Climatic controls on post-fire ponderosa pine and Douglas-fir regeneration and growth

NORTHERN ROCKIES FIRE SCIENCE NETWORK

Research Brief 8 | May 2020

Climate change is causing increased wildfire activity across the western US and creating post-fire conditions that are warmer and drier than they were in the past. Scientists and managers are concerned with the potential for post-fire tree recruitment failures in dry mixed-conifer forests (Figure 1). Tree seedlings are more sensitive to climate conditions than adult trees, which means that even in sites dominated by mature forest prior to a fire, the post-fire conditions may be too warm and dry for seedlings to regenerate. However, the exact climate conditions necessary for regeneration have not been well established. The goal of this study was to identify how seasonal climate conditions affect post-fire ponderosa pine and Douglas-fir regeneration and growth. We also explored how reductions in canopy cover, for example through stand-replacing disturbances such as wildfire, may alter microclimate conditions for seedlings near the ground level.

Key Management Findings

- **Climate conditions are limiting post-fire tree regeneration. The warmest and driest portions of ponderosa pine and Douglas-fir forests may not recover following wildfires as they have in previous decades, and managers might expect transitions to other vegetation types.**
- **Thinning and prescribed burning treatments that reduce future wildfire severity can increase post-fire regeneration by maintaining live trees on the landscape to provide seeds and to moderate microclimate conditions.**
- **After fire, tree plantings may be more effective when targeted at areas of high severity burn without a nearby seed source, but which have cooler and moister site conditions (e.g. north-facing aspects or higher elevations) that promote both seedling survival and growth.**

