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The Relationship between
Microclimatic, Soil and Vegetation Patterns within
Semi-permanent Snowbeds of the
Richardson Mountains, Northwest Territories

by

Norma Joann Kerby
B.Sc., University of British Columbia, 1971

A Thesis submitted in partial fulfilment of
the requirements for the degree of

Doctor of Philosophy
in the
Department of Biology.

Carleton University
Ottawa, Ontario
1979.

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The undersigned hereby recommend to the Faculty of
Graduate Studies acceptance of this thesis, submitted by
Norma Joann Kerby, B.Sc., in partial fulfilment of the
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Abstract

Semi-permanent snowbeds in the subalpine zone of the Richardson Mountains, 50 km west of the Mackenzie Delta, Northwest Territories, were studied from 1971 to 1973.

The microclimates of snowbeds differ from those of snow-free and snowpatch environments in several important respects: rapid burial by snow in the autumn; protection of ground surfaces from winter winds and severe temperature oscillations; winter ground temperatures from -0.5 to -4.0°C ; exposure of ground surfaces at least 2 weeks later than chionophobic plant communities; and low summer wind speeds, seldom exceeding 10-15 km/hr. Microclimatic variations within snowbeds are primarily the product of topographic location and differences in the number, not quality of days exposed during June and July. Vegetation and soil patterns within snowbeds reflect this, corresponding to gradients of increasing snow depth, decreasing length of exposure and variations in summer moisture regimes.

The snowbed environment was found to be highly variable, with fluctuations in microclimatic characteristics corresponding to yearly changes in regional climatic conditions. Some chionophilous plant species responded to these changes, by adjusting growth rates or phenological timing, but other species were unable to flower and set seed with decreases in length of exposure. Although vegetation zonation within snowbeds reflects broad distributions along microclimatic gradients, boundaries are not static. Species distributions within snow basins fluctuate in response to short and long term oscillations in climatic conditions.

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INTRODUCTION

Snowfall in many arctic and alpine regions is rapidly redistributed by strong winter winds, leaving exposed sites free of snow, filling small depressions and hollows, and forming large drifts along drainage pathways, lake shores, and other changes in topography (Benson, 1969). The effect of this variation in snow cover upon microclimate and the distribution of plants and animals in both arctic and alpine regions has been discussed by many authors (Formozov, 1946; Polunin, 1948; Bliss, 1956, 1962; Savile, 1961, 1972; Porsild, 1964; Smith, 1966; Geiger, 1966; Britton, 1967; Billings and Mooney, 1968; Billings, 1973; and Troll, 1973). Actual detailed examination of plant communities dominated by drifted snow has received only limited attention, with the main portion of the research being conducted in the alpine zone of the Western United States (Billings and Bliss, 1959; Holway and Ward, 1963; Rochow, 1969; Chabot and Billings, 1972; Canaday and Fonda, 1974; Fareed and Caldwell, 1975).

Areas of snow accumulation can be divided into two classes (Porsild, 1964). Snowpatches occur where snow collects in shallow depressions, usually to a depth of 1.0 meter or less. This snow cover is sufficient to protect the vegetation, normally dominated by woody shrubs, from wind abrasion and desiccation in winter, but is shallow enough to melt within one or two weeks of spring thaw. In contrast, snowbeds or snowbanks are found where storm and prevailing winds form large drifts along changes in topography. Snowbeds are characterized by specialized, chionophilous* plant associations which occur in distinct zones along the steep environmental gradients created by sequential exposure from snow. Although deep snow may protect underlying plants from winter damage and supply melt water throughout the thaw season, plant development can be restricted by the reduced growing season. In years of delayed snow melt, the growing season may be limited to only a few days, or none at all in deeper snow zones. Plant species here must be able to tolerate burial for one year or more.

