleaf forests and woodlands or chaparral by removing dominant conifers. A large stand-replacing fire at Cuyamaca Rancho State Park near San Diego (the Cedar fire, October 24-28, 2003) happened after eight decades of fire suppression. A seedling census four years after the fire found that while various oak species had re-established, few to no conifer seedlings had done so, resulting in the conversion of a mixed conifer-oak forest to one dominated principally by oaks (Goforth and Minnich, 2008). The authors did not examine changes in climatic conditions. The authors predict this transition is to be expected for the ~13.6 million acres of this forest type in California, including large swaths of the Sierra Nevada foothills and most of the forests and woodlands near coastal urban areas. This prediction is also in line with change documented on the western slope of the Sierra Nevada Mountains where lower elevations of coniferous forests are retracting upslope (Thorne et al., 2008; see *Ponderosa pine forest retreat* indicator). This is corroborated by a recent study that examined post-fire seedling regeneration after 14 large wildfires in Northern California. Welch et al. (2016) found that in 10 of the 14 fires, conifer regeneration was not high enough to meet US Forest Service stocking standards, indicative of a return of the site to a conifer forest.

Technical Considerations

Data characteristics

The indicator is based on a study comparing forested plots from the Wieslander Vegetation Type Map (VTM) survey (between 1929 and 1936) with US Forest Service



Forest Inventory Analysis (FIA) plots (between 2000 and 2010). Across California, 9,388 VTM plots and 5,198 FIA plots were identified as forested (having at least one tree >10.2 cm dbh, the cutoff for a tree in the VTM data). Only plots occurring within 5 km of a plot from the other time period were selected, resulting in 6,572 VTM and 1,909 FIA focal plots. The plots were similar in slope, aspect, and elevation, as well as location across latitudinal and longitudinal gradients.

A modified version of the Jepson Manual eco-regions of California was used in identifying plots by region, as follows: South and Central Coast; Transverse and Peninsular Ranges; North Coast; Foothills of the Sierra Nevada and southern Cascades; Highlands of the Sierra Nevada and southern Cascades. (The Central Valley and desert regions are not included because they did not have a sufficient number of forested plots). Changes in tree density were compared with changes in CWD between 1910–1940 and 1981–2010 using 30-year averages from each time period. CWD is the seasonally integrated excess in potential evapotranspiration (PET) versus actual evapotranspiration. Details on the methodology are described in McIntyre et al. (2015).

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 1930s historical vegetation survey, the plot areas surveyed were not permanently marked, and this comparison used contemporary US Forest Service plots to compare densities of trees in similar locations as paired plots that had similar slope, aspect and elevation. The VTM survey only classed trees to size classes, so the modern survey, which has actual diameter at breast height values for every tree was re-classed to the same size classes. This reduced some of the precision with regards to tree size. However, the historical VTM was one of the most complete and thorough efforts to document the forests of California, and the use of these data was a unique opportunity to examine shifts statewide.

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