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# Quantifying natural regeneration of high-elevation five-needle pines across climatic and disturbance gradients to support ecological restoration

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## Overview

High-elevation forests provide essential ecosystem services to their ecological and anthropogenic communities. Because they occupy environments near or beyond the physiological tolerances of other tree species, they provide irreplaceable wildlife habitat and stabilize snowpack, which serves as the primary water source to the Great Basin. Their extreme longevity and slow growth have allowed for their persistence through significant climatic changes, however unprecedented ongoing climate change coupled with threats from mountain pine beetle, white pine blister rust, and changes in fire activity now threaten the resilience of these important forest types. The overall goal of this study was to improve our understanding of climate and disturbance effects on limber, bristlecone, and whitebark pine regeneration to inform conservation and management efforts and facilitate their persistence under changing climate and disturbance regimes.

## Methods and Results

We evaluated natural regeneration in 70 sites across nine mountain ranges in eastern California and the Great Basin that varied in climatic and disturbance characteristics. Sites were either undisturbed or affected by one or more of the following mortality agents: fire, mountain pine beetle, and white pine blister rust. We found extensive beetle-induced mortality across the study area, as well as several recent high-severity wildfires in the subalpine zone and white pine blister rust infection in two mountain ranges. Natural regeneration was highly variable across mountain ranges and species. There was abundant natural regeneration of whitebark pine across varying disturbance and climatic conditions, while limber pine and bristlecone pine regeneration was significantly lower. While bristlecone pine regeneration was rare, mortality was also limited to small-scale lightning events. Preliminary models show that natural regeneration is driven by a complex network of abiotic and biotic factors. Favorable soil characteristics seem to be more important for whitebark and limber pine regeneration, while increased spring snowpack and summer temperature were important drivers of bristlecone pine regeneration. All species show reduced regeneration with greater understory competition. There was no clear response of regeneration to different disturbances, however further investigation of disturbance effects is underway.

## Conclusions

Our findings highlight the complex drivers of natural regeneration in high-elevation pine systems of eastern California and the Great Basin. Water availability, either through increased snowpack or soil characteristics, is an important driver of regeneration and water stress is expected to increase under projected future conditions. Disturbance effects were highly variable and require further investigation. We believe that bird dispersal in whitebark and limber pine may buffer the effects of disturbance by overcoming local seed source limitations, however, forest mortality may exacerbate harsh microclimate conditions, leading to increasingly rare opportunities for seedling establishment. Widespread mortality throughout eastern California and the Great Basin necessitate continued monitoring of its effects on natural regeneration and implications for the persistence of these iconic forests.

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