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Shrub Line Advance in Alpine Tundra of the Kluane Region: Mechanisms of Expansion and Ecosystem Impacts

by Isla Myers-Smith

INTRODUCTION

WITH A WARMING CLIMATE, northern ecosystems will face significant ecological changes such as permafrost thaw, increased forest fire frequency, and shifting ecosystem boundaries, including the spread of tall shrubs into tundra. In northern mountain ranges such as those in the southwestern Yukon, the shrub line will likely advance up mountain slopes with climate warming (Danby and Hik, 2007). This loss of alpine tundra will decrease the success of obligate tundra species such as hoary marmot (*Marmota caligata*), collared pika (*Ochotona collaris*), and ptarmigan (*Lagopus* sp.) (Martin, 2001). Vegetation changes in northern ecosystems are also likely to affect foraging mammals and birds (Hinzman et al., 2005). For example, increases in the biomass of woody shrub species such as willow may reduce habitat for caribou (Sturm et al., 2005a) while benefiting moose (Kelsall, 1972). In addition to modifying wildlife habitat, increased shrub height and density will make traversing tundra more difficult, a problem for hikers and hunters.

In the last 50 years, repeat aerial photography has documented rapid shrub expansion in Arctic Alaska (Sturm et al., 2001a, Tape et al., 2006) and the northern Yukon and Northwest Territories (T. Lantz, University of British Columbia, pers. comm. 2007). Paleoecological evidence suggests that tall shrubs last invaded tundra ecosystems in Alaska and northwestern Canada during the warm post-glacial period, between 7000 and 12 000 years ago (Ritchie, 1984). Growing-season temperatures are again warming in Alaska and western Canada (ACIA, 2004; Chapin et al., 2005), and satellite imagery shows a concurrent greening of the Arctic tundra (Jia et al., 2003; Stow et al., 2004). The correlation between warming and greening has been used to link climate change with shrub expansion (Sturm et al., 2001a; Epstein et al., 2003); however, the mechanisms driving shrub increase are likely more complex. A combination of changes in nutrient mineralization, snow depth, microclimate (Sturm et al., 2001b; Grogan and Jonasson, 2006), disturbance (Forbes et al., 2001; Racine et al., 2004; T. Lantz, University of British Columbia, pers. comm. 2007), and species interactions are all contributing to the landscape patterns of shrub expansion.

Increased shrubs in Arctic and alpine tundra alter the partitioning of solar energy during the growing season, the trapping of snow in the winter, and soil thermal dynamics year round (Sturm et al., 2001b). These changes create feedbacks that alter both the structure and the function of ecosystems (Sturm et al., 2005a). Increases in the density and distribution of tundra shrubs change organic matter inputs to soil, accelerate carbon cycling (Mack et al., 2004), and modify nitrogen dynamics and plant species interactions (Bret-Harte et al., 2002). As the canopy height and expanse of shrubs increase on the landscape, albedo (reflection of light) will decline, and this will create a positive feedback to climate warming (Chapin et al., 2005). Increased shrubbiness is a major structural change to Arctic systems, with implications for alteration of microclimates, biogeochemical cycles, and ecological habitats.

FIELD SITES

My field research is based at the Arctic Institute of North America's Kluane Lake Research Station and remote field camps in the Ruby Range Mountains, Burwash Uplands, and Kaskawulsh Glacier Valley (Fig. 1). Since this region of the southwestern Yukon is located at the convergence of the coastal and Arctic air masses, climate change could lead to increased variability in winter temperatures and precipitation (Northern Climate ExChange, 2006). The study area varies in elevation, aspect, and proximity to glaciers, making it an ideal location to test shrub expansion hypotheses (Fig. 2).

STUDY OBJECTIVES

My objectives for this study are threefold: 1) to quantify patterns of shrub expansion across the landscape in relation to warming and disturbance; 2) to investigate the impact of

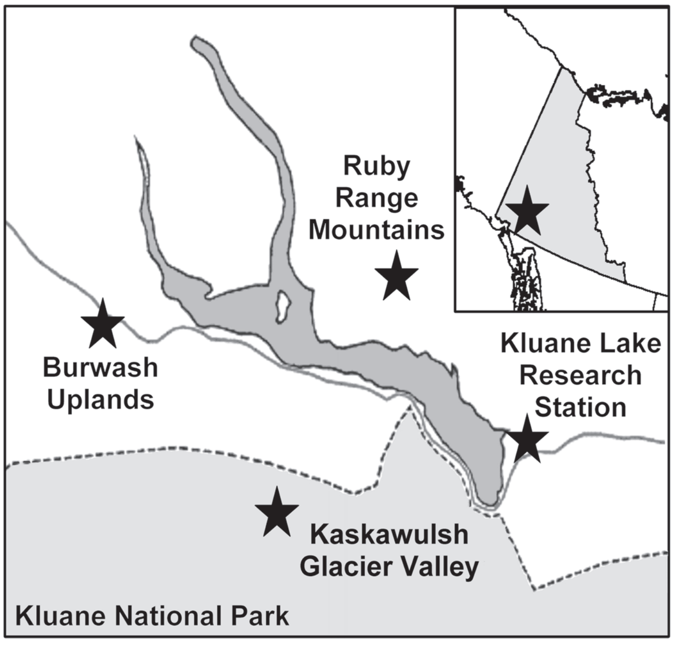

FIG. 1. Map of study region, showing the Kluane Lake Research Station and the three research sites in and adjacent to Kluane National Park.

