How big is big enough? Exploring drivers of fire-induced giant sequoia mortality from the individual to the stand level

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Background: Before EuroAmerican settlement, Sierra Nevada mixed conifer forests supported a fire regime dominated by frequent, low severity burning, with mean fire return intervals averaging roughly 10-20 years. This long-term fire regime maintained lower tree densities and fuel loads than are typical today, after a century of fire exclusion. The long-term lack of fire has resulted in forest conditions that are conducive to high severity burning, which is increasing canopy tree mortality and other negative ecosystem impacts. Giant sequoias grow in the mixed conifer belt of the Sierra Nevada, and they are paradigmatic of the types of adaptations that characterize fire-tolerant trees, including very thick and fire-resistant bark, self-pruning of lower branches, and serotinous cones cued to open after moderately-severe fire. However, since 2015 roughly 17% of all large sequoias (≥1m DBH) have been killed by wildfire, most of them in the 2020 and 2021 fire seasons.

Prior work has established mortality rates and investigated tree-level characteristics associated with delayed sequoia mortality. Despite forest density being a well-established driver of fire severity, this is the first study to explicitly test whether surrounding forest structure predicts individual giant sequoia mortality from wildfire. The study compares drivers across spatial scales and finds that fine scale structure around individual trees showed no detectable effect, but that stand level tree density did predict mortality.

MANAGEMENT IMPLICATIONS

- Landscape and stand-scale density need to be treated as the primary levers for sequoia management, not fine-scale (i.e. single-tree) point protection. These broader scales are more likely to have a bigger impact with point protection being a secondary tool whose real-world effectiveness remains largely untested.
- Density reduction is most likely to lower mortality in fires that do not burn the entire stand; it should not be expected to prevent complete mortality under extreme fire conditions.
- Crown ratio can be used as a fast field-triage for individual point protection, predicting which specific trees are more likely to die allowing it to be used to prioritize management resources to high-risk sequoias.
- Modern sequoia stand densities are mostly much higher than historical averages, leaving many dense stands at increased risk of high severity fire.

Drivers of Individual Tree Mortality: Of the 620 large sequoias surveyed, 41% were dead, with an average of 52% total crown damage across all surveyed trees. There was high grove-to-grove variation in observed mortality, with Alder Creek the lowest (27% dead) and Belknap (51% dead-or-likely-to-die) and Freeman Creek (45% dead-or-likely-to-die) the highest. No forest-structure variable (density, basal area, QMD, relative SDI, shade-tolerant conifer dominance) or topographic variable (slope, northness, topographic wetness index, Topographic Position Index) was significant at either the 7.5m or 15m neighborhood scale. The one robust predictor was crown ratio. Smaller crown ratios significantly increased mortality probability ($p<0.01$) with surviving trees averaging 0.67, dead trees 0.57.

Drivers of stand-level severity: For the binary outcome: 100% basal area mortality vs not (n=94), none of the tested variables were significant, including density itself. Restricting to plots that did not burn at complete stand replacement (n=38, 1-99% mortality), tree density became a significant predictor of mortality severity ($p<0.01$). The authors attribute the binary outcome null result to substantial density overlap between stand-

replacement and non-stand replacement plots. In other words, density did not predict whether a plot burned at complete stand replacement, but among plots that were not completely killed, denser plots lost a greater share of their basal area.

Departure from reference conditions: Observed tree density (>30 cm DBH, sequoias excluded) averaged 194.4 trees/ha across 94 stand level-plots. This is roughly double the 97.5 trees/ha historical average for 1911 high basal area mixed-conifer stands (Stephens et al. 2015); only 6 of the 94 plots were at or below that figure. For individual-tree plots, inferred pre-fire density averaged 184 trees/ha (max 586); only 16% of plots fell within or below the historical range. Basal area, by contrast, was close to historical values. The departure lies mainly in stem density, particularly the number of smaller trees. Current management targets call for 50 to 250 trees/ha among trees smaller than 80 cm DBH. In 65% of individual-tree plots, small-tree density exceeded the 250 trees/ha upper limit, and only 18% fell below the 150 trees/ha midpoint.

Key Conclusions: Preserving the remaining giant sequoias is essential to protecting high-value old-growth forest structures. The authors assert that fuels and prescribed fire treatments should be prioritized in the sequoia groves most vulnerable to high-severity fire, thereby increasing wildfire resistance and reducing the risk of complete mortality events in future wildfires.

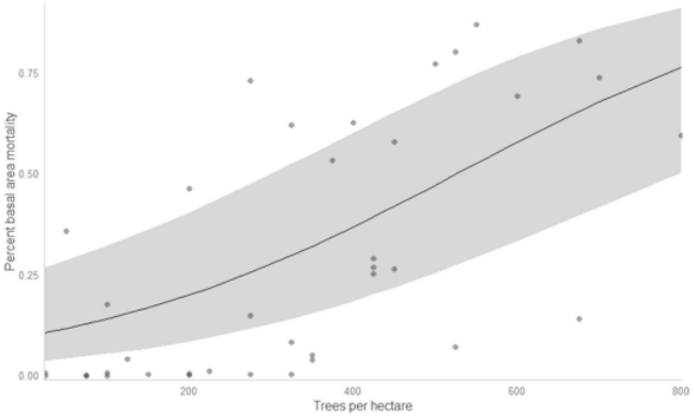


Figure 1 : Model response curve for the best performing model that predicted the percentage of basal area mortality outside of stand-replacing wildfire (<100% mortality), which only included tree density (ha–1). Points represent observed data, the black line represents predicted values from the final model, and the shaded envelope represents ±1 SE

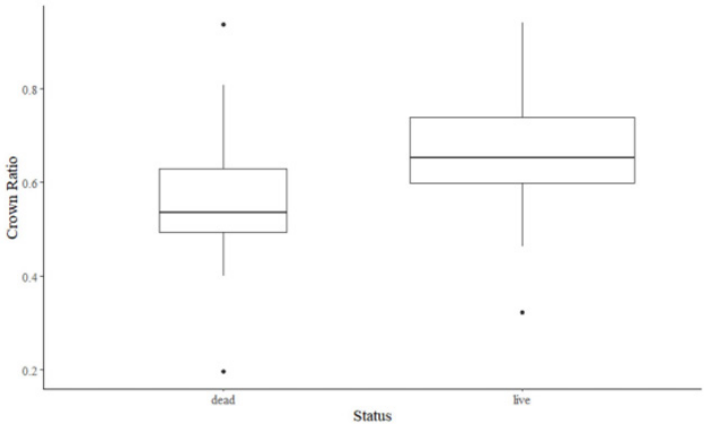


Figure 2: Box plot of crown ratio and mortality status (live, dead) for individual, large giant sequoias. Pre-fire, live trees had significantly larger crown ratios than trees that were killed by fire (mean of 0.67 for live trees and mean of 0.57 for dead trees, p<0.01). Boxplot widths are scaled to sample size, where boxes denote first and third quartiles, lines the median, and whiskers the 1.5 inter-quartile range. Dots are outliers

Additional Information

This brief is based on the following article:
Hardlund, L.J., Collins, B.M., Bernal, A.A. et al. How big is big enough? Exploring drivers of fire-induced giant sequoia mortality from the individual to the stand level. Fire Ecol 22, 75 (2026). https://doi.org/10.1186/s42408-026-00502-7

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