Short-interval high severity reburns change the playing field for forest recovery

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What are reburns and why do they matter?

In fire-prone forests, postfire tree recovery may be limited by climate conditions and fire activity that exceed the range of conditions under which these forests evolved, leading to major shifts in forest structure and composition. Transformations of forest to sparse woodland, shrubland, or grassland are emerging in forests where fire return intervals fall below the time it takes for trees to mature and produce cones, in places affected by drought, and in trailing-edge populations. However, fire-prone forests are diverse in species' traits and climatic setting, suggesting that responses to changes in climate and fire activity will vary.

Reburns are sequential overlapping fires that occur within a relatively short timeframe. They are expected to become more common and widespread in the coming decades with increases in the frequency and duration of fire-conducive weather. The ecological consequences of reburns vary by system; in subalpine forests of the Northern Rockies, we consider high-severity fires separated by less than 30 years to be reburns. Although fuel limitations reduce the likelihood or severity of reburns for about a decade after a high-severity fire, repeated high-severity burning can disrupt the mechanisms that forests rely on to regenerate after fire. Short-interval high-severity reburns that are outside the historical range of variability of a system can erode the resilience of subalpine forests by undermining fire-adaptive traits and changing the microclimate that affects tree seedling establishment.

How do fire-adaptive traits shape ecosystem responses to reburns?

While climate is an important—and often dominant—driver of tree regeneration in many postfire landscapes, much of the Northern Rockies will remain climatically suitable for the establishment of native tree species for the foreseeable future. In these settings, regeneration depends on interactions between fire size, fire severity and the **fire-resistant** (e.g. bark thickness) or **fire-embracing** (e.g. serotiny or resprouting capacity) traits that enable individuals or populations to persist on the landscape despite regular fire activity. Reburns can undermine these traits if they lead to conditions that were uncommon over the last several millennia when these traits evolved to enable species to become dominant.

Key Management Findings

- **Reburns are fires that burn in the same location in a short timeframe. In subalpine forests of the Northern Rockies, high-severity fires separated by less than 30 years are beginning to catalyze change in forest structure and composition.**
- **Species that resist fire (e.g., western larch, ponderosa pine, Douglas-fir) or resprout after fire (e.g., quaking aspen) are more resilient to reburns than obligate seeders (e.g., lodgepole pine), which regenerate only from seeds released by cones.**
- **The effects of aspect on microclimate can be amplified after reburns because repeated high-severity fires remove residual forest structure. Forest stands on south-facing slopes and convex ridges, which are warmer and drier than other landscape positions, may transition to grass or shrublands when they are affected by reburns.**
- **Dry, south-facing slopes may be candidates for alternative adaptation strategies after fire, like allowing them to convert to grass and shrublands rather than reforesting; replanting the site with different, more dry-adapted species than were present before the fire; or replanting with the same species using seed stock from locations that are already warmer and drier than the restoration site.**
- **"Micro-siting," or the practice of planting seedling plugs in favorable conditions, remains an important tool for postfire reforestation, especially after a reburn when residual forest structure is consumed by the fire.**

We conducted studies of early postfire tree regeneration after short-interval high-severity reburns in Glacier National Park (GNP) and the Greater Yellowstone Ecosystem (GYE) to understand how these fires can alter forest recovery. In GNP, we compared two sites where forests of similar historical composition were burned by long- and short-interval fire:

1. The long-interval Sprague Fire of 2017 burned subalpine forests across several drainages south of Lake McDonald. These forests were mature; stand ages generally exceeded 200 years and included individuals that were likely much older.

2. The short-interval Howe Ridge Fire of 2018 reburned through young postfire forests and abundant downed coarse wood, almost entirely within a 2003 fire perimeter.

In both areas, we focused on high severity burned patches with no surviving trees. Before 2003, the forests burned in both fires were dominated by western redcedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) along the edge of Lake McDonald. Stands upslope from Lake McDonald were a mix of lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), Engelmann spruce (*Picea engelmannii*), and subalpine fir (*Abies lasiocarpa*), depending on specific disturbance histories, site conditions and topography.

Compared to the historically typical, long-interval Sprague Fire, the Howe Ridge reburn initiated a regenerating seedling cohort that was less dense and less diverse (Fig. 1). Substantial differences in the structure and composition of tree seedling regeneration after long- vs. short-interval burns at the same time-since-fire could signal a departure from historical recovery pathways. Postfire tree seedling densities were substantially reduced by the reburn; mean total seedling density was 45 times higher after the long-interval fire than after the short-interval fire.