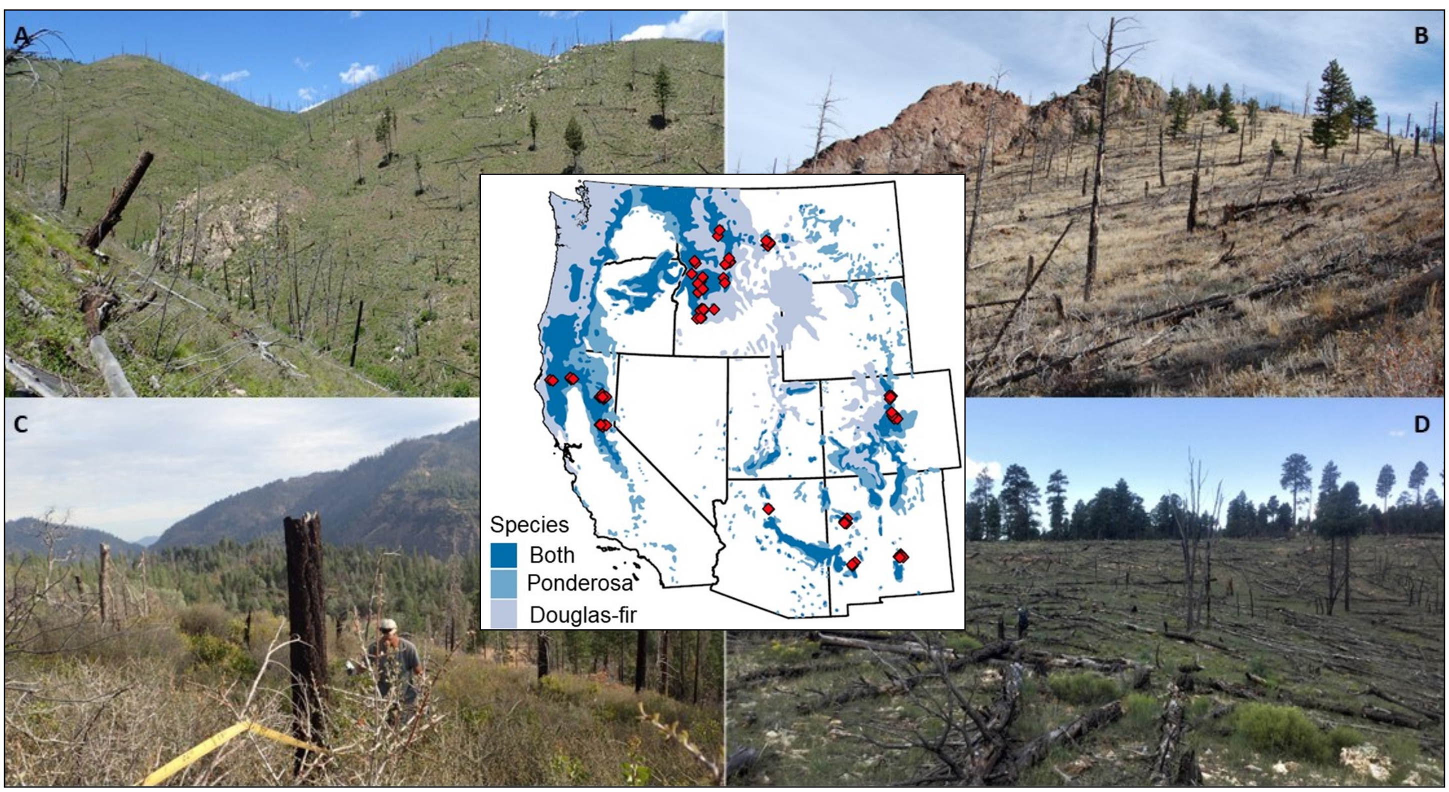

Figure 1. Locations of study sites (red points on map) and photos showing limited post-fire tree regeneration in each study region. (A) A grass and shrub dominated site 17 years post-fire on the Bitterroot National Forest, MT. (B) A grass dominated site 10 years post-fire in Boulder County Parks and Open Space, CO. (C) Shrub dominated site 12 years post-fire on the Shasta-Trinity National Forest, CA. (D) A grass dominated site 11 years post-fire on the Kaibab National Forest, AZ. Photo credit for (A), (C), (D) is K. Davis; (B) is W. Foster.

Methods

Climate - Post-fire Recruitment Relationship

To quantify the relationship between seasonal climate and post-fire recruitment, we identified 90 sites that had burned between 1988 and 2007 across four broad regions of the western US (Northern Rockies – NR; Colorado Front Range – CO; Southwest – SW; and northern California – CA; Figure 1). These sites were in the warmest and driest portion of the range of ponderosa pine and Douglas-fir within each of the regions. Along transects at each site, we collected all juvenile trees (<25 years old; 1630 ponderosa pine, 1190 Douglas-fir) that had established following the fire. In the lab, we aged these trees to the year they had germinated. We then compared annual tree seedling recruitment rates to the seasonal climate conditions (temperature, humidity, soil moisture) at each site while controlling for other factors that affect post-fire regeneration, including distance to seed source, fire severity, and time since fire.

Climate - Tree Growth Relationship

For all juvenile trees sampled in the Northern Rockies (1431 trees), we also measured the ring widths to quantify growth rates. To include adult trees (>24 years old) in our growth analysis, we sampled 12 additional sites in the Northern Rockies, which burned between 1910 and 1987, by coring 427 trees close to the ground level and processing cores in the lab with standard dendrochronological methods. To assess the relationship between growth and climate, we compared annual growth rates to growing season (April-September) climate conditions.

Forest Canopy Effects on Microclimate

To examine how forest canopy cover affects seedling microclimate, we selected six sites that spanned the moisture gradient from the drier Lubrecht Experimental Forest near Missoula, MT to the wetter Dunn Experimental Forest near Corvallis, OR. At each site, we set up seven sensors near the ground surface to monitor the temperature and humidity every 30 minutes for three growing seasons (2014-2016). One sensor was placed in the center of a large opening with no canopy cover and six sensors were placed surrounding the clearing at subplots with varying levels of canopy cover. We calculated the daily difference in temperature between each of the six forested subplots and the non-forested opening.

Results

Post-fire Recruitment

We found that post-fire conifer recruitment is strongly related to climate conditions during the summer. Ponderosa pine recruitment declined rapidly once thresholds of low humidity and low soil moisture during the driest month were crossed (Figure 2). Douglas-fir recruitment declined once thresholds of high surface temperature and low spring soil moisture were crossed (Figure 3). Climate conditions have become increasingly unsuitable for post-fire regeneration at the study sites since the late 1990s, particularly for ponderosa pine (Figure 4). Post-fire recruitment also declined with increasing distance to seed source, time since fire and, for ponderosa pine , fire severity (Davis et al. 2019a).

Juvenile and Adult Growth

Adult growth of both ponderosa pine and Douglas-fir declined with increased water deficit (drier conditions). Warm and dry conditions were associated with reduced juvenile ponderosa pine growth; however, juvenile Douglas-fir growth was less related to climate conditions.

