VEGETATION-SNOW DEPTH RELATIONSHIPS IN THE BOREAL FOREST-TUNDRA ECOTONE OF EASTERN CANADA

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ABSTRACT

Snow depth was found to influence the morphology of plants and species diversity and predominance along a vegetation gradient between a forested valley bottom and the adjacent exposed ridgetop. Upland habitats, with maximum snow depths less than 30 cm, produced the most exposed vegetation communities. These were dominated by a lichen-heath association, stoney earth circles, and an absent or poorly developed shrub layer. Strong winds were responsible for snow removal from these sites. At the other extreme, woodland snow depths exceed 100 cm, drifting is common, and snowpacks may persist until early summer. In this most protected environment, vascular plants, particularly well-developed black spruce trees and dense birch thickets, predominate and lichens are virtually absent.

Snow depth variations provide differing microhabitats in which competing vascular and non-vascular plants may develop. In addition to common climatic data, snow depths and distribution are useful tools for the biogeographer and plant ecologist for understanding vegetation dynamics in high latitude environments.

INTRODUCTION

The impact of snow on the earth's surface includes physical, biological and geographical components. The presence of snow on the landscape influences the interaction between the biotic and abiotic realms. Two important characteristics of snow cover are depth and distribution. Snow distribution helps determine the annual energy budget of the

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*Present address: Department of Geography, University of Wisconsin-River Falls, River Falls, WI 54022 earth due to its reflectivity of solar radiation; it influences the presence or absence of certain types of vegetation (Hiltunen, 1980); and it controls photosynthetic activity and seed germination (Richardson and Salisbury, 1977). The depth of snow cover controls the degree of protection provided to plants and animals from harsh winter conditions; it regulates the light environment of underlying vegetation (Richardson and Salisbury, 1977); and it provides insulation from extreme temperature fluctuations by limiting heat losses from the earth's surface.

Snow controls the climatic environment of the subarctic and high latitude regions of the earth because it covers the surface for six to ten months of the year. Yet, topographic variations introduce variability in both the distribution and depth of snow cover over a small area. In the eastern Canadian subarctic, the regular ridge and valley topography of the Labrador Trough leads to an observable change in vegetation from wooded valley bottoms to barren tundra ridgetops. During winter, an equally obvious snow depth gradient is evident from ridgetop to valley bottom where crests are often blown free of snow while woodlands may be blanketed by as much as 2 m of snow. Such a gradient may occur over a 1 km transect with an elevational drop of only 200 m.

We believe that the correspondence between the observed vegetation gradient and the snow depth gradient in this region is not coincidental. It appears that physiognomic variations, as well as species composition, of the natural vegetation along topographical transects are related to the presence and depth of wintertime snow cover. Such relationships have been studied in Fennoscandia since the late nineteenth century (Clark et al., 1985) and recent interest has focussed on remote sensing applications to snowmelt hydrology. Relatively little discussion has centered on North American alpine and high latitude regions. Thus, the objective of this paper is to discuss the relationship between vegetation type, species distribution, and snow depth along topographic gradients in the eastern Canadian subarctic. We will also attempt to identify snow depths which are associated with the development of distinct vegetation habitats and species dominances along the vegetation gradient.

DATA AND METHODS

Detailed vegetation surveys were conducted along two slopes of opposing aspect of a ridge located approximately 30 km WNW of the Schefferville, Quebec townsite (54° 48' N, 66° 49' W). The study area is devoid of anthropogenic influences and there was no evidence of recent fire. The vegetation surveys were compiled from five random throws of a 1 x 1 m quadrat at 5 m elevational intervals along the slope transect. The NNW-facing slope had 21 sample levels (100 m elevational decrease) along a 600 m transect. The SW-facing slope had 15 sample levels (70 m elevational decrease) along a 400 m transect. The ridgetop was chracterized by tundra vegetation (lichens, heaths) and stoney earth circles (periglacial features) while open lichen woodland comprised the valley bottoms (see Figure 1). Soils along these slopes are young, poorly developed, acidic, and have low organic content (Mulhern and Petzold, 1988).

The climate is considered to be continental subarctic and is characterized by low monthly mean temperatures (-22.2° C in January; +12.5° C in July, at Schefferville), a three month growing season, and a mean annual precipitation of 785 mm, of which half falls as snow (Petzold, 1982). Strong and persistent winds prevail over the region, flowing predominantly from the NW in every season.