Perhaps more significant than the changes in structure, we found changes in the species composition of regenerating forests. These shifts in composition suggest that species' fire-adaptive traits may or may not lead to a relative advantage as fire regimes change. For example, after high-severity fire, western larch can quickly repopulate disturbed areas from a single survivor. Mature individuals frequently exceed 30 m (98 ft) in height, produce hundreds of cones that are held high in the canopy, and disperse small, winged seeds widely onto the mineral soils they prefer. Fast growth rates allow individuals to outcompete other species. Larch can also succeed in a frequent, low-severity fire regime because they have thick bark that enables them to survive fires, self-prune lower branches, and replace scorched branches epicormically. In contrast, lodgepole pine relies on serotinous cones, in which seeds are bound by resin until heated. Serotiny is advantageous in ecosystems where infrequent, high-severity fires remove competition and expose large patches of mineral soil. Then, prolific seeding from serotinous cones of killed trees promotes the establishment of dense postfire cohorts. However, serotiny in lodgepole pine doesn't become dominant until trees reach about 30 years old, and cones held in these short-stature canopies are more likely to be consumed by fire and travel shorter distances from unburned islands or edges.

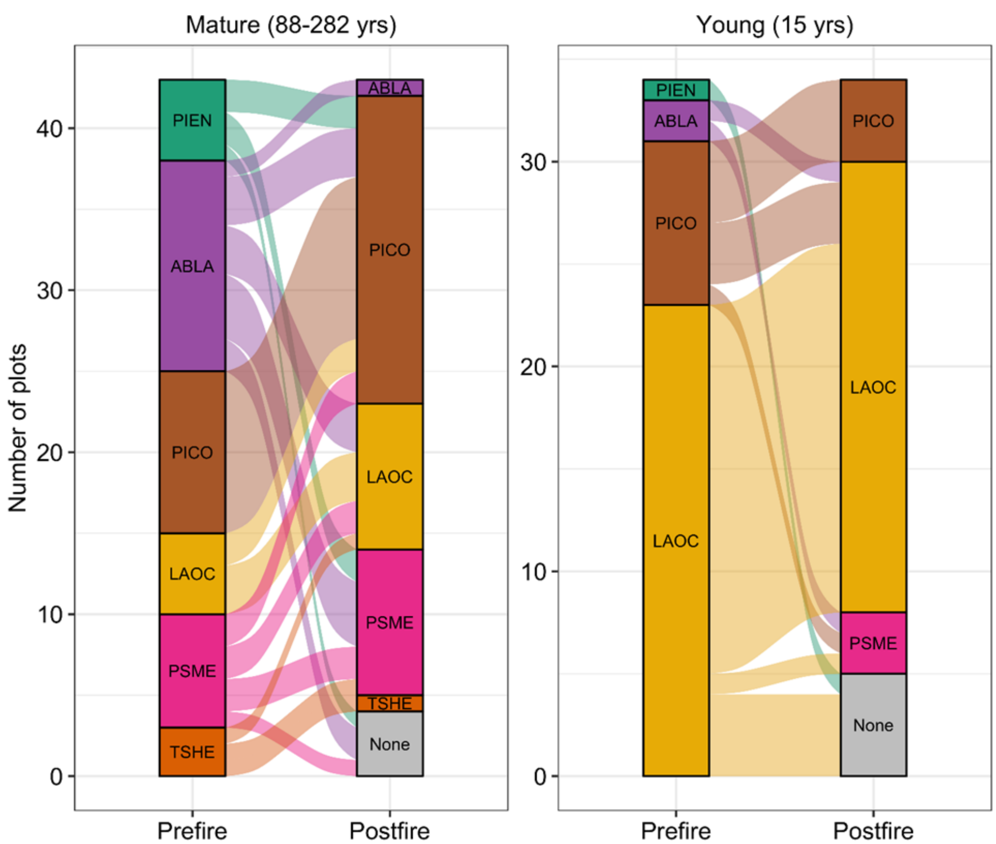

Figure 1. Alluvial diagram depicting the dominant species of plots (based on importance values) in mature and young forests before and after high-severity fires. Note that y-axes are scaled differently because the total number of plots in each site was different. PIEN: Engelmann spruce, ABLA: subalpine fir, PICO: lodgepole pine, LAOC: western larch, PSME: Douglas-fir, TSHE: western hemlock.