Canopy Cover and Microclimate

Canopy cover reduced the daily maximum temperatures during the growing season by an average of 3.4°C (6.1°F) across all levels of canopy cover, and by 5.3°C (9.5°F) when canopy cover was greater than 50% (Figure 5). Humidity was also significantly higher in areas with more canopy cover. The ability of forests to moderate temperature and humidity varied across biophysical gradients, with the largest effect of canopy cover on microclimate in wetter and more productive forests and the smallest effect in warmer and drier forests.

Management Implications

Our results suggest that the warmest and driest portions of ponderosa pine and Douglas-fir forests may not recover following wildfires as they have in previous decades, as conditions become too hot and dry for regeneration. Stand-replacing disturbances, such as high-severity fire, will cause significant increases in maximum temperature at the ground-level, where tree seedlings establish, due to a loss of canopy cover. Pre-fire management activities that reduce subsequent fire severity can increase post-fire regeneration by maintaining live trees on the landscape to provide seeds and to moderate microclimate conditions. Following fires, tree plantings may be most effective when targeted at areas of high severity burn that don't have nearby seed sources, but which have cooler and moister site conditions (e.g. north-facing aspects or higher elevations) that promote both seedling survival and growth. In the warmest and driest areas of ponderosa pine and/or Douglas-fir forests, managers might expect transitions to other vegetation types following fire (e.g. grass or shrubs).

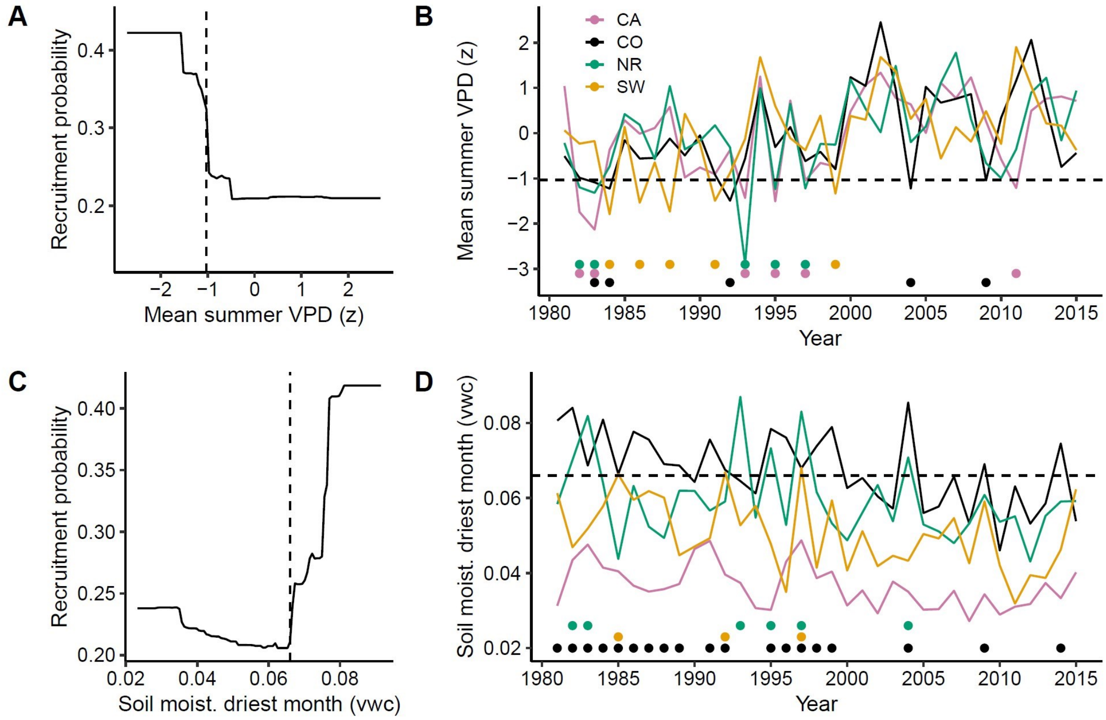

Figure 2. Ponderosa pine seedlings were absent or low in density on many of the sites at low elevations within 33 large fires sampled in California, Colorado, the US northern Rockies, and the southwestern US because high temperatures and low humidity (summer vapor pressure deficit VPD, z score) and low soil moisture (volumetric water content, vwc) during the driest month exceeded thresholds for successful recruitment (A and C) in many years. This is increasingly so in recent years (B and D; dots indicate conditions favorable for recruitment; colors indicate study area: California = pink, Colorado = black, US northern Rockies = green, southwest US = orange). Climate thresholds are identified with vertical (A & C) and horizontal (B & D) dashed lines. From Davis et al. (2019a).

