Reduced fire severity offers buffer to climate-driven declines in resilience—California and the Klamath

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Conifer forests of the western US (West) are largely fire adapted ecosystems that historically have recovered naturally in the years to decades following wildfire. As climate change alters the extent, frequency, and severity of wildfire, and causes warmer and drier post-fire conditions, forests may not be able to recover how they have in the past. Fire severity, which affects how many trees survive the fire and produce seeds for recovery, is a key driver of post-fire conifer regeneration. Climate is another key determinant of forest recovery because conifer seedlings are sensitive to hot and dry conditions. Understanding the relative importance and interactions between these two drivers of post-fire conifer regeneration is crucial for identifying vulnerability to post-fire forest loss and key opportunities for potential management interventions. This study assessed how the interactive impacts of changing climate and wildfire activity influenced conifer regeneration of eight widespread species across the West.

Methods

We compiled an extensive dataset of post-fire conifer regeneration from 10,230 field plots that represents 334 fires that occurred between 1984 and 2018 and spans the climatic range of eight widespread conifer species across the West (white fir, *Abies concolor*; grand fir, *A. grandis*; subalpine fir, *A. lasiocarpa*; Engelmann spruce, *Picea engelmannii*; lodgepole pine, *Pinus contorta*; Jeffrey pine, *P. jeffreyi*; ponderosa pine, *P. ponderosa*; and Douglas-fir, *Pseudotsuga menziesii*). Together, these species represent 89% of the conifer basal area in the study area (Figure 1).

We used this dataset to create statistical models to understand how fire severity, seed availability, average climate conditions, and post-fire climate conditions affect the likelihood of post-fire conifer regeneration. We created models for each species individually and for all species combined. We used these models to project the likelihood of post-fire conifer regeneration under multiple scenarios of fire severity (low- and high-severity) and climate change (2031-2050; moderate and high emissions scenarios).

Results

We found that warmer, drier conditions are leading to reduced tree regeneration after wildfires, a trend that we project will continue in upcoming decades. The percent of the study area considered unlikely to experience conifer

Key Management Findings

- **With large increases in burned areas that are unlikely to naturally regenerate, more planting may be necessary in the coming decades.**
- **Making climate-smart decisions on plantings will be critical for the future of many burned landscapes across the western US.**
- **Pre-fire management actions that reduce wildfire severity will likely increase the chances of post-fire regeneration.**
- **In California and the Klamath, low or moderate severity fire may be especially important to promote natural regeneration. Projections suggest very limited regeneration is expected for the study species in high severity burned areas.**
- **Climate suitability and consideration of different fire-resistant species found in the region, including those not focused on here, may be critical for long-term forest cover in this region.**
- **The most likely species to recover naturally in this region are true firs and Douglas-fir, thus a focus on pine species for replanting may be necessary to maintain pines on the landscape.**

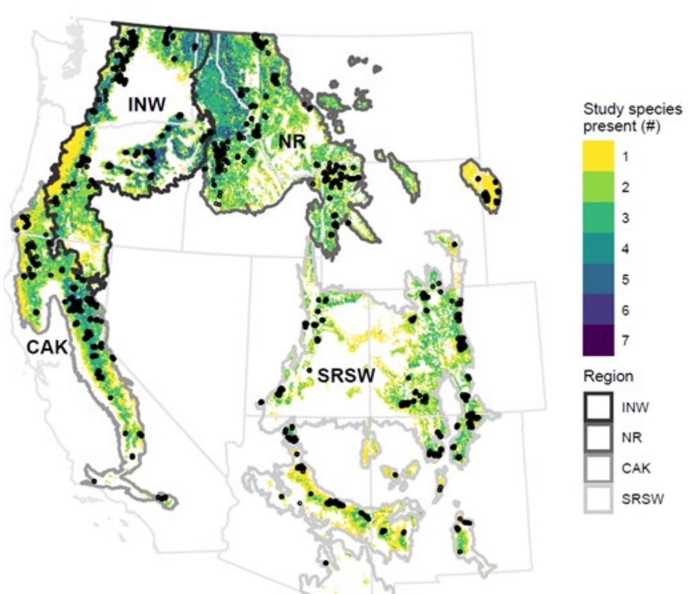

Figure 1. Study area and plot locations.