* chionophilous - able to withstand prolonged burial by snow;
'snow-loving'

Snowbeds represent a unique situation for ecological research. Environmental and vegetation gradients are steep over short distances. One can pass through the same range of conditions within tens of meters in snowbanks as would be encountered traversing several degrees of latitude or hundreds of metres of elevation. In order to quantify the relationship between vegetation and environment in snowbeds, though, it is necessary to define what portion of the variation is due to the snowbed itself and not to yearly climatic fluctuations. The characteristics of both regional climate and regional vegetation must be understood before one can discuss with any confidence which physical factors are important in determining biological patterns within snowbeds.

The purpose of this study was to examine snowbeds in the arctic-subalpine zone of the Richardson Mountains, Northwest Territories. Although chionophilous plant associations in the area had been previously described by Lambert (1968), detailed research had not been undertaken on the relationship between microclimatic/soils gradients and the distinct vegetation zones within semi-permanent snowbeds common in the region. The objectives of this study were to:

1. Examine the formation, distribution and ablation of snowbeds;
2. Quantify the associated microclimatic gradients;
3. Quantify vegetational and soil zonations across snowbed basins;
4. Examine the relationship between physical and vegetation patterns within snowbeds.

Field studies were carried out during 1971, 1972 and 1973 in the Canoe Lake area of the northern Richardson Mountains, a site chosen both for its ease of access and for existing data available on the area (Lambert, 1968).

Geology:

The Richardson Mountains are located west of the Mackenzie River, east of the Blow River, north of the Peel River, and south of the Arctic Coast, with a total length of 258 km and a width ranging from 24 km south of the Vittrekwa River to 81 km west of Mount Goodenough (Gabrielse, 1957). Formed during the late Cretaceous and early Tertiary ages, major topographic features have resulted from deformation of upper Paleozoic and Mesozoic strata (Rampton, 1972). Elevations of peaks range from 366 meters to a maximum of 1828 meters. An abrupt fault scarp, over 610 meters in height at Mount Goodenough, forms the eastern boundary with the Mackenzie Delta (Rampton, 1972).

The Richardson Mountains are composed of northerly-trending, folded, non-volcanic sedimentary sandstones, shales, and conglomerates with an absence of intrusive and highly metamorphosed rocks (Gabrielse, 1957; Rampton, 1972). Base camp for this study was located next to Canoe Lake (68° 04'N 135° 30'W) which lies in a thick shale bed between an Upper Jurassic sandstone layer to the west and a Lower Cretaceous sandstone bed to the east. The shale, black, soft and rich in organic material, eroded easily, forming a valley between the sandstone layers. The sandstone, clean, quartzose, fine to medium grained and medium bedded, forms north-south striking ridges, 610 meters a.s.l. to the west and 460 meters a.s.l. to the east (Lambert, 1968).

The Canoe Lake area, situated in the foothills zone of the Richardson Mountains, lies at the boundary between the unglaciated areas of the Yukon and Alaska, and the Laurentide ice sheet. At its maximum, the Laurentide ice reached elevations of 1067 metres above sea level on the eastern flanks of the Richardson Mountains, extending a maximum of 24 km to the west and 3.5 km to the south of Canoe Lake (Rampton, 1972; Hughes, 1972). During the most recent glaciation, ice moving north to northwest paralleled the eastern front of the Richardson Mountains, reaching elevations of only 100 meters (Mackay, 1963). Ice limits reached 16 km east of Canoe Lake, with deglaciation occurring along the eastern side of the mountains between 10,000 and 9,500 years B.P. (Hughes, 1972).

Topography in the unglaciated areas of the Richardson Mountains is rugged. Ground cover has been formed by discontinuous felsenmeer and colluvium over bedrock, with extensive covers of silt and organic material on valley floors and gentler slopes. Within glaciation limits, glacial features are generally lacking on slopes. Surficial deposits are usually discontinuous till over bedrock or valley floors, interspaced with felsenmeer and colluvium over bedrock on more exposed terrain.