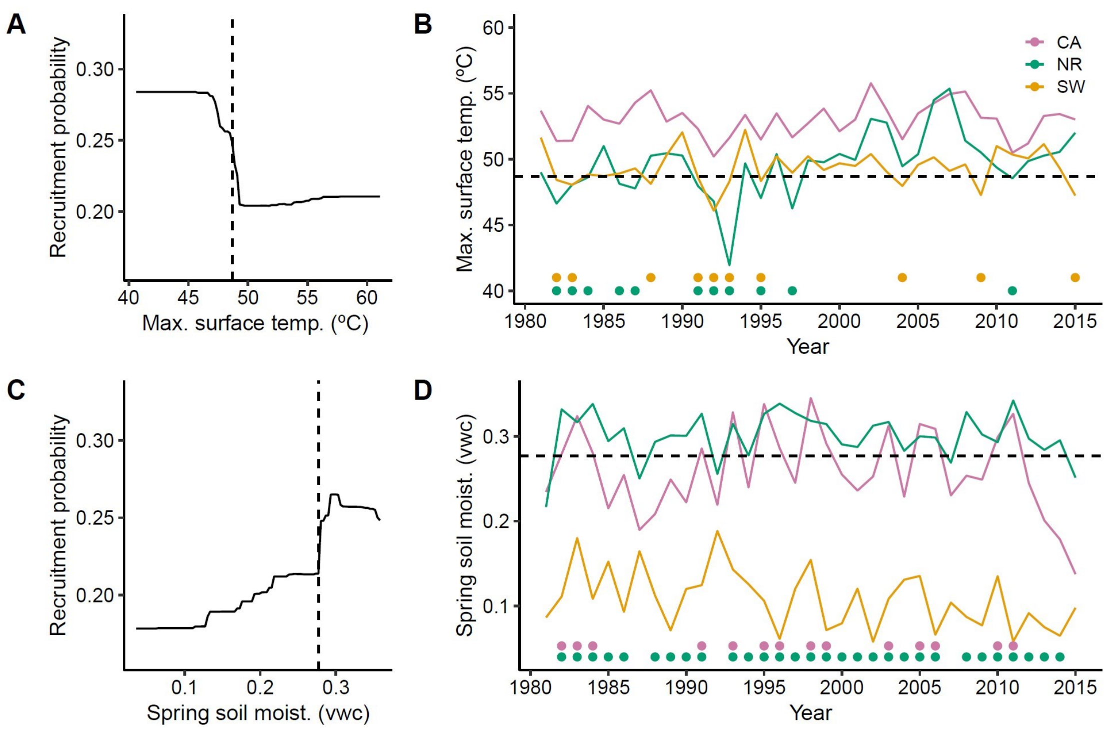

Figure 3. Douglas-fir seedlings were absent or in low density on some of the sites at low elevations within 33 large fires sampled in California, the US northern Rockies and the southwestern US because maximum growing season surface temperature (°C) and low spring soil moisture (volumetric water content, vwc) exceeded thresholds for successful recruitment (A and C) in many years. This is increasingly so in recent years (B and D; dots indicate conditions favorable for recruitment; colors indicate study area: California = pink, US northern Rockies = green, southwest US = orange). Climate thresholds are identified with vertical (A & C) and horizontal (B & D) dashed lines. From Davis et al. (2019a).