Surrogate snow data were obtained from two sources: average birch shrub heights and scar levels on spruce tree trunks. Chernov (1985) stated that the tops of birch, willow and alder shrubs growing on the tundra are "trimmed off" due to snow abrasion such that "when the thickness of the snow is measured, ... it reaches exactly the same height as that of the bushes" (p. 57). Thus, we measured the heights of five to ten birch shrubs (based on their abundance) at each sample level to produce an average surrogate snow depth value. A similar effect is observed in the growth habit of mature spruce trees at the treeline. There, wind blown snow and ice particles completely remove foliage at and immediately above the snow surface, resulting in the development of an elongated scar along the trunk (Marchand, 1987), facing the direction of prevailing wintertime winds (see Figure 2). Foliage below the snow level remains lush and healthy, while unprotected needles exhibit greatest mortality rates (Hadley and Smith, 1986) and bud and branch damage is greatest immediately above the snow level (Scott et al., 1987). It appears, therefore, that the edge of the trunk scar closest to ground level represents the average minimum long-term level of snow cover at each tree. These lower scar levels were measured for every tree growing at the treeline, at elevations upslope from the wooded valley bottoms. There were, however, only 13 mature trees to measure at 9 sample levels along these transects.

Figure 1. Tundra-dominated ridgetop, elevation 705 m a.s.l. (foreground) which grades downslope to a wooded valley bottom, elevation approx. 490 m a.s.l.

Figure 2. Abrasion scar on black spruce tree at the treeline in subarctic Quebec. Note the healthy branches at the lower level of the trunk.

RESULTS

1. Correspondence of Surrogate Snow Data Types

Two purposes are served by discussing the relationship between birch shrub heights and tree scar levels as surrogate snow depth data. First, the small number of trees exhibiting abrasion scars produced the need for further evidence of their viability as snow depth indicators. Second, by using two different sources of natural evidence to obtain surrogate snow depth, we can be more certain of the appropriateness of applying these surrogate data to understand vegetation dynamics along these slopes. To assess the correspondence between the two surrogate data sets, a simple linear regression was performed on matched pairs of data for the sample levels where both tree scar and birch height measurements were available. Figure 3 indicates a very close, direct relationship between the two snow depth indicators. The slope of the regression equation suggests an exact correspondence at all levels along these slopes, but there is a constant 5.5 cm growth differential in the birch shrub heights. It appears that both snow depth indicators are comparable and interchangeable; however, the results must be used with caution because of the small number of data pairs used to establish this relationship.