Climate:

The Canoe Lake area is located in a zone of overlap between arctic and alpine conditions. This zone extends across the north slope and foothills of the Richardson, British and Barns Mountains as far west as the Brooks Range (Billings, 1973). Regional climatic characteristics of the arctic-alpine zone in the Richardson Mountains are the product of modification, by elevation and topography, of weather systems from the Beaufort Sea and the Mackenzie Delta.

A. Solar Energy Regime

The Richardson Mountains potentially receive as much solar energy in June and July as temperate latitudes (Meteorological Branch, 1970). Although the angle of the sun's rays is low (on June 22nd, the sun is 42° above the horizon at noon and 3° above the horizon at midnight), decreased intensity of incoming solar radiation is compensated by the increased day length. For example, the Canoe Lake area experiences 24 hours of daylight from May 28 to July 16 (Smithsonian Tables, 1971). The total amount of incoming solar radiation striking the ground varies drastically with aspect, slope angle and shading by adjacent topographic barriers. As the sun is less than 10° above the horizon between 20:00 to 04:00 hours during the summer, the rugged relief of the mountains prevents most northerly-facing slopes from receiving any direct sunlight.

In winter, the sun is below the horizon from December 10 to January 5, and less than 10° above the horizon from October 20 to December 10, and January 5 to February 23. Although the period of twilight may be quite prolonged each day, the amount of incoming solar energy is minimal. Net energy balances are negative during this period, resulting in intensive cooling of ground and air (Burns, 1973).

The annual energy balance of the Richardson Mountains is further affected by the high albedo of snow and ice in winter, and cloud and fog layers in summer. More than 50% of annual incoming radiation is reflected back into the atmosphere. Only a small percentage of available energy actually remains to heat the air and earth's surface (Thompson, 1967).

B. Regional Weather Systems

The climate of the Western Arctic is related to large-scale circulation of the atmosphere in the Northern Hemisphere. Circulation patterns result from differences in solar heating between high and low latitudes and vary from season to season as the radiation balance itself changes (Burns, 1973). These circulation patterns are altered regionally by topographic barriers and variations in heating over vegetation, water, snow and ice (Meteorological Branch, 1970). The weather of the Canadian Western Arctic is most strongly influenced by a mean northwesterly flow aloft in winter which becomes more westerly and weakens in summer (Burns, 1973). This NW to SE flow is often the path of high pressure systems that from November to March move either from northern Alaska through the northern Yukon, or from the Beaufort Sea up the Mackenzie Valley. In contrast, low pressure areas do not appear to have major directions of movement in winter, although in May, June and July, they tend to move southeastward across the Richardson Mountains, passing over the Canoe Lake area (Burns, 1973).

The main circulation of air in winter is anticyclonic. A dome of cold Arctic air normally forms over the region, blocking the entrance of frontal lows. Low pressure systems occasionally penetrate the area, most frequently in fall and spring. These sporadic invasions of Pacific Maritime air can bring above freezing temperatures to the region in the middle of winter (Bird, 1967; Burns, 1973). The over-riding of the Arctic air mass by moist Pacific air aloft has a greater effect in mountainous regions of higher elevations, often producing heavy snowfalls. (Burns, 1973; Gill, 1976).

By summer, the dome of cold Arctic air is reduced through summer heating, and the Arctic high retreats northward. The percentage frequency of Arctic air over Canoe Lake drops from almost 100% in winter to 65% by July.

C. Winds

Excluding local effects, winds in the western Arctic average 18 to 22 km/hr from December to April, with slightly lower values during the summer. The most severe winds occur in the fall, with average speeds often in excess of 28 km/hr (Burns, 1973). Throughout the winter, periods of high winds are frequently interspersed with calm conditions which lower daily average wind speed values.

Mean hourly wind speeds tend to decrease southward from the Arctic coast. Mountainous regions, such as the Canoe Lake area, are further affected by horizontal and vertical deflections of air flow which can create mountain waves. Canalized wind flow may occur along narrow valleys under certain conditions, as well as diurnal katabatic and anabatic winds. Records of wind speed at a single location in a mountainous area can only be partially representative of regional wind characteristics. The effects of local conditions upon the wind may be of such magnitude as to completely obscure regional air flow.

