Soil moisture constrains subalpine tree seedling physiology, recruitment, and population responses to warming across an elevation gradient

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The elevational range of subalpine trees is known to be climate sensitive. Shifts in the distribution of trees with climate change are dependent on the demographic processes of recruitment, growth and mortality, which occur over decades to centuries for long-lived species. Chronic and acute physiological responses to climate variability can influence demographic outcomes at both leading and trailing edges of species distributions. We established the Alpine Treeline Warming Experiment at Niwot Ridge, CO, to examine effects of climate warming on seedling physiology and tree recruitment near the lower limit of subalpine forest, at upper treeline, and in the alpine. We used infrared heaters to increase surface temperatures and to lengthen the growing season, and watered some plots to distinguish heating from soil-drying effects. We used long-term demography plot data to quantify adult tree growth and mortality. We integrated this experimental and observational data into spatially explicit demography models to assess impacts of warming on tree population sizes and distributions over time.

Preliminary results show that across three species, survivorship increases with seedling age, as do cold and drought tolerance. Lodgepole pine, which rarely occurs at treeline, is less tolerant of freezing than treeline species (limber pine, Engelmann spruce), and had reduced spring but increased fall cold hardiness with warming. Differences among species in drought tolerance match relative abundances of the species in the treeline ecotone (limber pine most tolerant). Patterns of mortality do not match expectations from microclimate thresholds, suggesting slower-acting growth and carbon balance mechanisms determine survival. In limber pine, we find that low soil moisture and temperature can co-limit carbon accumulation at and above treeline, with warming exacerbating soil water limitations. Recruitment is similarly constrained by a combination of temperature and moisture, with warming reducing recruitment in low elevation forest but not enhancing recruitment at treeline or in the alpine due to water limitations. Preliminary model results indicate century-long lags between the onset of climate changes and tree population establishment in the alpine due to seed limitation and low recruitment. Population growth is also sensitive to summer soil moisture, including in the alpine, suggesting that warming may not always result in upslope range shifts. Finally, we find rapid a decline in Engelmann spruce populations at low elevations due to recruitment failure. Linking field experiments and observations with models of population change provides a novel approach to projecting changes in altitudinal distributions of forest with climate change over time.