CALIFORNIA FIRE SCIENCE CONSORTIUM

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Research Synthesis for Resource Managers

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Early 1900's forest structure in the mixed conifer forests of the Sierra Nevada, California

This synthesis summarizes six papers that use a variety of methods to reconstruct the historic forest structure and composition of the mixed-conifer forests of the Sierra Nevada.

Management Implications

- Managers of mixed conifer forest ecosystems can use historical reconstructions to inform their restoration goals
- Most mixed conifer forests now have increased density of small-diameter trees (especially white fir and incense cedar) and reduced density of large-diameter trees compared with the early 1900's
- Heterogeneity is a key structural component of historical mixed conifer forests
- Managers can promote growth and survival of larger trees by using prescribed fire and thinning small trees

BRIEF MIXED CONIFER NATURAL HISTORY

The Sierra Nevada range spans over 380 miles on the eastern side of California, with elevations from 490 to more than 14,400 feet. The region is dominated in many areas by mixed conifer forests, which include a mixture of species such as yellow pines (ponderosa and Jeffrey pine), sugar pine, incense cedar, Douglas-fir, and black oak.

Several Native American tribes have lived in the Sierra Nevada region going back thousands of years, including the Yokut, Sierra Miwok, Maidu, Paiute, and Washoe (Ingram & Kocher 2015). Euro-American people arrived in California in the mid to late 1800's, introducing disease, relocating Native Americans, and murdering Native inhabitants. These Euro-American actions devastated Indigenous populations and reduced Indigenous peoples' capacity to tend the ecosystems of the Sierra Nevada using cultural fire. For example, in the Lake Tahoe basin, the Washoe utilized fire to promote desired species and forest structure. Fire was abruptly removed from the landscape during Euro-American settlement, and many forests in the Sierra Nevada landscape have now experienced more than 100 years of fire suppression. As a result, forest structure and composition have changed substantially. Mixed conifer forests now have an abundance of small-diameter trees (often white fir or incense cedar), fewer large diameter trees, and much higher canopy cover. In general, these modern forests are more susceptible to disturbances like high severity fire, drought, and bark beetle outbreaks than their historic counterparts.

This research synthesis provides a snapshot of research investigating changes in mixed conifer forest structure and composition since the early 1900's. The historic reference conditions documented in these studies can inform management decisions regarding target forest density and composition in mixed-conifer forests.

NORTHERN REGION

Beaty, R. Matthew and Alan H. Taylor. 2007. Fire disturbance and forest structure in old-growth mixed conifer forests in the northern Sierra Nevada, California. Journal of Vegetation Science 18: 879-890.

In this study, the authors sought to understand how historical and current fire regimes have influenced the composition and structure of old growth forests of the Lake Tahoe Basin of the northern Sierra Nevada. Forests throughout the region have been influenced by humans for thousands of years. For instance, the Washoe people used fire in the region to improve hunting and promote the growth of important plants for food and fibers (Lindström 2000). While nearly 70% of the Lake Tahoe watershed was logged during settlement by Euro-Americans, there are pockets of old growth forest that have not been logged. The authors conducted a study in one such area, the General Creek Watershed on the west side of Lake Tahoe. The authors identified 12 stands that have never been logged, and that were not burned in any recent prescribed fires. They used stand assessments and dendrochronology techniques (the study of tree rings) to infer the influence of fire on each stands' size- and age-structure, spacing of trees, and historical fire return intervals.

At the time of the study, all twelve of the stands had similar size- and age-classes of trees, though the species composition was somewhat variable, with pine-dominated stands on south facing slopes and red fir-dominated stands on north facing slopes. Like many other mixed conifer forests that have endured 100+ years of fire exclusion, the overstory of these stands was dominated by widely-spaced, large-diameter trees, while the understory and mid-canopy was dominated by abundant white fir trees less than 120 years old.

There was little difference in the fire regime characteristics across the 12 stands. During the pre-settlement (1700–1850) and settlement (1850–1900) periods, these stands burned on average every 9–17 years with low to moderate severity. Historically, the majority of fires (75%) occurred during the dormant season. There was little synchrony in fire occurrence across stands, except during drought years. None of the stands have experienced fire since approximately 1880. Prior to Euro-American settlement and the removal of native people and traditional burning practices, frequent low to moderate severity fires in the region helped to maintain open stands with large trees and few small-medium sized trees or seedlings. Fire exclusion is now the dominant influence on the landscape and has likely contributed to the reduced resilience of these forests.