D. Air Temperatures

If spring and autumn are determined by the dates when the average air temperature rises above 0° C and falls below 0° C respectively, then spring begins in the Canoe Lake area during the last week in May, with autumn returning between mid-August and the beginning of September. During the thaw season of 12-15 weeks, sudden drops in temperature to around 0° C are common. Significant cooling does not occur until autumn, when average air temperatures decrease under conditions of reduced incoming solar radiation and continuous radiative cooling. Minimum air temperatures are normally reached by January. Late in February, the return of longer daylight hours provides enough energy to reverse the cooling trend. With lengthening days, temperatures normally climb slowly in March. During April, the contrast between daytime heating and cooling at night can be extreme--diurnal temperature fluctuations can be in the range of 15 to 20° C. With the return of continuous daylight at the end of May, average temperatures normally rise above the freezing point.

E. Precipitation

Precipitation in the Richardson Mountains can be divided into two main seasons--from mid-May to mid-September, a period dominated by rainfall, and from mid-September to mid-May when precipitation is normally in the form of snow.

Rainfall from June to early September can be extremely variable from year to year in the western Arctic. Precipitation during this time is related to frontal lows from Siberia and the Bering Sea, and cyclones of Pacific origin. July and August are normally the wettest months, with most areas experiencing light rain and drizzle over 30% of the time (Meteorological Branch, 1970; Burns, 1973).

September and October are the stormiest months of the year for the western Arctic. Areas of open water remaining in the Beaufort Sea provide moisture and relatively warm air for the low pressure systems moving through the region. The greatest portion of the annual snowfall occurs during these months. From December to April, the atmosphere of the Arctic contains little moisture. Snowfalls are very light and infrequent during this period. Heavier snowfalls may occur again in April and the beginning of May, with the return of more unstable air conditions (Thompson, 1967; Meteorological Branch, 1970).

The annual snowfall in the Richardson Mountains is unknown. Snowfall is rapidly redistributed by winds, sweeping many areas free of snow and forming large drifts in the lee of obstacles. It is not possible to accurately measure snowfall borne on high winds--snow gauges in windswept areas will catch as low as 25% of total snowfall in snowstorms (Benson, 1969; Gill 1976). Trying to determine winter snowfall from snow on the ground at the end of the season is also not accurate (Benson, 1969; Pearson and Nagy, 1976). Mackay (1973) suggests that the Richardson Mountains show a substantial increase in precipitation over adjacent areas, which, according to Burns (1974), is in the range of 20% per 300 metres elevation. Burns (1974) gives a figure of 127 cm mean annual snowfall for the mountains, and Bird (1967), 100 to 125 cm.

Considering that the mean snowfall between September and May inclusive for Shingle Point (1957-1970) was 78 cm, for Aklayik (1926-1962) 135 cm, and for Inuvik (1957-1973) 183 cm (Monthly Records, Atmospheric Environment Service), the figures for the Richardson Mountains are considerably lower than expected. It is likely that winter snowfall totals are within the range of 200-400 cm for the Richardson Mountains.

Vegetation:

The Richardson Mountains lie between the sub-Arctic taiga, which extends into the Mackenzie Delta, and the low Arctic tundra along the continental coastline. Vegetation in the Mountains reflects a transition between Arctic and alpine conditions (Billings, 1973). The vegetation of the low Arctic subalpine zone of the Richardson Mountains was studied by Lambert (1968), who described plant communities after the Zürich-Montpellier method and outlined some of the associated successional trends and ecological factors.

