# Extreme Weather and Forest Structure Jointly Increase Wildfire Severity in Industrial Forests

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Increases in high-severity wildfires can be linked to extreme weather and forest management practices, though their relative impact remains debated. This study compares private industrial and public forests, examining how different forest management practices affect high-severity wildfire risk. Private industrial forests are typically more intensively managed than public forests, resulting in uniform and continuous stands of trees that are similar in size. Public forests, on the other hand, tend to be less intensively managed, resulting in stands with a mix of small and large trees and heavy fuel loads due to fire suppression policies. This study asks: (1) Are private industrial or public forest lands more likely to experience high-severity fire? (2) Which forest structure, climate, and spatial characteristics are linked with high-severity fire, and how does extreme weather influence these relationships? and (3) Can differences in fire severity on private industrial and public lands be attributed to differences in forest management?

## MANAGEMENT IMPLICATIONS

- The effects of tree density are magnified under severe weather. Reducing tree density lowers the likelihood of high-severity fire, especially under extreme weather conditions.
- Increase structural heterogeneity in plantations. Reducing uniform tree spacing and promoting a mix of tree sizes can lower the likelihood of high-severity fire, even during extreme weather conditions.
- High-severity fire is contagious. Implement treatments at a landscape scale; reducing severity in one area can lower severity in adjacent areas.

The study covers an area in northern Sierra Nevada, including Plumas National Forest and surrounding private land, of which 82% is publicly managed, 12% is private industrial forest, and 7% is non-industrial private land. Forests here are typically yellow pine and mixed-conifer forest types, adapted to frequent, low-severity fire regimes. Between 2019 and 2021, five large wildfires (Dixie, North Complex, Sugar, Sheep, and Walker Fires) burned 70% of the study area, including 39% at high severity.

The authors used airborne light detection and ranging (LiDAR) data collected pre-fire to quantify forest structural characteristics known to affect fire behavior (tree density, height, canopy gaps, and ladder fuels), linking these with estimates of burn severity derived from satellite imagery. They also estimated weather and landscape conditions using nearby weather stations and additional satellite data, focusing on fire weather (hot, dry, and windy conditions, fuel moisture), recent fire behavior, topography, and longer-term climate conditions. The authors examined how land ownership, forest structure, weather, climate, and topography influence the likelihood of high-severity fire using a combination of statistical and machine-learning models that account for spatial patterns and uncertainty.

The study found that lands owned by private industry were more likely to experience high-severity fire than publicly owned lands or other privately owned non-industrial lands. Private industrial land had 1.45x higher odds of experiencing high-severity fire compared to public land, and 2.1x higher odds compared to non-industrial private forest land, even after accounting for differences in weather, climate, and topography.

Incoming fire severity (the average severity of a fire as it moves into an area), forest structure, and weather were all key predictors of fire severity. Incoming severity was the single most important factor, meaning that severe fires tend to continue burning at high severity. Forest structure and weather were also important predictors. Forests with dense trees, uniform tree spacing, large amounts of ladder fuels, and smaller trees were most at risk, while less dense, more heterogeneous stands with taller trees were generally less prone to high-severity fire (fig. 1). The most influential forest structure metric was density—a one standard deviation increase in tree density corresponded to a 1.4x increase in the likelihood of high-severity fire. Weather also influenced the probability of high-severity fire, with high hot-dry-windy index values increasing that probability, and higher fuel moisture reducing it. The most influential weather metric was hot-dry-windy index, where a one