Figure 2. Photos taken nine years following the 2007 Moonlight Fire on the Plumas National Forest, CA. On the left is a study plot in a large high severity patch with no natural regeneration or nearby seed sources. On the right is a study plot within 100 m of an area burned at low severity with natural ponderosa pine seedlings regenerating.

regeneration, regardless of fire severity, increased from 5% in 1981-2000 to 26-31% by mid-century.

How these changes to post-fire tree regeneration unfold varies between species and across the West. Lower elevation species (ponderosa pine, Jeffrey pine, Douglas-fir, grand fir, and white fir) have already experienced a significant decline in the likelihood of post-fire regeneration over the past forty years, while higher elevation species such as lodgepole pine and Engelmann spruce are predicted to experience more declines in the coming decades in some regions. Similarly, forests in the California and Klamath (CAK; Figure 1) and southern Rockies and AZ/NM mountain (SRSW) regions saw significant declines in recruitment probability over the past forty years. We project similar patterns to expand northward by 2050, especially in drier forests of the interior Northwest (INW). However, wetter and cooler portions of the INW and much of the northern Rockies (NR) were projected to remain climatically suitable for post-fire regeneration of the study species through mid-century.

Despite the importance of climate, our results suggest that reductions in overall fire severity or the size of high-severity patches could partially offset expected declines in post-fire regeneration attributed to climate change alone. This is largely due to the importance of distance to seed source for post-fire conifer regeneration (Figures 2 and 3). In our projections across the West, changes in fire severity, which included changes to seed availability, had a greater relative effect on the likelihood of post-fire conifer regeneration than did changing climate conditions for most species (Figure 4). In much of the study area (40-42%), we project post-fire conifer regeneration to be likely following low-severity but not high-severity fire under future climate scenarios (2031-2050) (Figure 3).

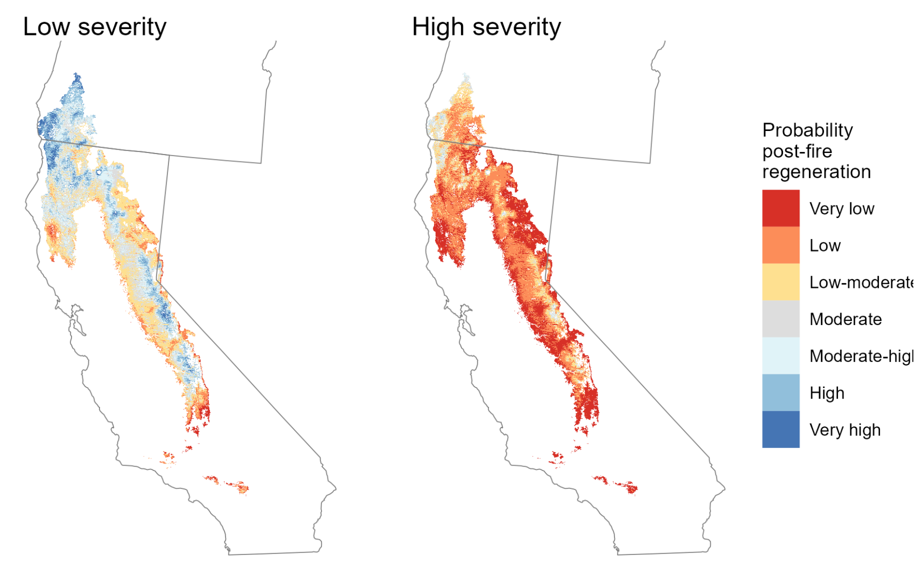

Figure 3. Projected probability of post-fire regeneration under a future climate scenario (2031-2050; moderate emissions RCP 4.5) and either low severity (left) or high severity (right) fire scenarios for all study species combined. In the low severity scenario the nearest seed source is 10 m away, while in the high severity scenario it is 150 m away.