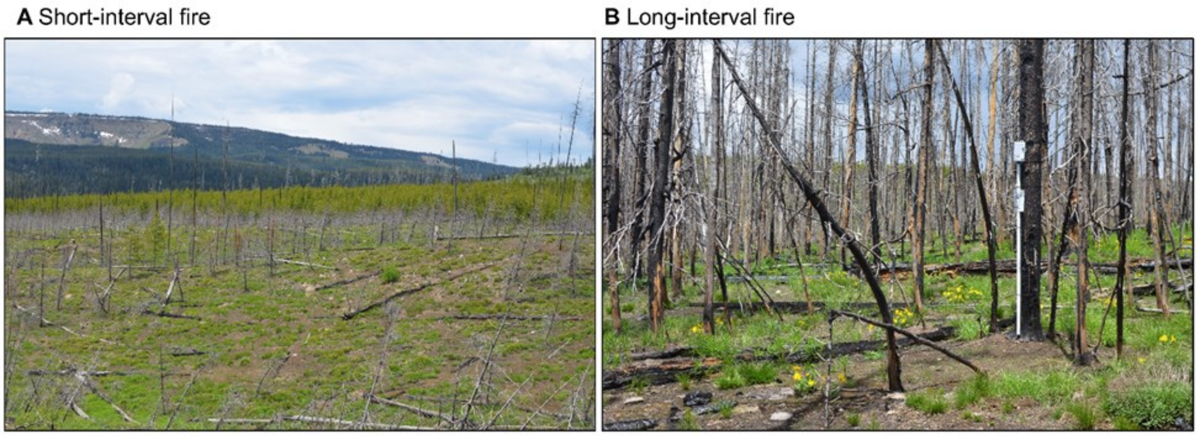

Figure 2. Areas burned by short-interval (16-year) fire were characterized by limited standing or downed woody debris and low vegetation cover (A), whereas adjacent areas burned by long-interval (> 150-year) fire were characterized by abundant legacy structure (B). Soil temperatures in the short-interval fire were >2 °C (10%) warmer and soil moisture was up to 0.05 m3 m−3 (25%) lower than the long-interval fire, which were separated by <500 m.

We also found evidence of the effects of short-interval, high-severity fire on postfire tree regeneration following the 2016 Berry and Maple Fires in the GYE. These late-summer fires reburned areas that regenerated after fires in 1988 or 2000. Lodgepole pine seedlings established within one year in all plots we sampled. However, seedling densities were reduced six-fold relative to the previous long-interval fire, and high-density stands (>40,000 stems/ha) were converted to sparse stands (<1000 stems/ha). A seed dispersal experiment we conducted in these reburns revealed that few seeds made it into the reburns, primarily because trees in the surrounding live forest were still young and short in stature (Gill et al. 2021). Postfire tree densities had not changed significantly in our study plots five years after fire.

If the short-interval fires we studied in GNP and the GYE are indicative of future conditions, increased fire activity may eventually shift these systems toward a more fuel-limited fire regime characterized by low-density forests and woodlands composed of fire-resistant tree species and fire-embracing shrubs and grasses. When fire return intervals fall below the time for trees to mature and produce serotinous cones, serotiny loses its adaptative advantage, and fire-resistant traits are favored over fire-embracing ones. Douglas-fir, western larch and Ponderosa pine, for example, grow thick insulating bark that allows mature individuals to survive fire and provide seed to the burned patch. Species that can resprout, like quaking aspen (*Populus tremuloides*), were not the focus of our studies but are also well-positioned to succeed because they can resprout from belowground roots and are capable of dispersing seeds very long distances. Similarly, grasses and shrubs are resilient to very short fire return intervals, as evidenced by persistent shrub fields appearing across the West after reburns. Self-reinforcing feedbacks between fire and vegetation in a warm and dry future climate scenario could promote persistent transformations but determining whether immediate shifts in postfire ecosystem structure and composition are temporary or indefinite remains extremely challenging.

How do reburns alter microclimates

Field studies indicate that climate is increasingly constraining postfire tree regeneration. Lower rates of survival are documented for seedlings growing in hot, dry regions (e.g., low-elevation forests in the southern Rockies) and sites (fine scales, e.g., south-facing slopes). Likewise, rates of seedling establishment are lower during exceptionally warm and dry growing seasons.

