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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 increasing stress as environmental conditions and disturbance regimes change. Whether forests retain structure and function or transition to alternate states, particularly when simultaneously affected by multiple stressors, remains unresolved. Subalpine forests in Yellowstone National Park experience stand-replacing wildfires, and successful postfire-tree regeneration is necessary for resilience. Regional drying is projected, causing frequent, larger wildfires that could reduce seed supply, plus droughts that constrain establishment. We asked *how might warming-drying conditions and changing wildfire regimes interact to cause postfire-regeneration failure in Yellowstone's conifer forest?* We conducted a factorial simulation experiment with an individual forest-process model, iLand, to identify combinations of fire frequency (10yr-100yr interval), fire size (50m-1000m patch size), climate (historical, mid-21st century, late 21st century), substrate, and elevation where regeneration of lodgepole pine and Douglas-fir failed.

Douglas-fir stands were vulnerable to regeneration failure in the middle of large burned patches. Ninety-eight percent of stands 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 (90% of stands) or located on substrates with poor water retention (57-88% of stands). Drought constrained regeneration of all species. However, enhanced establishment due to release from cold-temperature limitation during mid-to-late 21st century outweighed drought effects in Douglas-fir. Forest processes unfold slowly and disturbances occur infrequently, making it difficult to study whether and why forests may transition to alternate states. Simulations helped identify the multiple conditions under which postfire-regeneration failure occurred in Yellowstone.