What makes a resilient landscape? Climate, fire and forests in the Northern Rockies

NORTHERN ROCKIES FIRE SCIENCE NETWORK

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Determining whether forest landscapes can maintain their resilience to fire – that is, their ability to rebound and sustain – given rapid climate change and increasing fire activity is a pressing challenge throughout the American West. Many western forests are well adapted to fire, and even subalpine forests that experience infrequent, high-severity fires historically recovered long before they burned again. However, current rates of warming portend a mismatch between historical and future fire regimes. How forest changes will unfold, whether forest resilience will be compromised and whether tipping points could be surpassed during this century remain largely unresolved. Resilient landscapes are a fundamental goal of the National Cohesive Wildland Fire Management Strategy, but understanding how to promote them has proven challenging. Fire and forest managers would benefit from knowing how to assess forest resilience; where, when and why resilience may be lost; and how management could promote resilience. Our project aimed to quantify multiple dimensions of resilience for Northern Rocky Mountain forests and to develop widely applicable methods for operationalizing forest and landscape resilience concepts.

Our studies addressed three questions: (1) How and why might warming climate and changing fire regimes push forest stands over a tipping point? (2) Where and when might management activities enhance or erode landscape resilience given projected changes in climate and fire activity? (3) How do stand and landscape indicators of resilience scale to the Northern Rockies ecoregion, and what geographical areas are most likely to be vulnerable or resilient to changing climate and fire regimes?

Key Management Findings

- **Under a hotter-drier climate, forest extent is projected to shrink during the 21st century, and remaining forests will be younger and sparser.**
- **Mean tree density and basal area may decline sharply as fire rotations become shorter and postfire tree regeneration is projected to decline.**
- **Fire-sensitive tree species are likely to show the greatest declines, whereas fire resisters and resprouters are likely to expand.**
- **Fire suppression is unlikely to alter the trajectory of 21st-century subalpine forest landscape change, which will be driven primarily by large fire years and increasingly arid conditions.**
- **In areas of wildland-urban interface (WUI), clustering developments and applying fuels treatments on 10-30% of the landscape every 10 years can reduce fire risk across multiple scales.**

Assessing Forest Resilience

"Resilience" is a widely used but nebulous term, and how to assess or manage for resilience is unclear. Use of "resilience" has risen in both scientific publications and management documents since about 2010, and there is common ground associated with "climate change" in both types of documents (Selles and Rissman 2020). In computer models used to assess forest resilience, we found a gap in the processes that underpin forest resilience, such as tree regeneration, soil processes and disturbance legacies. Thus, many contemporary forest models may be poorly suited for studying forest resilience during an era of accelerating change (Albrich et al. 2020).

To assess resilience of Northern Rockies forests across space and time, we used iLand, a "next-generation" forest landscape simulation model that includes the basic processes that drive forest dynamics. We extended iLand to include dominant tree species in the Northern Rockies, tested the model with independent empirical data and compared stand development to those generated by the Forest Vegetation Simulator (FVS; Braziunas et al. 2018). Fire modeling capability was further extended by linking iLand with current models of fire behavior (Braziunas et al. 2021). Finally, we integrated new statistical projections of potential fire occurrence, location and maximum potential size based on climate to simulate fire spread and burn severity based on available fuels, weather and topography (Turner et al. 2021). The resulting forest landscape simulation model iLand performs well in the US Northern Rocky Mountains.

Projecting 21st-century Forest Change

Postfire tree regeneration is necessary for forests to maintain their resilience, so understanding why postfire tree regeneration may succeed or fail is critical. We simulated postfire regeneration of lodgepole pine and Douglas-fir under different combinations of fire-return interval (FRI), distance to seed source and postfire climate in iLand. Changes in fire regime had a greater effect on postfire lodgepole pine and Douglas-fir regeneration than did climate (Figure 1). Douglas-fir was more vulnerable to regeneration failure than lodgepole pine, usually in stands >500 m from a seed source. Serotinous lodgepole pine stands were resilient, but regeneration failed for very short (20 yrs) FRI and long distances (>500 m) from seed source. Douglas-fir regeneration increased with warming, and lodgepole pine regeneration was unaffected by the warmer climates simulated in this study (Hansen et al. 2018).