Stephens, Scott L., Jens T. Stevens, Brandon M. Collins, Robert A. York, and Jaime M. Lydersen. 2018. Historical and modern landscape forest structure in fir (Abies)-dominated mixed conifer forests in the northern Sierra Nevada, USA. Fire Ecology 14:7.
https://doi.org/10.1186/s42408-018-0008-6

In the western Sierra Nevada, white and red fir become more dominant at higher elevations with increased moisture availability. While many studies have investigated the historical structure and composition of the lower-elevation ponderosa pine and mixed conifer forests, much less is known about historical fir-dominated forests. In this study, the authors compared historical timber survey records (1923 and 1936) to modern Forest Inventory and Analysis surveys (2001–2010) to assess changes in forest structure and composition in the fir-dominated mixed conifer forests of the northern Sierra Nevada in the El Dorado National Forest.

Broadly, the authors found that these fir-dominated forests now have much higher densities of small- (15.2–30.5 cm DBH) and medium-sized (30.5–61 cm DBH) trees and lower densities of large trees (> 61 cm DBH) than they did in the early 20th century. Across the study area, there was little change in total basal area. Instead, fire suppression in the region has promoted infilling by smaller-sized trees, counteracting the loss of large tree basal area on the landscape. The authors argue that the loss of large trees on the landscape during the 20th century was likely due to preferential logging of large trees. They also note that higher modern tree density (due to infilling by smaller trees) may make large trees more susceptible to mortality from drought and bark beetles.

The authors also assessed environmental conditions that favored fir forests with different tree densities. In general, the highest historical densities of small- and medium-sized trees were found on sites with high precipitation in the form of rain and lower climatic water deficits (lower water stress). Modern small- and medium-sized tree densities followed similar patterns, with the highest levels of infilling in areas with the highest precipitation in the form of rain. Similarly, the highest historical large-tree densities were found in areas with lower climatic water deficits. The largest declines in large tree density were found in areas with the highest historical large-tree densities.

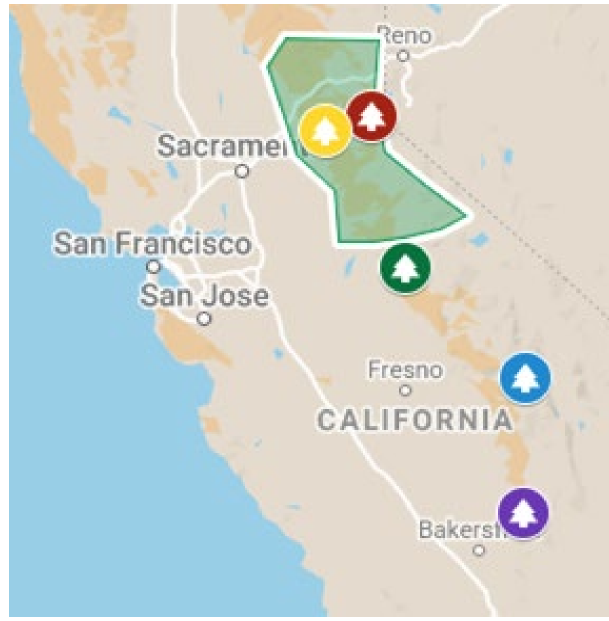
While the changes in these fir-dominated forests are smaller in magnitude than the changes observed in pine-dominated mixed-conifer forests, the changes have important implications for forest management. First, large trees are an important feature of California spotted owl habitat and the loss of large trees on the landscape during the 20th century likely reduced the available habitat for this species. Second, the authors recommend that restoration-based logging objectives target retention of large trees while removing trees from small- and medium-size classes. Lastly, considering historical forest conditions while developing restoration plans is recommended, as restoration strategies in these fir-dominated sites are likely to differ from strategies in ponderosa pine-dominated areas.

NORTHERN + CENTRAL

Dolanc, Christopher R., Hugh D. Safford, James H. Thorne, and Solomon Z. Dobrowski. 2014. Changing forest structure across the landscape of the Sierra Nevada, CA, USA, since the 1930s. Ecosphere 5(8): Article 101.

The authors studied mixed conifer forests in the northern and central Sierra Nevada to determine how these forests have changed since the 1930s. To do so, the authors compared historical tree densities in different diameter size classes from the Wieslander Vegetation Mapping Type Project (1928–1940) to those from modern Forest Inventory and Analysis surveys (2001–2010).

