Wildfire effects on microclimate conditions and tree regeneration in mixed conifer forests

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The western U.S. is experiencing increasing wildfire activity and warmer, drier climate conditions, with declining post-fire tree regeneration observed in many areas in recent years. Seedlings of mixed-conifer and subalpine forest species are sensitive to seasonal climate conditions, particularly in the first few years after a fire when many seedlings establish. Conifer seedlings may also be sensitive to microclimate, defined here as the air temperature and moisture near the ground where seedlings live. Microclimate conditions can vary dramatically at fine spatial scales and are affected by local topography and surrounding vegetation. To anticipate how forests will change in a future with more fire and warmer, drier climate, we need to understand how fire and climate interact to affect post-fire tree regeneration. The goal of this study was to quantify the impacts of wildfires on microclimate conditions relevant to conifer seedlings, and evaluate how fire severity and microclimate affect early post-fire seedling regeneration and survival in mixed-conifer and subalpine forests.

Key Management Findings

- **Wildfires increase microclimatic extremes by removing canopy cover, resulting in warmer and drier growing season conditions in the years immediately after a wildfire. These impacts are most pronounced during mid-summer, in areas burned with high severity, and in wetter topographic settings.**
- **Forest recovery after wildfires can be robust under moderate seasonal climate conditions, given that seeds are available and microclimate and microsite conditions are suitable.**
- **Our results suggest that retaining canopy cover, even from standing snags, moderates microclimate conditions. Management actions that remove standing dead trees could further increase microclimate extremes, with the potential to impact seedling survival and regeneration.**
- **Reforestation may be most effective in areas that burned at high-severity far from live seed sources, in cool-moist topographic settings, and when targeting favorable microsites.**
- **Spatial models were effective at predicting post-fire seedling density based on topoclimate data and fire severity information, supporting the use of similar models in reforestation planning.**

Methods

This study was conducted in two large lightning-ignited wildfires that burned from July to September 2017 in western Montana (Fig. 1): the Lolo Peak (54,000 acres) and Sunrise (26,000 acres) fires. In 2018, 69 field plots were set up across both fires, spanning a range of local climate (via elevation and aspect) and fire severity (unburned, moderate, and high-severity). Dominant species included ponderosa pine at low elevations and dry aspects, Douglas-fir and western larch across a broad elevational range, and lodgepole pine, subalpine fir, and Engelmann spruce at higher elevations.

At each plot, a 60-m-long belt transect was used to quantify post-fire seedling density. We monitored individual seedlings for survival and growth in permanent 1-m^2 subplots for three years after the fires. Plot characteristics including distance to the nearest live seed source, pre-fire stem density and basal area, overstory mortality, canopy and ground cover, and soil nitrogen availability were also measured. To quantify post-fire microclimate conditions, sensors were deployed at 46 plots from June to September during the first two years post-fire (2018-2019). Data were aggregated to daily maximum temperature (°C) and vapor pressure deficit (VPD, kPa), which is a measure of the dryness of the air. We characterized the climate at each plot using gridded datasets of climatic water deficit (250-m resolution), precipitation, and heat load, as well as our field-based microclimate data. We built statistical models to assess the influence of seed availability, climate, and fire severity variables on seedling regeneration and survival.

Results

Microclimate

We found that wildfire increased warm, dry microclimate extremes during the growing season. Plots burned at high severity experienced on average 3.7 °C (6.7 °F) higher daily maximum temperatures and 0.81 kPa higher daily maximum vapor pressure deficit relative to unburned forest in similar topographic settings (Fig. 2). Differences in microclimate between burned and unburned plots were largest when it was hotter, both during the day and over