Stand-level simulations of short-interval reburns in subalpine forests also demonstrated that disruption of the normal fire-recovery cycle leads to substantial delays in carbon recovery. Postfire recovery of live tree carbon would be delayed by about 80 years following atypical short-interval (<30 yrs) reburns in lodgepole pine forests. Furthermore, downed coarse wood and total aboveground carbon stocks did not recover over the 150-year simulation (Turner et al. 2019).

We next used iLand to simulate fire and forest dynamics across five landscapes that span environmental gradients in Greater Yellowstone. We tracked forest extent, stand age, tree density, basal area, aboveground carbon stocks, dominant forest types, and species occupancy through 2100 for six climate scenarios (Turner et al. 2021).

Key results of our simulations include the following.

- Hot-dry climate scenarios led to more fire, but stand-replacing fire peaked in mid-century and then declined even as annual area burned continued to rise.
- Where forest cover persisted, previously dense forests were converted to sparse young woodlands.
- Increased aridity and fire drove successive abrupt annual declines (≥ 20%) in tree density, basal area, and extent of older (>150 yr) forests, while declines in carbon stocks and mean stand age were always gradual.
- Stabilizing greenhouse gas concentrations by mid-century would slow the declines, moderating fire activity and dampening the magnitude and rate of forest change.
- Forest loss during the 21st century was most likely in landscapes with less complex topography dominated by fire-sensitive tree species (Engelmann spruce, subalpine fir, lodgepole pine) and where fire resisters (Douglas-fir) were not already prevalent.

As fire rotations (FR) decrease, our models suggest that subalpine forests may cascade through a series of tipping points. In Greater Yellowstone simulation landscapes, average stand density and basal area decline first (if FR < 80 years), then aboveground carbon storage (if FR < 60 years), and then forested area (if FR < 40 years). Thus, subalpine forests may be resilient to changing fire regimes until thresholds are passed. Simulations with reduced greenhouse gas emissions were less likely to cross these thresholds (Ratajzcak et al. in prep.)

Scaling Up

To project regional-scale forest transitions, we simulated the 2.9 million ha forested area in Greater Yellowstone and estimated the probability for vegetation transitions during the 21st century. Sizable areas on the Yellowstone Plateau

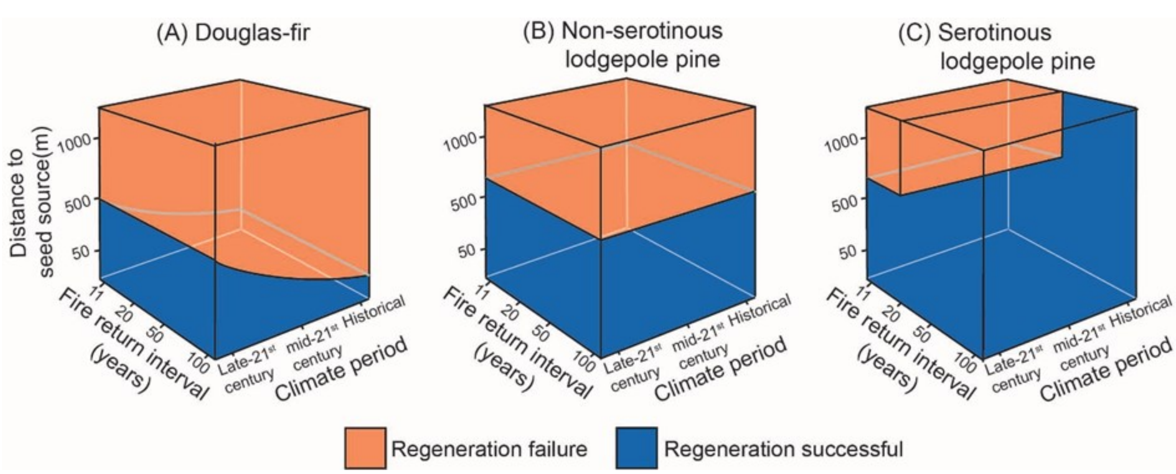

Figure 1. Combinations of postfire distance to seed source, fire return interval, and climate that can cause regeneration failure for Douglas-fir and lodgepole pine. Regeneration failure generally occurred in stands far from seed for Douglas-fir and non-serotinous lodgepole pine, and following short-interval fires -for serotinous lodgepole pine. From Hansen et al. (2018).