Beyond the importance of fire severity for determining how many seeds are available to promote post-fire regeneration, we also found that lower fire severity and higher surviving tree cover can help to moderate the effect of warm, dry post-fire conditions. For most species, post-fire regeneration was more

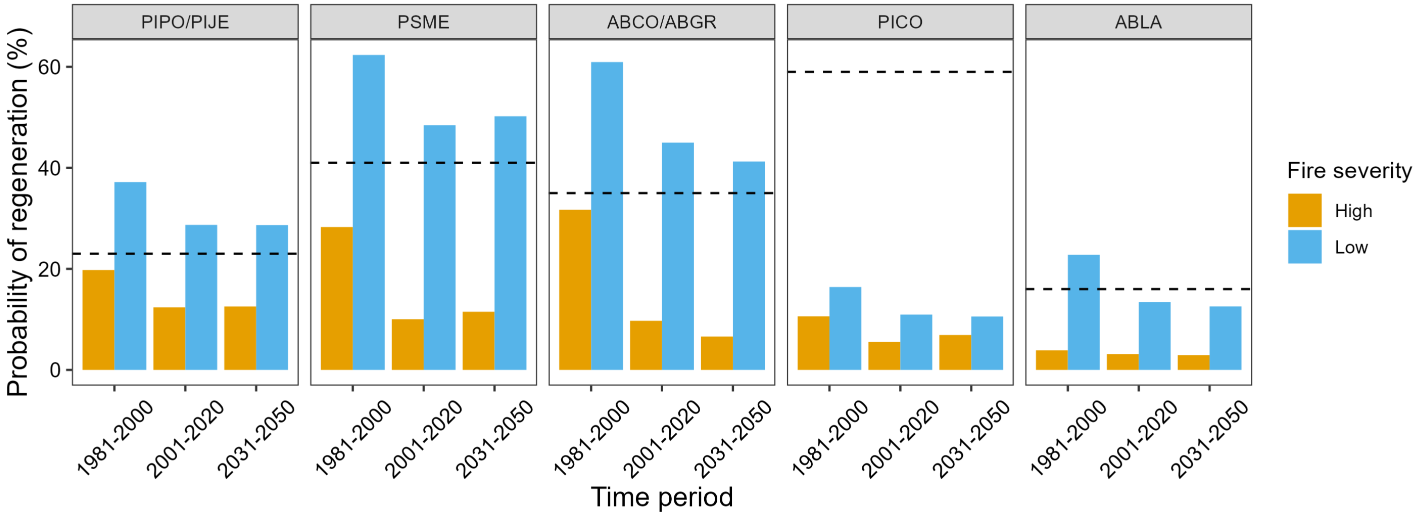

Figure 4. Median probability of post-fire regeneration for individual species across the range of each species within the California and Klamath region (Fig. 1). The dashed black line is the threshold probability above which regeneration is likely (which varies by species). "PIPO/PIJE" is ponderosa/Jeffrey pine; "PSME" is Douglas-fir; "ABCO/ABGR" is white/grand fir; "PICO" is lodgepole pine; "ABLA" is subalpine fir.

likely to be negatively impacted by warm and dry years following the fire in areas that burned at high compared to low severity.

Management Implications

Our results suggest that in many areas, especially the warmer and drier regions of the West, we should expect and plan for reduced natural post-fire conifer regeneration (Figure 5). For example, managers may need to plant tree seedlings following fire in more areas than they have historically if the goal is to maintain forests. Thinking ahead about which species make sense to plant, where planting is most likely to be successful, and if there is enough seed and nursery capacity to produce the seedlings for post-fire reforestation may help post-fire management efforts proceed more smoothly.

Given the importance of fire severity and seed availability for post-fire regeneration, our results also suggest that pre-fire management interventions that reduce wildfire severity will increase the chances of natural post-fire regeneration. This is true in many areas of the West. But in some areas, such as the drier portions of the Southwest and California, the window of opportunity is short. In these areas, forest treatments that modify wildfire or jump-start recovery will be most effective in the next few decades, setting up seedlings to better withstand near-term warming.