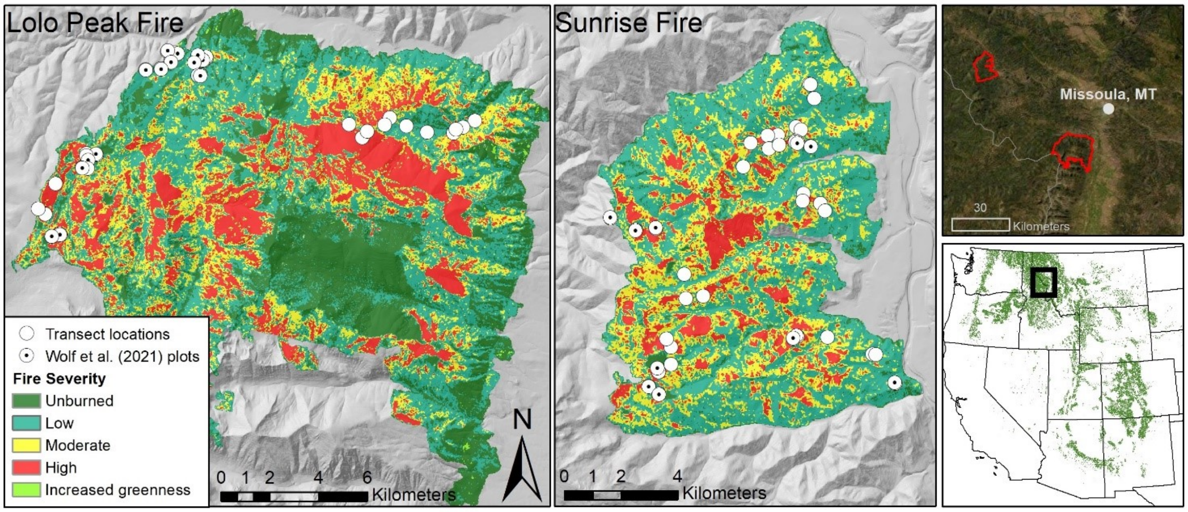

Figure 1. Map of study area and sample sites in the Lolo Peak (n = 35 transects) and Sunrise (n = 34) fires. Sample sites include those with regeneration data (white circles) and those which also have microclimate measurements (white circles with black dots). Fire severity classifications are from the Monitoring Trends in Burn Severity project (MTBS 2019), and satellite imagery is from Esri. The green area in the lower right panel delineates the extent of Rocky Mountain forest cover from LANDFIRE.

the course of the summer (Fig. 2, 3). Microclimate differences were also larger in plots with less total canopy cover (live and dead) and in cooler, wetter topographic settings. These results highlight that canopy cover, including shading from dead stems, was a key variable affecting post-fire microclimate conditions. Importantly, wetter, more productive forests (e.g. at higher elevations or north facing aspects) have a greater ability to moderate microclimate conditions in the understory, such that wildfire had a larger relative impact on microclimate in those forests (Fig. 3). In drier, low-elevation forests, microclimate differences between burned and unburned plots were less pronounced.

Seedling Regeneration

Overall, we found abundant natural regeneration by the third year after fire (median 1,147 seedlings acre^{-1}), with 68% of burned plots at or above replacement density. Because our plots were purposefully within 100 m of a live seed source, this robust regeneration is due, in part, to seed availability. In addition, annual climate conditions during the three study years were near the 1980-2020 mean. Mild post-fire climate supported high seedling survival rates, which averaged >50% across the three years and were highest in cool-moist plots.

Tree density three years post-fire spanned a wide range among burned plots (c. 10 - 200,000 seedlings acre^{-1}), and was mostly explained by variability in seed availability, microclimate, and fire severity variables (Fig. 4). Regeneration was most abundant for lodgepole pine and Douglas-fir, and tended to be higher in plots close to live seed sources or dominated by lodgepole pine with serotinous cones. Seedling densities were greater in plots with cool, moist microclimate conditions and in areas of high tree mortality, and varied depending on seedbed and soil conditions (Fig. 4). Extensive post-fire moss and forb cover (mainly fireweed) and little bare ground cover were associated with high seedling density, survival, and growth, with western larch having the fastest height growth on average.

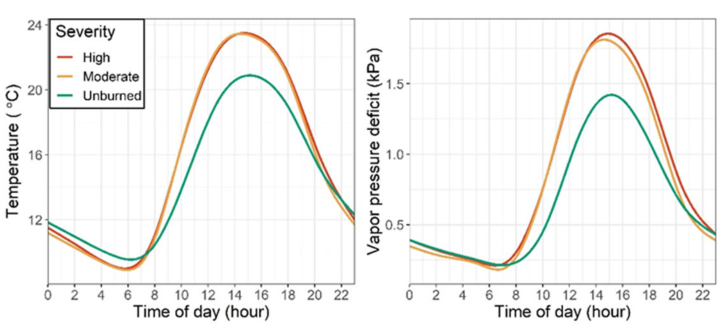

Figure 2. Daily variability in post-fire microclimate conditions averaged across both fires over the growing season (June to September) in 2018 and 2019, with curves fit by time of day and grouped by fire severity.