Across most of the study area, the authors found that modern forests have higher densities of small- (10.2–30.4 cm DBH) and medium-sized (30.5–60.9 cm DBH) trees, and lower densities of large (> 61.0 cm DBH) trees than they did



Locations of the six studies in this research synthesis are represented by different colored tree symbols. Red: Beaty & Taylor (2007), yellow: Stephens et al. (2018), green: Barth et al. (2015), blue: Stephens and Elliot-Fisk (1998), purple: Stephens et al. (2015). The large green area represents the Dolanc et al. (2014) study area.

historically. These changes in tree density were consistent across the range of elevation and latitude represented by the study area, as well as the majority of tree species that they analyzed. In smaller size classes, the trees that increased the most were tan oak, canyon live oak, interior live oak, and incense-cedar. The biggest declines in large tree density were observed for ponderosa pine, sugar pine, white fir, red fir, and lodgepole pine.

The authors identified fire suppression as the primary mechanism causing the increase in mid-elevation small tree density since the 1930s. While there was no increase in small-tree density in forests where at least two fires occurred since the Wieslander surveys, unburned plots or plots with only a single burn had increased small tree density. Additionally, the species contributing to increased forest density tend to be fire intolerant, shade tolerant species (e.g., white fir, incense cedar, tan oak). In contrast to mid-elevations, the authors state that fire suppression is not the likely cause of increased tree density at higher elevations (>2,500 m). Instead, changing climatic patterns with increased temperatures and longer growing seasons at high elevations may have improved growing conditions and promoted infilling of these forests.

The authors identify both timber harvesting and climate change as potential mechanisms for the decline in large trees since the 1930's. While majority of the logging activity in the region had already taken place by the 1930's, ongoing logging likely caused a further reduction in large tree density since the 1930's. Additionally, warmer climates may have led to increased drought-induced mortality for large trees.

CENTRAL

Barth, Molly A. F., Andrew J. Larson, and James A. Lutz. 2015. A forest reconstruction model to assess changes to Sierra Nevada mixed-conifer forest during the fire suppression era. Forest Ecology and Management 354: 104-118.

In this study, the authors use stand reconstruction models to estimate the forest structure and composition that existed at the time of the last fire in the Yosemite Forest Dynamics Plot. By analyzing tree increment cores and cross-sections, the authors were able to estimate both tree growth rates and fire history at the site. They then used this information to inform competition-dependent and site-specific tree growth models to estimate stand structure during 1900, and then compared these estimates to field surveys from 2010.

Prior to the fire suppression era, the authors found that the mean fire return interval at the Yosemite Forest Dynamics plot was 29.5 years. The last widespread fire occurred in 1900. Based on their reconstructions, sugar pine and white fir were the most abundant species in 1900, representing 62–74% and 19–30% of the basal area, respectively. In contemporary surveys, these two species are still the most abundant, but sugar pine has declined in percent basal area while white fir has increased (both currently represent ~45% of the total basal area). Other species at the site include incense cedar, black oak, and Pacific dogwood.

The authors found that overall tree density (trees ≥ 1 cm DBH) increased from 110–175 to 1,391 stems per hectare between 1900 and 2010. The greatest tree density increases were observed in the smallest size classes (< 10 cm DBH), but there were also increases in the larger size classes (10–100 cm DBH and > 100 cm DBH). The authors do note that their stand reconstruction models may have underestimated the number of large sugar pines on the landscape due to a lack of species-specific information about decay rates.

While this study uses stand reconstruction models to reconstruct historic stand structure (rather than dendrochronological techniques or historic surveys), the authors provide additional insight about pre-fire suppression reference conditions in the Sierra Nevada.

SOUTHERN

Stephens, Scott L., and Deborah L. Elliott-Fisk. 1998. Sequoiadendron giganteum-mixed conifer forest structure in 1900-1901 from the Southern Sierra Nevada, CA. Madroño 45(3): 221-230.

In this study, the authors take advantage of a 1900–1901 field survey conducted by George Sudworth as part of the United States Geological Survey's efforts to inventory the forest reserves and timber resources of the Sierra Nevada. These early field notebooks provide an indication of the structure and composition of the giant sequoia and mixed-conifer forests that now make up Sequoia-Kings National Park. Sudworth's original notebooks contain records from eight mixed conifer plots and four giant sequoia-mixed conifer plots, focusing on trees greater than 30.5 cm DBH.