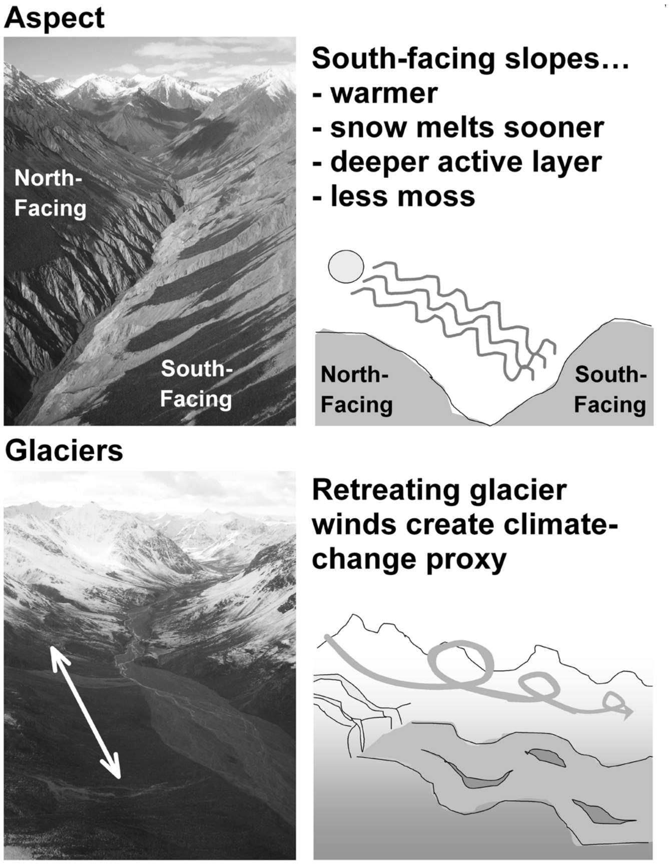

FIG. 2. Proxies for climate variation found in the Kluane region include north- and south-facing aspects and proximity to glaciers.

increased shrubs on ecosystem properties including species composition and carbon cycling and 3) to evaluate experimentally the relative importance of ground temperature and nutrient increases as drivers of shrub expansion.

PATTERNS OF SHRUBS ON THE LANDSCAPE

To quantify shrub expansion, I will compare the age of shrubs at and below the shrub line (the maximum extent at which shrubs occur) through an analysis of growth rings from sections of willow stems. I predict that shrubs growing at higher elevations will be younger and have thinner annual growth rings, though this pattern may differ with aspect and with proximity to the St. Elias icefields. By constructing the historic rates of shrub expansion, I hope to better understand the current and future rates of spread.

Clonal growth of willow is likely to be the dominant form of invasion at the shrub line. Sexual recruitment through seed dispersal might also allow some shrubs to establish above the historic shrub line. Shrub abundance in the Kluane region appears to be correlated with the presence of disturbances, such as drainage channels, soil slumps, landslides, and animal burrows (Fig. 3). I predict that the prevalence of each shrub species and hybrids will differ with elevation and aspect. I also expect to find a higher diversity of shrub species in areas undergoing greater levels of disturbance. Preliminary samples for shrub-ring and genetic analysis of willow shrubs were collected during the growing season of 2007, and further field sampling will take place during the growing season of 2008.

IMPACTS OF SHRUB INCREASE

The potential impacts of shrub expansion are warmer winter soils, enhanced nutrient cycling, and altered plant communities (Sturm et al., 2001b, 2005a; Bret-Harte et al., 2002; Mack et al., 2004). Previously, greenhouse and nutrient-addition experiments and modeling exercises have been used to project impacts of expanding shrub tundra (Walker et al., 2006). In this study, I am investigating species composition, plant phenology, nutrient fluxes and pools, soil temperatures, and other ecosystem-level variables that will be altered by increasing shrubs. Preliminary results indicate that species diversity and the dominance of herb tundra plant species are reduced under a dense shrub canopy.