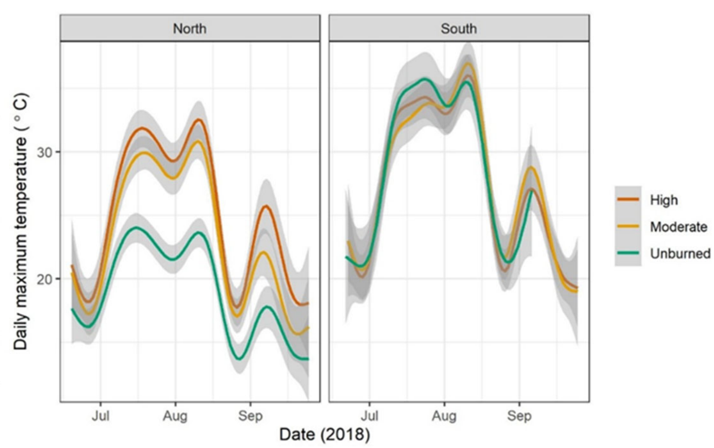

Figure 3. Seasonal variability in post-fire daily maximum temperatures in 2018. Curves represent averages among plots grouped by fire severity and aspect, with shaded bands representing 95% confidence intervals for the mean.

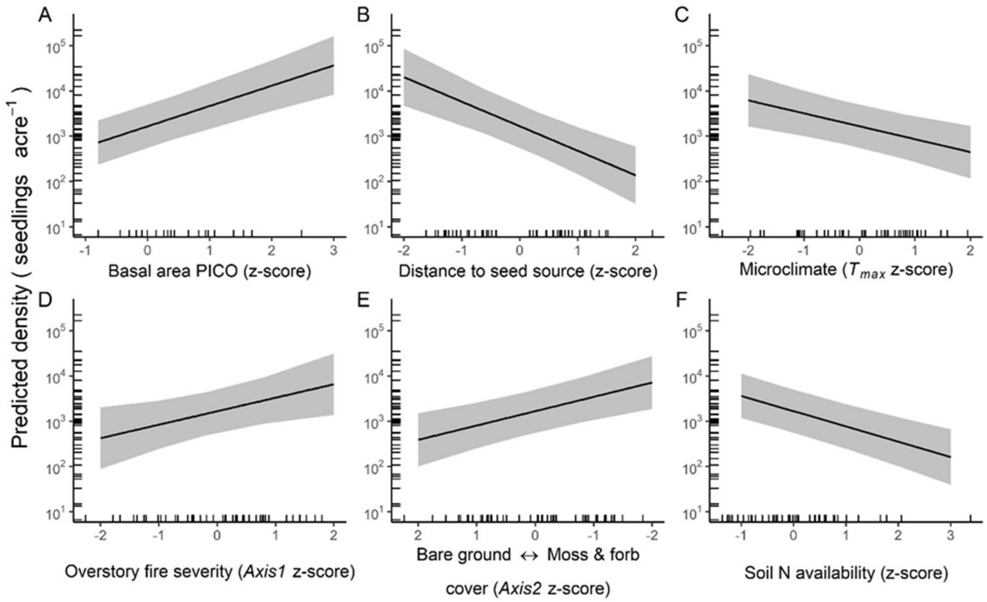

Figure 4. Relationship of each variable to predicted seedling density in the third year after fire after accounting for the effects of all the other variables. Variables include basal area of lodgepole pine (live and dead), field-measured distance to the nearest live tree, post-fire maximum temperature from microclimate data (Tmax), an index of fire-caused overstory tree mortality (Axis1), an index of understory cover (Axis2), and soil nitrogen availability measured using field-incubated ion-exchange resin capsules. Variables are scaled to a mean of zero and a standard deviation of one to make their effects comparable.

Management Implications

We found that wildfires caused increases in maximum air temperature and aridity in the understory due to losses of canopy cover. Management actions that remove standing dead trees could further increase microclimate extremes by reducing shading, with the potential to impact seedling survival and regeneration.

Despite microclimate effects, we found that natural seedling regeneration and survival in mixed conifer forests can be robust in years of moderate post-fire climate. The high variability in seedling density reflected differences in seed availability, microclimate, and fire severity. Management actions aimed at promoting spatial variation in fire effects may help support natural regeneration, by increasing seed availability (by reducing the distance to live trees) and increasing the availability of favorable microsites for seedlings. These actions could include pre-fire fuels management to alter fire behavior and lower fire severity, especially in in low-elevation dry forests; managed wildfire under moderate fire weather; and reforestation to promote heterogeneity in tree density and stand structure.

Our results support that reforestation efforts are most effective in areas of high-severity fire far from seed sources, in relatively cool, wet sites such as north-facing aspects, and in microsites with live or dead canopy cover that helps moderate microclimate. Our results also suggest that selecting microsites with moss and forb cover could improve seedling survival and growth, although additional investigation is warranted to understand the underlying mechanisms. Further, despite the importance of field-based microclimate, our statistical models explained much of the variation in post-fire seedling density even without direct microclimate measurements. This supports the use of predictive spatial models that account for dispersal distance, fine-scale climate (in this study 250-m resolution), and fire severity to aid in reforestation.

References

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