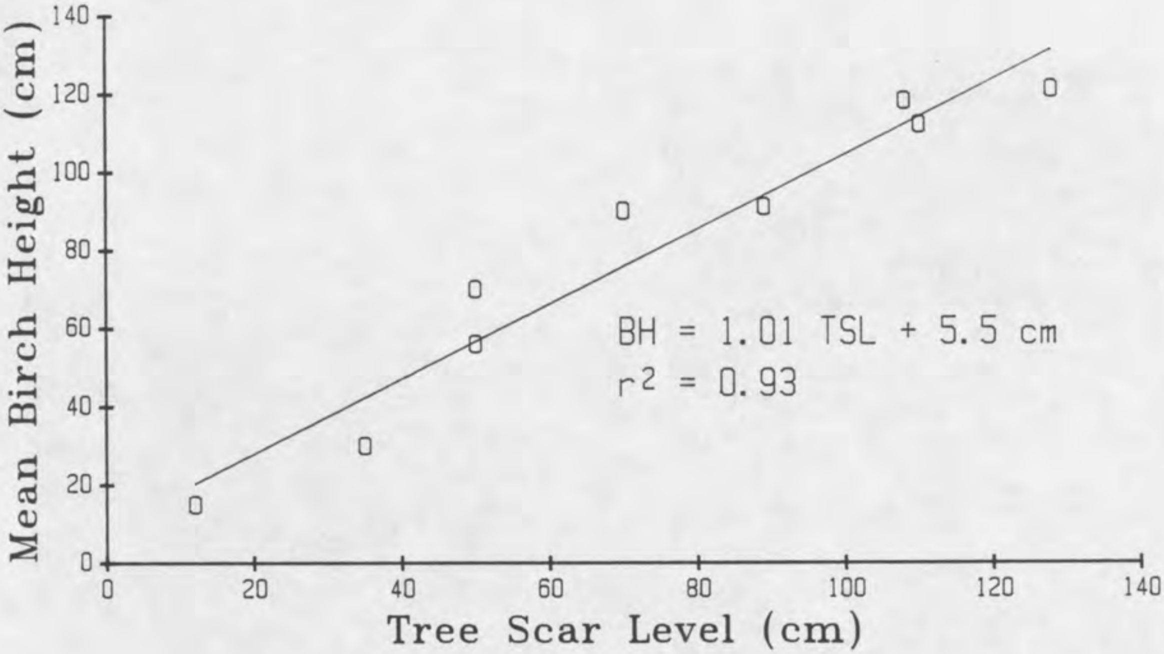

Figure 3. Relationship between mean birch heights (BH) and the lower level of trunk scars (TSL) on trees growing at the tree line between the tundra ridgetop and adjacent wooded valley bottoms.

2. Snow Depth Variations Along the Slopes

Average surrogate snow depths are plotted in the scattergrams of Figure 4 for each slope. As expected, snow depths generally increased downslope toward the valley bottom. Birch shrubs did not grow on the crest of the ridge, hence we assume that the ridgetops are blown free of a protective snow layer throughout much of the winter season. A short distance downslope, however, prostrate birch hug the surface, finding complete protection under a snow layer as shallow as 10 cm. Mean annual snow depths approach 1.5 m at the base of the slopes, affording the highest degree of protection to the underlying vegetation.

Generally, snow depths along the NNE-facing slope were less than those along the SW-facing slope. This was particularly evident at mid-slope elevations. Slope orientation

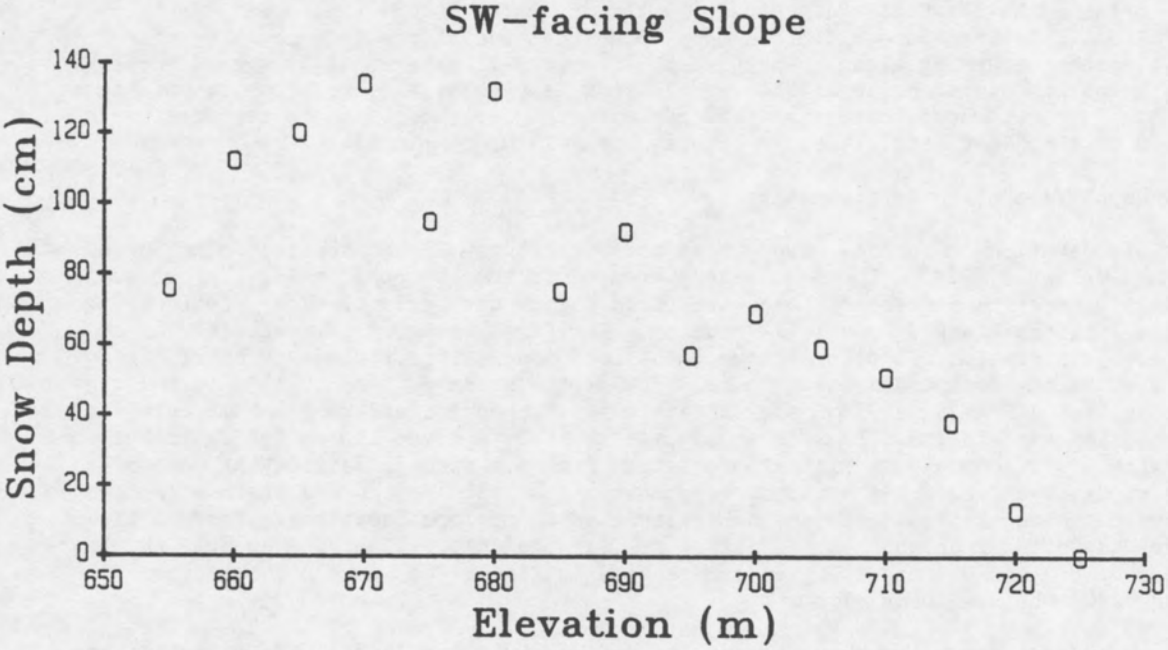

Figure 4a. Mean snow depths along the SW-facing slope, derived from birch height and spruce trunk scar data.