Given the importance of postfire climate as a driver of regeneration and to better understand how reburns modify the postfire seedling microclimate, we conducted an experiment in four reburns that occurred in 2016 in the GYE. We measured soil moisture and temperature continuously in experimental plots in which we recorded germination, establishment, and growth after planting locally sourced lodgepole pine and Douglas-fir seeds in 2017. When we compared soil measurements across aspects in places where forests burned once to areas burned twice within 30 years, we found that residual structure (standing dead snags) buffered the soil from extreme temperatures, much like a live forest canopy (Fig. 2). Dead snags usually stand for about 10 to 20 years, which is the same length of time in which most postfire regeneration occurs in subalpine forests. We also found that the effect of aspect was amplified after short-interval reburns. Soils at south-facing sites were about 2 °C (3.6 °F) warmer than north-facing sites, and soils in reburned areas were about 2 °C warmer than soils in older burns (Fig. 3). This means that effects of reburns are compounded on south-facing sites; they are exposed to long periods of intense sun, and the lack of snags provides little protection.

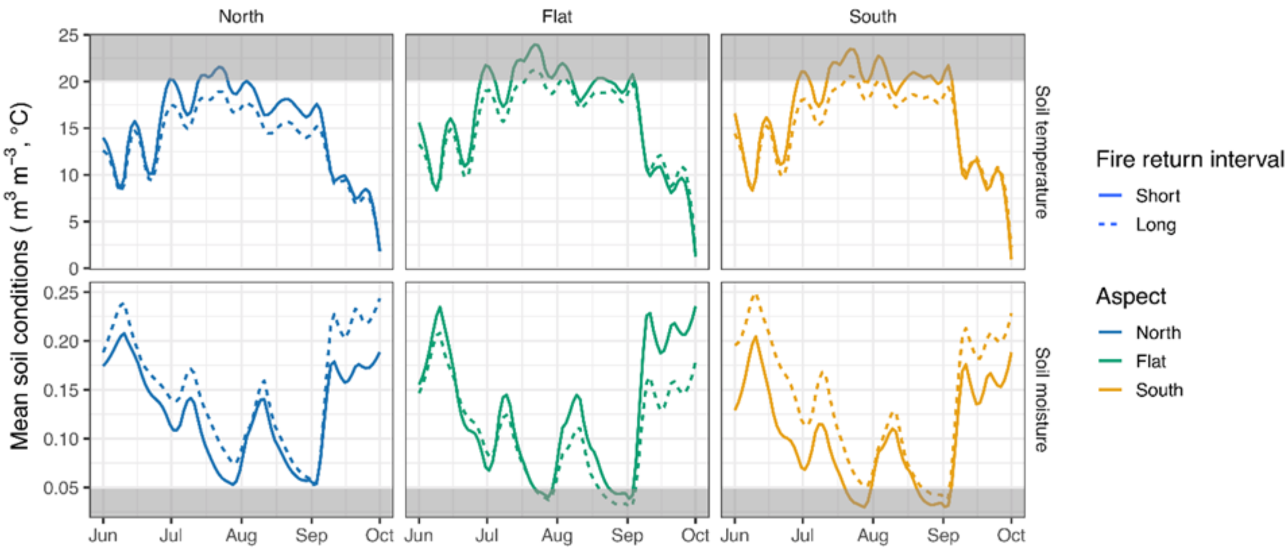

Figure 3. Soil conditions from June 1 – October 1, 2019, in forests that burned under short (16 years, solid line) vs. long (> 150 years, dashed line) fire return intervals. Values are smoothed 14-day means of daily mean values. Line color indicates slope aspect where sensor was located (blue=north, green=flat and yellow=south). Grey boxes are a visual cue to highlight differences among panels, and span 0.00–0.05 m3 m−3 soil moisture and 20-25 °C soil temperature.

Management Implications

This interaction between aspect and reburns means that when warm, dry microsites (e.g., south-facing slopes) burn twice within a few decades, they face a high risk of crossing lethal thresholds for young tree seedlings, leading to local regeneration failure. In places where reforestation may not be an acceptable tool (e.g., in national parks or wilderness areas), this knowledge can help managers anticipate future changes in the patchiness of their forests. The driest microsites may eventually transition to grasslands, while wet microsites may provide critical refugia for trees and forest-dependent species. In areas where management plans call for active reforestation, this information underscores the importance of "micro-siting," planting seedling plugs in favorable conditions.

The amplified effect of aspect after reburns implies that south-facing slopes may be candidates for alternative adaptation strategies like allowing them to convert to grass and shrublands rather than reforesting; replanting the site with different, more dry-adapted species than were present before the fire; or replanting with the same species using seed stock from locations that are already warmer and drier (i.e., dry-adapted genotypes or provenances).

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