A perfect storm: multiple stressors interact to drive postfire regeneration failure of lodgepole pine and Douglas-fir forests in Yellowstone

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Twenty-first century forests will experience increased stress as environmental conditions and disturbance regimes change. Whether forests retain their structure or transitions to alternate states, particularly when affected by multiple stressors, remains unresolved. Subalpine forests in Yellowstone National Park, WY experience large severe wildfires, and postfire-tree regeneration is necessary to assure resilience. Drying is projected, causing frequent larger wildfires that could reduce seed supply and drought that could constrain postfire-seedling establishment. We asked *what combinations of warming-drying conditions, increased fire frequency, and increased burned-patch size cause postfire tree-regeneration failure in Yellowstone?* We conducted a simulation experiment to identify combinations of fire frequency, fire size, postfire climate, substrate type, and elevation where lodgepole-pine and Douglas-fir regeneration failed. We expected postfire densities to be reduced if burned-patch sizes exceeded effective dispersal distance, sequential fires burned before trees reached reproductive maturity, or drought occurred after fire. We also expected regeneration failure only where multiple stressors occurred simultaneously at low elevation or on poor substrates.

Douglas-fir stands were most vulnerable to regeneration failure. 98% of simulated Douglas-fir stands located in the middle of large burned patches failed to regenerate 30 years post fire. Lodgepole-pine stands in the middle of large burned patches failed to regenerate if they were also located at low elevations (93%) or at higher elevations on soils with poor water retention (73%). Stands of serotinous lodgepole (i.e., trees with closed cones that open when heated) also failed to regenerate if fire recurred before trees were reproductively mature (82%). Drought constrained postfire regeneration, yet, enhanced establishment due to release from cold-temperatures during mid-to-late 21st century often outweighed drought effects. Postfire tree regeneration arises from the interplay between multiple factors; some constraining establishment and others enhancing it. To understand 21st-century climate and fire effects on postfire tree regeneration and forest resilience, a reductionist approach is insufficient.