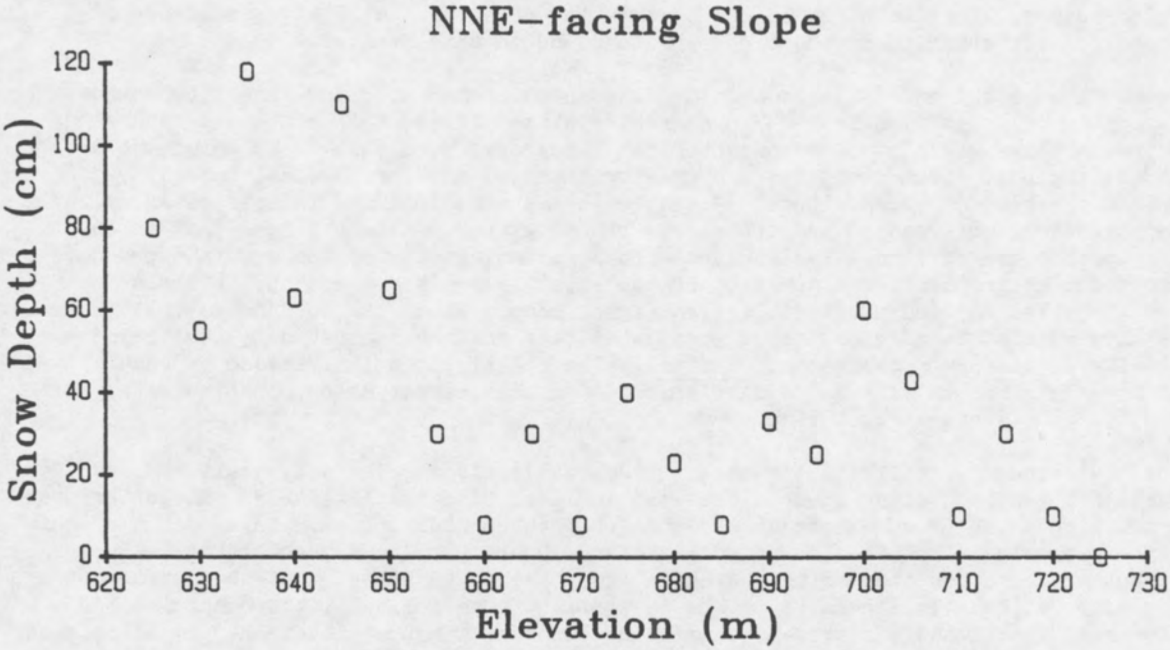

Figure 4b. Mean snow depths along the NNE-facing slope, derived from birch height and spruce trunk scar data.

with respect to the prevailing NW winds appears not to be a contributing factor because the ridge is oriented NW-SE, thus winds generally blow parallel to the ridgecrests in this region. The NNE-facing slope exhibited many more local variations in topography with several terraces occurring along the transect. The step-like terraces triggered snow drifting which introduced noise in the general snow depth-elevation relationship of Figure 4b. We have observed deep, extensive snow packs on the lee side of these terraces, near the bottom of the NNE-facing slope, as late as early-July.

3. Snow Depth-Vegetation Relationships

The distribution of surface cover types and constituent lichen species is presented by Petzold and Mulhern (1987). These data were grouped further by considering the protection afforded by wintertime snowcover/summertime birch canopy development. Four distinct vegetation associations emerged from this grouping. The first category is predominantly a lichen-heath association of upslope-ridge crest locations. This includes a total of nine sample levels along both transects. There, snow depths averaged less than 30 cm and birch shrubs constituted less than 5% of the surface cover. Spruce trees were not observed in this vegetation association. In such an exposed habitat, a mixed lichen mat dominates the surface with 60-70% coverage. Minimal protection from the strong, dessicating, and often abrasive winds is afforded the existant vegetation. Low snow depths and their corresponding lichen-heath vegetation cover are not restricted to upslope locations. Terrace lips along the NNE-facing transect also exhibited similar characteristics, for example at elevations of 660, 670 and 685 m a.s.l., as can be seen in Figure 4b. Such a displacement is not observed on the SW-facing slope.