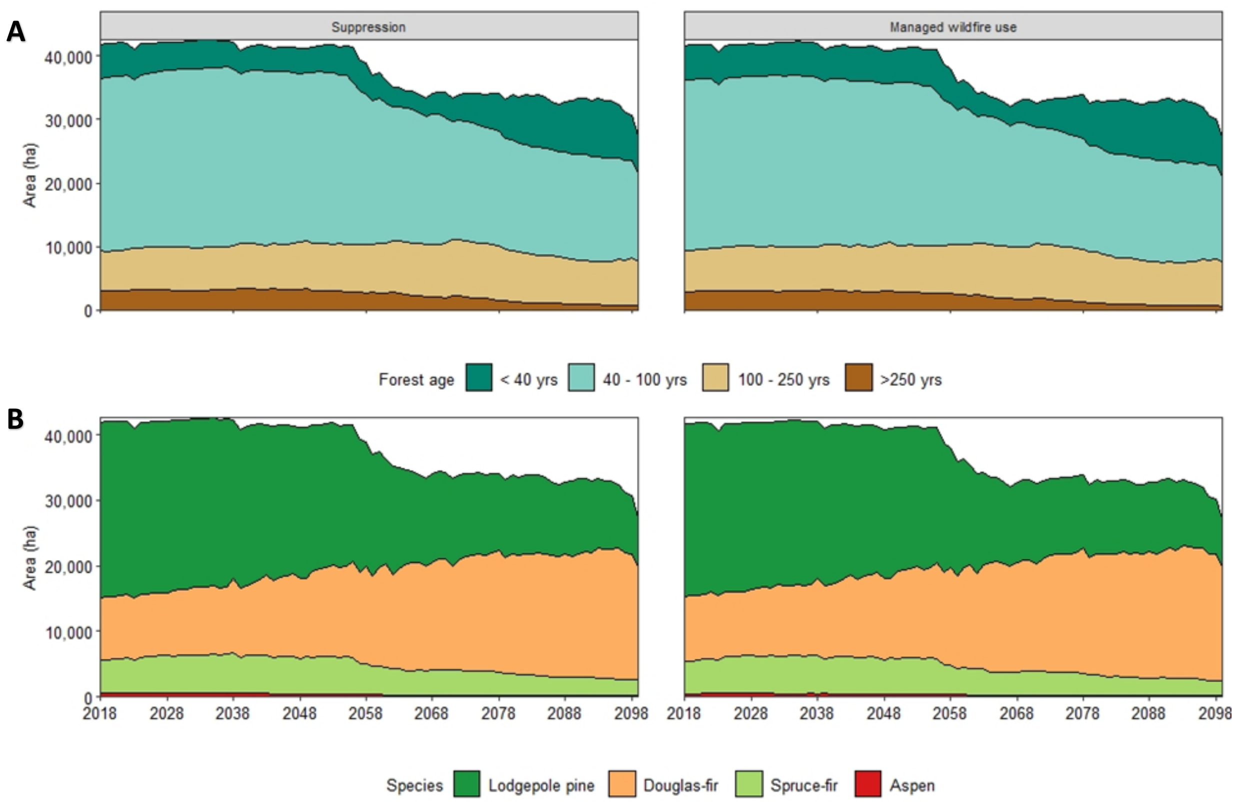

Figure 2. (A) Forested area (ha) that is < 40, 40 – 100, 100 – 250, or > 250 yrs old in suppression and managed wildfire use scenarios. (B) Forested area (ha) dominated by lodgepole pine, Douglas-fir, spruce-fir, or aspen between 2018 and 2099 in suppression and managed wildfire use scenarios. Values in (A) and (B) are means for 20 replicate simulations using a CNRM-CM5 GCM, 8.5 RCP climate scenario.

reburned twice or more through 2100, and dominant forest types failed to regenerate in 28-59% of the areas they currently occupy (Rammer et al. 2021).