To quantify the influence of shrub expansion on nutrient cycling and ecosystem function, I am investigating nutrient cycling. I have installed anion and cation exchange resin probes (Plant Root Simulator™ probes from Western Ag Innovation Inc. Saskatoon, Saskatchewan, Canada) to measure ammonium and nitrate bioavailability, and litter bags to quantify the rate of decomposition under shrubs and in adjacent shrub-free tundra. Tying together flux rates, decomposition, and nutrient pools will help to elucidate the impact of shrubs on carbon storage. I hypothesized that rates of CO_2 efflux would be higher under the

FIG. 3. Animal burrows are associated with both the presence and diversity of willow shrubs in the alpine tundra. (Photo: Isla Myers-Smith)

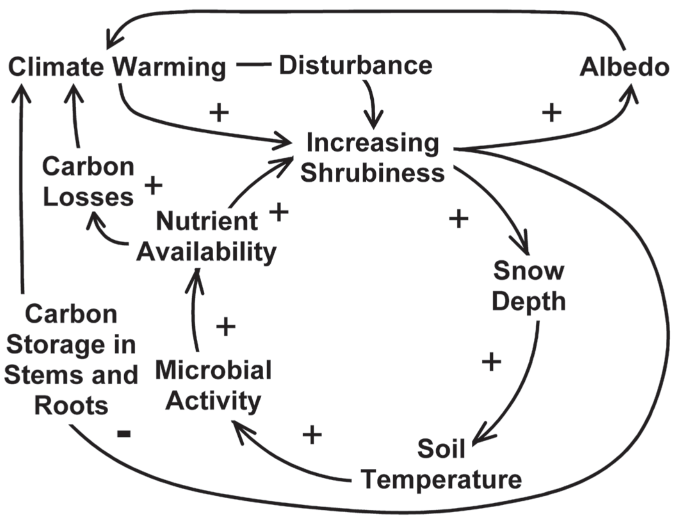

FIG. 4. Positive feedbacks among shrubs, climate change, snow, and nutrients (after Chapin et al., 2005).

shrub canopy during the growing season due to enhanced decomposition and higher autotrophic respiration. To test this hypothesis, I conducted CO_2 flux measurements using a Li6400 infrared gas analyzer (LI-COR Environmental Lincoln, Nebraska USA) from May to September 2007, in plots under the shrub canopy and in adjacent shrub-free tundra. Preliminary data do not show a significant relationship between shrub cover and CO_2 efflux however.

MECHANISMS OF SHRUB INCREASE

Tundra shrubs can significantly modify the distribution and physical characteristics of snow, and influence the exchanges of energy and moisture between terrestrial ecosystems and the atmosphere (Liston et al., 2002). In the winter, snow trapping can insulate soils (by trapping heat)

FIG. 5. Isla Myers-Smith installing snow stakes in September 2007. (Photo: Helen Wheeler)

and has been proposed as a positive feedback mechanism for promoting the expansion of shrubs in the Arctic (Sturm et al., 2001b; Grogan and Jonasson, 2006). During spring, dark-coloured shrubs that extend above the snow alter the albedo and accelerate local snowmelt (Sturm et al., 2005b; Pomeroy et al., 2006). Surveys after snowfall in September 2007 showed much lower reflectance of shrub plots compared to shrub-free tundra plots.

Winter soil warming has also been attributed to enhanced nutrient cycling and reduced soil carbon stores (Mack et al., 2004). During summer, conversely, shading by shrubs decreases soil temperatures under shrub canopies (Pomeroy et al., 2006). Though complex, the interactions between shrubs, snow, and soil warming may act as a positive feedback to shrub expansion (Fig. 4, Chapin et al., 2005). To measure the influence of snow-capture by shrubs on soil warming, I have manipulated shrub cover to compare soil temperatures beneath plots with (a) intact shrubs, (b) shrubs removed, (c) artificial vegetation canopies, and (d) adjacent, shrub-free tundra. In September 2007, six artificial shrub and tundra plots were constructed by cutting down shrubs and affixing them to stakes in the soil in adjacent shrub-free tundra (Fig. 5). Six manipulation plots and paired control monitoring plots are instrumented with snow stakes that have iButton Thermochron temperature loggers (Dallas Semiconductor

Corporation, Dallas, Texas, USA) at 2, 5, 25, 50, 100, and 150 cm along their length, and with Hobo micro station 12-bit temperature sensors (HOBO, Onset Computer Corp., Massachusetts, USA), installed at 2 and 5 cm below the soil surface. The experiment will test whether shrubs trap more snow than the adjacent tundra, whether this snow melts out earlier in the spring season, and how much this snow insulates the soil.

SIGNIFICANCE OF RESEARCH

This study will contribute to our understanding of vegetation changes in northern alpine ecosystems. It will provide data on shrub expansion in the southwestern Yukon, which will contribute to a synthetic examination of shrub expansion in Alaska and northwestern Canada and provide better estimates of the strength of climate forcing mechanisms such as changes in albedo and carbon storage. Improved projections of the trajectory of alpine vegetation change will assist the Yukon territorial government, Yukon First Nations, and Parks Canada to manage their natural resources and ecological capital.

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