Integrating Field Observations and Multi-scale Remote Sensing to Understand Tall Shrub Distribution in Arctic Tundra

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The Arctic region has experienced some of the most rapid climate warming on Earth. In response to this warming and associated permafrost thaw, an increase in the abundance of tall shrubs (those that can potentially grow greater than 2 m tall) has been observed across the Arctic, with significant implications on Arctic biodiversity, energy balance, and the biogeochemical cycling of carbon, water, and nutrients. However, uncertainties persist in quantifying the primary drivers of the distribution and rate of shrub expansion in Arctic tundra. While warming temperatures and permafrost thaw are expected to be a key driver, shrub distribution is also likely limited by other biotic and abiotic factors that do not favor their growth (e.g., topographic control and soil moisture). Changes in these limiting factors could have larger or more direct impacts on shrub expansion. In this study, we combined ground observations and multi-scale remote sensing data, including occupied aerial system (UAS; 5 cm), NASA's Airborne Visible / Infrared Imaging Spectrometer (AVIRIS-NG; 5 m), ArcticDEM (30 m), high-resolution down-scaled climate data (60 m), and model simulated soil data (500 m), to investigate the drivers and limits of tall shrub distribution in Western Alaska. We first mapped the fractional cover (FCover) of two key tall shrub genera (alder and willow) using AVIRIS-NG imagery collected on the Seward Peninsula and a vegetation cover scaling approach that we have developed for AVIRIS-NG. We then combined the alder and willow FCover maps with topographic, climate, and soil moisture data to investigate the primary determinants of tall shrub distribution. We found that topography is a primary control on tall shrub distribution in the Arctic. The distribution of alder is strongly limited by elevation and slope, with a higher cover found within the 100 - 300 m, MSL elevational band. In contrast, the distribution of willow is more closely tied to surface wetness. To understand the biological mechanisms of these differences, we further examined their biochemical and physiological traits, and found that willow has a lower instantaneous water-use efficiency than alder, suggesting why willow is found in wetter conditions. These findings suggest that different shrub species may respond to the climate change differently. Improved understanding of the controls on tall shrub distribution is important to accurately forecast the response of arctic ecosystems to current and future climate change.