An interactive map displaying project results is available at: https://kimberleytaylor7.users.earthengine.app/view/mapping-postfire-conifer-regeneration-probability

References

Davis, Kimberley T, +62 other authors. 2023. Reduced fire severity offers near-term buffer to climate-driven declines in conifer resilience across the western United States. PNAS 120(11). https://doi.org/10.1073/pnas.2208120120

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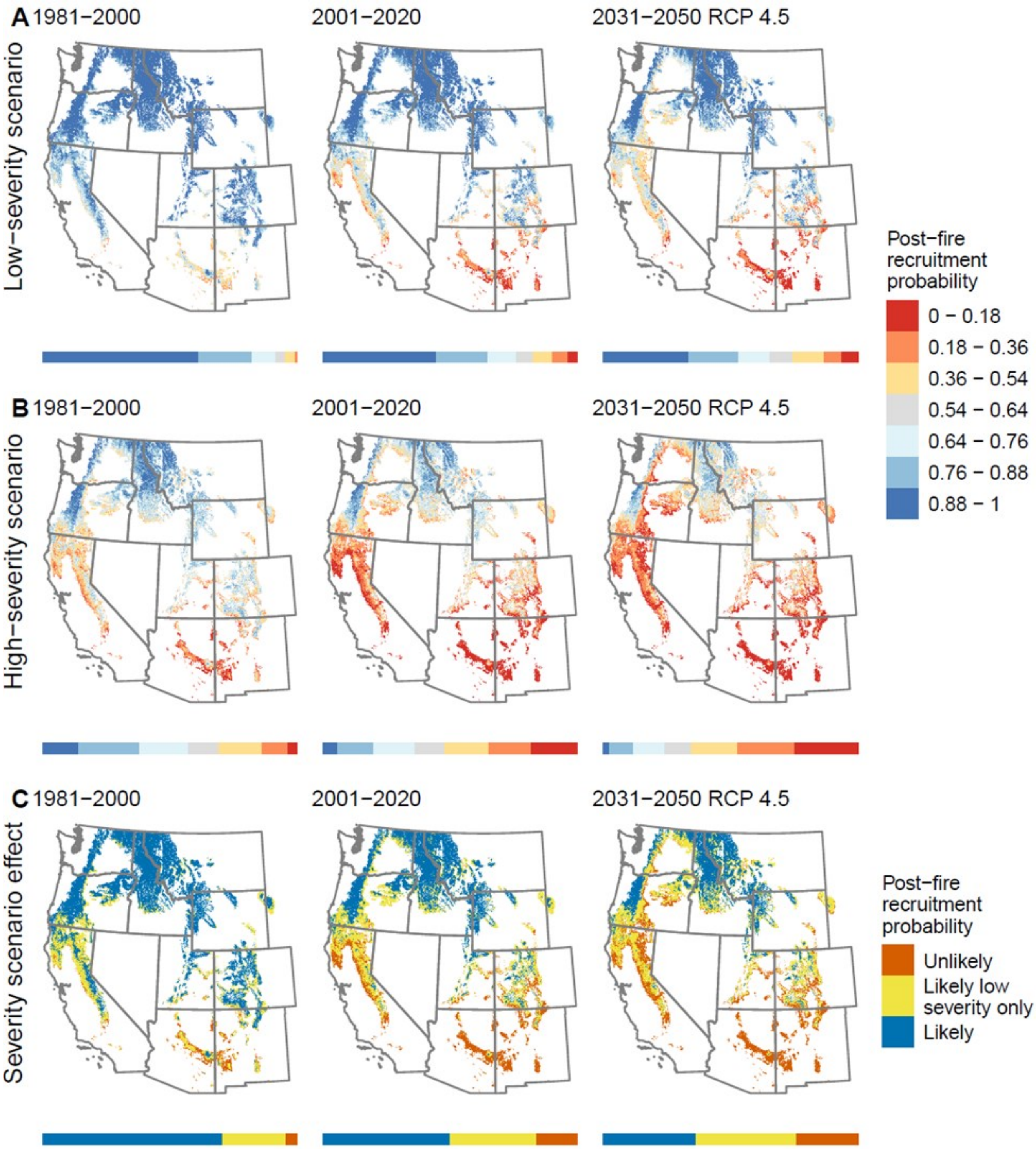

Figure 5. Projected probability of post-fire regeneration for all study species combined across all regions under different climate and fire severity scenarios. In the low severity scenario the nearest seed source is 10 m away and tree cover surrounding the plot is 30%, while in the high severity scenario the nearest seed source is 150 m away and tree cover surrounding the plot is 10%. The future climate scenario represents moderate emissions.