In the mixed conifer plots, the most abundant tree species was white fir, with an average DBH of 91 cm. Sugar pines were the largest trees on the landscape (average DBH of 152 cm) and made up the highest proportion of forest basal area. The largest recorded sugar pine in these stands had a DBH of 305 cm. Other common species were incense-cedar, ponderosa pine, Jeffrey pine and red fir.

The most abundant species in the giant sequoia-mixed conifer plots was also white fir, with an average DBH of 81 cm. Giant sequoia trees represented the highest percent of basal area (77%), with an average DBH of 282 cm. The largest recorded giant sequoia had a DBH of 536 cm. Sugar pine was also common in these plots, with smaller amounts of red fir and Jeffrey pine.

Sudsworth's notebooks focus on trees > 30.5 cm DBH and on areas with little recent fire activity. He did note that there was very little regeneration across the plots, except in small open patches. Additionally, Sudsworth noted that the forests were already impacted by pressures from EuroAmerican settlement. He observed frequent signs of grazing, fires set by livestock herders, and logging.

Stephens, Scott L., Jamie M. Lydersen, Brandon M. Collins, Danny L. Fry, and Marc D. Meyer. 2015. Historical and current landscape-scale ponderosa pine and mixed conifer forest structure in the Southern Sierra Nevada. Ecosphere 6(5): 79.

In this study, the authors compared historic and modern forest structure and composition in the Greenhorn Mountains of the southern Sierra Nevada. This region had a historic fire return interval of 5–20 years, but has rarely experienced fire since the late 1800's. Focusing on unlogged areas, the authors compared a 1911 timber survey with Forest Inventory and Analysis data collected between 2001 and 2008. The authors asked how historic stand structure varied across their study region, and how forests have changed during the past century.

The authors identified four common forest types across their study region: 1) 15% of the study area contained forests with high basal area and stem density dominated by white fir and incense-cedar, typically found at high elevations (mean 1,935 m) and northerly aspects; 2) 34% of the study area was dominated by incense-cedar and co-dominated by white fir and ponderosa pine; 3) 10% of the study area contained a mix of larger diameter ponderosa pine and incense cedar, with an understory dominated by the shrub mountain misery; and 4) 41% of the study area was dominated by a low density of large ponderosa pine, which typically occurred on sites with lower elevation, southwesterly aspects, and high evapotranspiration.

In assessing evidence of fire damage, the 1911 surveyors noted low or moderate fire damage across most of the study area. Approximately 1–6% of the mixed conifer forest had evidence of high severity fire, while ~17% of the area dominated by ponderosa pine had evidence of high severity fire.

During the past century, the density of small (30.4–61.0 cm DBH) and medium (61.1–91.4 cm DBH) trees increased across all forest types, with the greatest increases in sites dominated by ponderosa pine (> 400% increase in small tree density). In contrast, the density of large trees (>91.4 cm DBH) declined across all forest types. Similarly, canopy cover increased to approximately 49% in all forest types, whereas historically, ponderosa pine forests had half the canopy cover of the mixed conifer forests (12% vs. 25%, respectively).

The authors concluded that fire played an important role in shaping the historic southern Sierra Nevada forests, and the loss of fire on the landscape has led to denser forests with greater canopy cover. The authors also noted that stand characteristics were widely variable across forest types and emphasized the importance of accounting for forest type and forest heterogeneity when developing restoration goals.

Summary

The six studies reviewed here provide strong evidence that forest structure and composition in the mixed conifer forests of the Sierra Nevada have changed substantially during the past 100-120 years. Prior to Euro-American settlement, low- to moderate-severity fires occurred every 5-30 years and helped to maintain open forests dominated by widely-spaced, large-diameter trees. During Euro-American settlement, extensive logging and the abrupt loss of Native American cultural burning presaged what would become nearly 120 years of fire suppression in these fire-adapted forests. Across the Sierra Nevada, mixed conifer forests now have much higher densities of small- and medium-sized trees, increased canopy cover, and decreased density of large-diameter trees. These higher-density forests are more susceptible to damage from high-severity fires, drought, and bark beetle outbreaks than their historic counterparts. Management activities that restore historic forest structure and/or promote the return of low- and moderate-severity fire to the landscape may improve the resilience of these mixed conifer forests.

Authors

This synthesis was initially drafted in fulfillment of an upper-level college course at UC Berkeley by Carina Bilodeau and Julia Toro during Spring 2020 and was revised by A. Paulson.

Suggestions for further reading

Ingram, K., and S. Kocher. 2015. California Naturalist Series: Natural History of the Sierra Nevada.

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