Fire Management During A Time of Rapid Change

We explored several questions related to fire and fuels management. In Grand Teton National Park, simulations showed that climate-driven increases in fire activity during the 21st century had a stronger effect on forest extent and pattern than fire suppression (Figure 2). Fire suppression (1989-2017) under historical climate had little effect on forest landscape patterns; scenarios with and without managed wildfire use differed little in the number, size and severity of fire. Under a hot-dry future climate, fire activity increased and followed nearly identical trajectories with or without fire suppression. Fire suppression could reduce burned area somewhat during the 21st-century but would have little effect on forest extent and structure. Strategic suppression of subalpine fires will likely have few consequences for 21st-century forests (Hansen et al. 2020).

Analysis of fire incident reports between 2008 and 2013 in the Northern Rockies found that managers chose full suppression for nearly half the fires. Full suppression was more likely on non-federal land; for fires burning earlier in the year; in areas with higher housing density; when regional or national incident management teams rather than local teams were in charge (Daniels 2019); and for fires with human-caused ignitions, larger sizes, and lower growth potential.

We also considered fuels management in forested wildland urban interface (WUI) landscapes. Simulation experiments varied fuels treatment, housing amount and configuration and projected future climate. Our models suggest that clustering WUI developments and treating between 10 and 30% of the landscape every 10 years can reduce fire risk across multiple scales (Braziunas et al. 2020).

Management Implications

Our study suggests that future fire activity in the Northern Rockies will differ substantially from the past.

- Areas of high-severity fire may peak in the middle third of the century then decline even as annual area burned continues to rise.
- The shorter fire rotations observed in today's forests may be the longest rotations observed by the end of the century.
- Forests could shift in extent, structure and composition more than they have for thousands of years; not all forests will be resilient.

Fire Suppression and Fuels Management

Fire suppression and fuels treatments will likely slow rates of change rather than alter long-term forest outcomes, but such actions could buy more time for ecosystems to adjust. Strategic use of fire suppression in subalpine forests might be warranted not only for protecting high-value assets (e.g., buildings and infrastructure) but also for maintaining essential ecosystem processes and attributes (e.g., old growth forest, wildlife habitat). Forest transitions can be irreversible for thousands of years if seed sources are depleted by frequent fire (e.g., especially for fire-sensitive species). Thus, fuels management might be desirable in areas where forest recovery could be in jeopardy, or where protecting certain forests is important. In addition, factors limiting postfire regeneration could be countered by management. Assisted migration of genetic ecotypes or species likely to thrive in a changing climate might be worth considering in areas not managed for wilderness values. However, it is equally important to allow ecological processes to play out without interference in wilderness landscapes that are critically important for learning.

Wildland Urban Interface

In forested WUI landscapes, fire risk to structures is expected to increase in the coming decades, and some exposure to high intensity fire is likely unavoidable even when defensible space is treated. However, fuels reduction in the WUI has potential to substantially reduce fire risk to structures, with effectiveness of different actions varying with scale. Our study offers a template for assessing fire risk to structures at multiple scales to better incorporate different mechanisms of structure ignition due to wildfire.

Looking Forward

Ultimately, our results suggest that managers should consider the potential effects of reduced forest cover and younger, sparser forests for wildlife habitat, aesthetics, timber production and recreational use in the Northern Rockies. Minimizing additional stresses on forest ecosystems (e.g., invasive species) may become increasingly important. Monitoring postfire tree regeneration in recent and future fires will be especially important for assessing whether postfire recovery has been compromised. Ongoing forest monitoring (e.g., FIA plots) will allow forest managers to track regional change in forest structure and composition and determine whether forests are approaching a tipping point of resilience to fire.

Citations and Additional Information

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For details on the iLand model, see http://iland-model.org/startpage

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