The second category, low shrub tundra (as defined by Bliss (1981)), is characterized by average snow depths of 20-60 cm. The surface is still dominated by mixed lichens (65-75% coverage); however, birch shrubs and krummholz (dwarfed) spruce are more evident on the landscape. Nine sample levels at mid-slope elevations comprised this category. Although the protective snow cover is deeper and the birch are taller, the surface remains relatively exposed to strong winds and intense solar radiation. The birch-spruce cover, being only 10-15% of the surface, is not sufficient to ensure a stable snow cover from year to year. We believe that this vegetation association may be blown free of snow during part of the winter season. This is based on our observation of an unusually high incidence of branch and bud tip abrasion of the birch shrubs found in this habitat.

Forest tundra (Bliss, 1981), commonly called open lichen woodland, constitutes the third grouping of vegetation-snow depth characteristics. Here, tall birch and mature spruce trees become a dominant component of the landscape, such that the development of a woodland is apparent (tree densities are greater than 10% and shrubs constitute 10-20% of the surface cover). On these slopes, 13 sample levels were included in this category. Snow depths average between 60 and 100 cm and the snow pack persists longer than in any other vegetation association. Because the structure and density of the woodland produces a more protected environment, bud abrasion of the shrub layer is not common. Lichens comprise a smaller (35-60%), but still significant component of the surface cover. These lichens have adapted to more protected, mesic habitats and are dominated by the "reindeer mosses" (i.e., lichens of the genus, Cladina). The relatively moist, shaded surface beneath trees and shrubs allows the development of a moss carpet which constitutes approximately 25% of the surface vegetation.

The last category, tall shrub tundra (Bliss, 1981), is a relatively small component of the vegetation gradient along these slopes and includes five sample levels. Slope terraces induce drifting which produce mean snow depths of greater than 100 cm. As a result of this protection, vascular plant species predominate and shrubs grow in dense thickets. Such dense shrub growth attenuates solar radiation and prevents ventilation of the surface, thus reducing evaporation. This results in the development of a moist habitat conducive to extensive moss growth and effectively eliminates lichens. Shrub thickets may be associated with spruce woodlands or may develop independent of tree growth.

DISCUSSION

Snow is a climatic agent which is active for half of the year in this subarctic environment; yet, its effects may be experienced by the vegetation throughout the growing season as well. Many of these effects are immediately apparent after a snowfall (i.e., bud abrasion, trunk scarring). Others may be less noticeable, because they are internalized with other climatic and edaphic factors by the vegetation. In this article we are assuming that the birch shrub heights and minimum tree scar levels are a manifestation of both the internal and external impacts of snow on the vegetated surface. Despite the limited sample size of our data set, it appears that both snow depth surrogates contain the same information and are in agreement.

Based on our results, snow depth variations contribute to the competition between vascular and non-vascular (lichen) plant growth. An average wintertime snow depth of less than 30 cm, associated with an unstable snow pack, provides an apparent advantage to non-vascular plants because they are better able to survive the effects of persistent exposure to abrasive, dessicating winds and to greater fluxes of solar radiation.

There is a dichotomous relationship between snow depth/distribution and the vegetation which grows beneath it. Initially snow benefits the vegetated surface, acting as a protective cover which allows plants to reach their maximum height and development. Once the vegetation achieves equilibrium with the snow microenvironment, the vegetation plays an active role in the depth and distribution of the snow. Trees and dense thickets serve to trap snow and trigger drifting. Such a mutual interrelationship also has been suggested by Clark et al. (1985) for subarctic vegetation in Finland.

This study has implications at the macroscale as well. The changes in vegetation that we observed along these 400 and 600 m transects may be considered analogous to an observable latitudinal-vegetation gradient from the spruce woodlands of Sept-Isles, Quebec (51° N), to the subarctic tundra found on southern Baffin Island at 64° N (Aleksandrova, 1980). In snow-dominated environments of the world, the certainty of surface-based snow measurements is diminished, because of the increased frequency of drifting in treeless or sparsely-treed environments. Therefore the use of surrogate snow data is an additional means of assessing snow and vegetation dynamics in northern latitudes of the world.

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