According to Lambert, the tundra vegetation of the Canoe Lake area can be divided into two groups: plants intolerant of deep snow covers (chionophobic plant communities) and plants adapted to prolonged burial by snow (chionophilous plant communities). On xeric to mesic slopes where snow cover usually lasts less than 9 months of the year, or can be absent altogether, vegetation is often limited to cracks between rocks and small depressions. Four main chionophobic plant associations occur under these conditions, ranging from sparse covers of dwarf willow on the barren upper limits of ridges, to complete plant cover over hummocky solifluction terrain where shrub species predominate. Lichens tend to be more important on xeric slopes, and mosses more common in hummocky areas. Further community variations occur with increasing moisture in wet seepage zones and semi-terrestrial habitats. In comparison, three chionophilous plant communities are associated with areas of deep snow: a shrub willow (Salix pulchra) community with chionophilous herbaceous species forming the undergrowth (Salicetum pulchrae); an early melting meadow community of prostrate willows, sedges and grasses (Salicetum chamissonis) and a very late melt association with plant cover less than 50% (Salicetum pseudopolaris).

Some differentiations of chionophobic and chionophilous plant communities by slope, aspect, elevation, topography, frost action and soil type were recorded by Lambert. Of over 400 plant species studied, he noted that many taxa had broad tolerance ranges and were poor indicators of environmental variation. Other species, though, had more limited abilities to adapt to changing conditions and were good indicators of ecological units.

A. Climatic and Physical Measurements

The locations of major semi-permanent snowbeds in the Canoe Lake study area are shown in Figure 1. The locations and descriptions of sites and instruments used for climatic measurements are outlined in Table 1.

Three semi-permanent snowbeds were chosen for intensive study. Snowbed #1, closest to Canoe Lake, was used for detailed microclimatic measurements. Snowbeds #2 and #3 were chosen to act as checks on the representativeness of values obtained at Snowbed #1 and to provide additional data on the physical characteristics of snowbeds around Canoe Lake. Several other large snowbeds in the immediate area were observed throughout the summer and, as time and access permitted, surveys of major semi-permanent snowbeds in the region were undertaken over the three field seasons.

At Snowbeds #1 and #2, reference grids were established at 5 and 10 meter intervals. In Snowbed #1, the base line to this grid lay across the SE-facing slope with grid lines at right angles to the base line. In addition, three other profile lines (ED, CD, and WD) were established perpendicular to the long axis of Snowbed #1. Similar profile lines were established at Snowbeds #2 and #3. These reference grids were used for surveys of snow depth, ablation patterns, topography and vegetation.

Snow depths were determined by snowpits dug to ground level, heights along wooden poles installed the previous autumn and probing with an aluminum rod.

Ablation rates were calculated from snow drop along white wooden poles placed at 5 to 10 meter spacing and snow density measurements, with water equivalent values for snow melt calculated at 1-3 day intervals. To record horizontal retreat of the snow, snow borders were marked with colored flagging tape at 3 to 7 day intervals and photographs were taken from fixed points at each snowbed.

Incoming shortwave radiation and albedo were measured along profile lines with a portable MK6 Sol-A-Meter (Matric Inc., Phoenix, Arizona). This meter, with a spectral response between 0.35 and 1.15

Figure 1. Location of Snowbeds and
Topographic Features,
Canoe Lake, N.W.T.

Source: ~~the~~ Survey and Mapping Branch,
Department of Mines and Technical Surveys

Table 1

Description of Sites and Instruments used for
Climatic Studies, Canoe Lake, N.W.T.

Site	Elevation (m)	Slope (°)	Aspect	Location	Vegetation	Instruments
Snowbed #1 - upper	425	0	SE	at upper lip of snowbed	snowpatch	hygrothermograph, anemometer, rain gauge, actinograph, soil thermograph
- lower	395	0	S	base of snowbed basin	meadow next to 1 m high willows	anemometer, rain gauge
Snowbed #2	460	0	SE	at upper lip of creek gully	snowpatch	hygrothermograph, anemometer, rain gauge
Snowbed #3	460	3	SSE	at side of broad creek basin	snowpatch	hygrothermograph
Ridge	490	0	SE	on top of Ridge #1	broken bedrock, sparse lichen and vas- cular plants	hygrothermograph, anemometer, rain gauge
NE-facing slope	472	30	NE	on steep slope of Ridge #1	intermit- tent moss and lichen cover	hygrothermograph