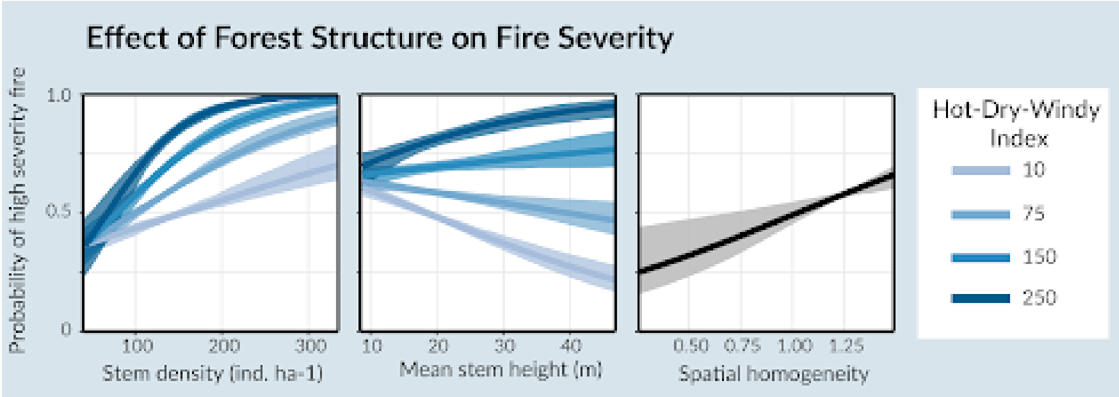


*Figure 1. Effects of forest structure and weather on fire severity. Estimated effects of forest structure and weather on the probability of a 30 m by 30 m pixel burning at high-severity. Shaded regions represent 95% confidence intervals, estimated using spatial block bootstrapping(Materials and Methods). Solid lines indicate a statistically clear relationship (95% CI does not contain 0), whereas dotted lines indicate the lack of a clear relationship. Darker blue colors illustrate the relationship under more extreme weather conditions (higher hot- dry-windy index). All relation-ships are shown for the stand scale (390 m by 390 m) model.*

standard deviation increase resulted in a 1.5x increase in the odds of high-severity fire, on average.

Notably, weather also impacted the relationship between forest structure and fire severity. For example, the effect of tree density on the probability of high-severity fire was magnified in extreme weather conditions, meaning an equivalent change in tree density was more impactful in extreme conditions than in mild ones. Extreme weather conditions could even reverse the effect of tree size, making larger trees (typically associated with a lower risk of high-severity fire) a liability for high-severity fire. In contrast, extreme weather conditions reduced the impact of ladder fuels on the probability of high-severity fire.

Forest structures commonly found on private industrial forests (dense, spatially homogeneous stands with high ladder fuels) were strongly linked to high-severity fire, potentially explaining the increased incidence of high-severity fire on these lands. Private industrial forests also experienced more extreme fire weather, likely because they were often at lower or mid elevation sites. However, even when accounting for these differences in weather, private industrial forests had a higher probability of high-severity fire, suggesting the importance of forest management in driving high-severity fire risk.

This study demonstrates that forest structure strongly influences wildfire severity, even during very large fires and extreme weather conditions. Dense forests with uniform tree spacing and abundant ladder fuels were more likely to burn at high severity, with tree density emerging as a predictor as influential as hot, dry, and windy conditions. Moreover, the effects of forest structure and weather interacted strongly, leading forest structure to become even more important in extreme weather conditions—an encouraging result in light of concerns that climate change will render fuel reduction and thinning treatments ineffective.

High-severity fires were more likely on private industrial forests than on public or non-industrial private lands, largely due to forest structure differences associated with even-aged plantation management. However, high-severity fire was widespread across all ownership types and much higher than historic levels, indicating that current management practices are not adequately reducing risk on private or public lands. Overall, the results suggest that reducing tree density and ladder fuels and increasing structural heterogeneity are key strategies for reducing future high-severity fire, even during extreme weather events.

## Additional Information

This brief is based on the following article:

*Levine, J. I., B. M. Collins, M. Coppoletta, and S. L. Stephens. 2025. " Extreme Weather Magnifies the Effects of Forest Structure on Wildfire, Driving Increased Severity in Industrial Forests." Global Change Biology 31, no. 8: e70400. https://doi.org/10.1111/gcb.70400.*

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