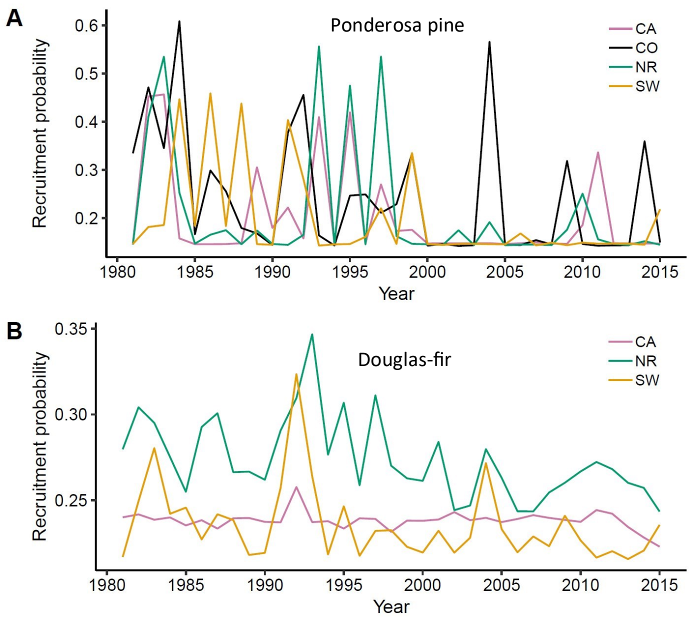

Figure 4. Modeled annual recruitment probability for ponderosa pine (A) and Douglas-fir (B), in California (pink), Colorado (black), the US northern Rockies (green), and the southwestern US (orange). Modeled annual recruitment probability varied with annual climate conditions while other variables in the model were held constant (time since fire at 1 yr, distance to seed source at 50 m, and fire severity at dNBR 412). Figure from Davis et al. (2019a).

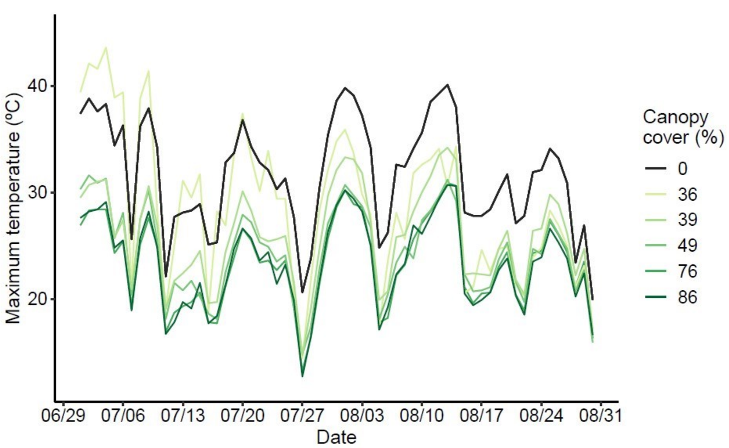

Figure 5. Maximum temperature near the ground surface during July and August 2015 at a site on the Nez-Perce Clearwater National Forest, ID. Data from six subplots with different levels of canopy cover are shown.

Citations

Davis KT, Dobrowski SZ, Higuera PE, Holden ZA, Veblen TT, Rother MT, Parks SA, Sala A, Maneta MP (2019a) Wildfires and climate change push low-elevation forests across a critical climate threshold for tree regeneration. PNAS. DOI: 10.1073/pnas.1815107116.

Additional Publications and Information

Davis KT (2019) Climatic controls on post-fire regeneration and growth in ponderosa pine and Douglas-fir [Webinar]. Northern Rockies Fire Science Network and University of Montana. Webinar recording available at https://www.nrfirescience.org/event/climatic-controls-post-fire-regeneration-and-growth-ponderosa-pine-and-douglas-fir

Davis KT, Higuera PE, Sala A (2018) Anticipating fire-mediated impacts of climate change using a demographic framework. Functional Ecology 2018; 00:11-17. https://doi.org/10.1111/1365-2435.13132

Davis KT, Dobrowski SZ, Holden ZA, Higuera PE, Abatzoglou JT (2019b) Microclimatic buffering in forests of the future: the role of local water balance. Ecography 42: 1-11. 10.1111/ecog.03836

Hankin LE, Higuera PE, Davis KT, Dobrowski, ST (2019) Impacts of growing-season climate on tree growth and post-fire regeneration in ponderosa pine and Douglas-fir forests. Ecosphere 10(4):e02679. 10.1002/ecs2.2679

Northern Rockies Fire Science Network Post-fire Tree Regeneration Hot Topic webpage. https://www.nrfirescience.org/hot-topics/post-fire-tree-regeneration

Stevens-Rumann C, Morgan P, Davis KT, Kemp K, Blades J (2019) Post-fire tree regeneration (or lack thereof) can change ecosystems. Northern Rockies Fire Science Network Science Review No. 5. Available at https://www.nrfirescience.org/resource/20639.

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Research was funded by the Joint Fire Science Program 16-1-01-15, the National Science Foundation grant BCS 1461576, and the University of Montana.
Editing and layout – Signe Leirfallom and Cory Davis, Northern Rockies Fire Science Network.

The Northern Rockies Fire Science Network (NRFSN) serves as a go-to resource for managers and scientists involved in fire and fuels management in the Northern Rockies. The NRFSN facilitates knowledge exchange by bringing people together to strengthen collaborations, synthesize science, and enhance science application around critical management issues.