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Understanding the role of wildland fire, insects, and disease in predicting climate change effects on whitebark pine: Simulating vegetation, disturbance, and climate dynamics in a northern Rocky Mountain landscape

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Climate changes are projected to profoundly influence vegetation patterns and community compositions, either directly through increased species mortality and shifts in species distributions, or indirectly through disturbance dynamics such as increased wildfire activity and extent, shifting fire regimes, and pathogenesis. High-elevation landscapes have been shown to be particularly sensitive to climatic change, and are likely to experience significant impacts under predicted future climate change conditions. Whitebark pine (*Pinus albicaulis*), a high-elevation five-needle pine species that is important for snowpack retention, resource provision, and other ecosystem services in alpine environments in the northern Rocky Mountains, is particularly sensitive to an interacting complex of disturbances - climatic change, altered fire regimes, white-pine blister rust, and mountain pine beetles - that have already caused major changes in species distribution and density. Further changes in abiotic and biotic conditions will likely pose additional threats to the success of this keystone alpine tree species. We used the mechanistic simulation model Fire-BGCv2 to assess potential interacting effects of climate changes, pathogens, and wildfire on the distribution and density of whitebark pine in a high-elevation watershed in Glacier National Park, Montana, USA. The FireBGCv2 modeling platform is uniquely structured to address questions of future species distribution in response to interacting disturbance agents; further, we integrated a range of potential future climate conditions derived from downscaled Global Circulation Models to examine multiple potential future climatic contexts. Our results show that the distribution of whitebark pine is severely reduced under potential future climates, and that increased fire frequency and severity resulting from warmer, drier conditions further reduces the presence of the species on the simulation landscape. Simulation model results highlight the sensitivity of whitebark pine to a complex suite of interacting disturbance agents, suggesting that conservation efforts must target these multiple threats. Furthermore, alternative predictive methods that do not account for multiple disturbance interactions may fail to capture the complex dynamics that drive whitebark pine distributions.

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