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Alpine grassland responses to warming in Tibet are mediated by permafrost status

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The Tibetan Plateau is the largest and highest Plateau in the world, supports the world's most extensive high altitude grassland ecosystems, and comprises 75% of the Northern Hemisphere's mountain permafrost. Many studies have focused on the effects of climate warming on aboveground vegetative net primary production (ANPP) and diversity on the Tibetan Plateau; however, a comprehensive understanding of the effects of climate warming on community structure and function remains uncertain due to the diverse results obtained across studies. In this synthesis, we selected 12 field sites that span climate, cryosphere, and vegetative community conditions across the Tibetan Plateau and that had also undergone experimental warming. We examined the relationships among ANPP and environmental factors (temperature, precipitation, drought index and soil moisture) under current conditions. We also tested the response of ANPP and diversity to experimental warming and investigated how permafrost, average climate conditions, and ambient drought status influenced warming effects. Across sites, ANPP accumulated with increasing mean annual precipitation (MAP) regardless of permafrost presence or absence, while diversity was not significantly related to any tested environmental factors. Experimental warming increased ANPP at sites with permafrost, but decreased ANPP at non-permafrost sites. Across all sites, ANPP responded more positively to warming in relatively wetter years. Warming, through effects on permafrost and soil moisture, generally decreased plant diversity and increased vegetation height across all sites. These results support the emerging understanding that water plays a central role in shaping the structure and function of cold environments. They also elucidate the nuanced roles of different hydrologic factors - MAP, drought, direct and indirect warming effects on soil moisture - on mediating these relationships over time. Study results suggest that as sites cross a threshold from permafrost to non-permafrost states, a greater proportion of the Tibetan Plateau may experience declines in ANPP. Thus, estimating ANPP changes under current permafrost conditions likely underestimates the decline in ANPP in a warmer future as permafrost cover declines. This warming-permafrost-vegetation feedback needs to be accounted for when predicting future carbon cycling, energy balance, forage, and vegetation status of important Tibetan Plateau ecosystems under a warming climate.