Photo 1. Snowbed #1, July 12, 1972, looking northeast.
Key: † - figure of person

Photo 2. Snowbed #2, May 28, 1973, looking north
Key: † - figure of person

Photo 3. Snowbed #3, August 14, 1973, looking north
Key: ↑ - figure of person

Photo 4. Accumulation of Snow Debris within a Late
Melt Zone, July 14, 1971

microns, measures incident and reflected solar energy with $\pm 5\%$ and $\pm 2\%$ accuracy respectively. All values were taken perpendicular to the local slope. Daily incoming shortwave radiation was also measured at Snowbed #1 by a recording bimetallic actinograph (C.F. Casella and Co. Ltd., London). Although the actinograph was placed on flat ground, readings were affected by its location on a SE-facing slope as the site was shaded from direct radiation throughout the "night-time" hours. Daily maintenance and desiccant were used to keep the glass dome of the actinograph as free as possible from frost and condensation. Both the actinograph and Sol-A-Meter gave reasonable representations of available solar energy, since the major portion of incoming solar energy lies near 1.0 microns, with all but 1% of the energy falling between 0.15 and 4.0 microns (Lowry, 1970).

Wind speeds throughout the summer were measured with a hand-held anemometer (Casella Model 204026). Measurements were taken at 1 meter above the ground and averaged over 2 minutes. Wind direction was determined with a compass. Total windruns were measured with three integrating anemometers placed at 1.5 m above the ground. These anemometers (Casella Model W5002), with an accuracy of ± 1.6 km/hr, were located on a transect down Ridge #1. Wind speeds were also taken at Snowbed #2 between May 18 and June 25 for comparison purposes.

Summer air temperatures and relative humidity at the three snowbeds were determined with recording hygrothermographs (Fuess Model E9389, Berlin) with a respective accuracy of $\pm 1^\circ$ C and $\pm 3\%$. Each hygrothermograph was placed in a standard white Stevenson Screen 30cm above the ground at the upper edge of the snowbed. During 1973, two other hygrothermographs were placed on the ridge behind Snowbed #1: one on the broken bedrock at the summit and one on a platform braced into the steep NE-facing sidehill on the opposite side. For determination of daily averages, chart values were taken every half hour. Maximum and minimum values were taken from the entire daily chart records. Occasional gaps in data occurred due to wind, animal and insect damage to the instruments. Estimates of missing values were made, where necessary, from other snowbeds or, in the case of the ridge and NE-facing slope, from each other or from Snowbed #1.

Additional temperatures at Snowbed #1 were determined using two 12-volt recording thermistor thermographs (Carleton Instruments, Ottawa), accurate to $\pm 0.2^\circ \text{C}$. Records were taken from October, 1972 to July, 1973, and from November, 1972 to May, 1973. During the winter months, the first instrument recorded temperature once daily at 18:00 hours local time. Thermistors were placed at 84 cm above ground, ground level, and 20, 40 and 60 cm into the soil at an exposed, lichen-dominated, well drained tundra site. Five other probes were installed within the snowbed area, coincident with the June 25, 1973 snow melt line, at ground level, and at 20, 40, 60 and 80 cm in the soil. The second instrument, located in the snowbed at the June 9, 1973 melt line, was used to record snowpack temperatures at ground level and 50, 100, 150, 200, 300, and 350 cm above the ground surface. These probes were installed along a wooden pole on November 24, 1972, when snow depth was 183 cm. The 200 cm thermistor became buried in March, but the 300 and 350 cm thermistors remained above the snow surface all winter. Readings were recorded once a day at noon until May 14, after which manual readings were taken until June 8 when the snow melted. Gaps in data for both recording units resulted from instrument malfunction.

Active layer depths were measured throughout the summer by probing, soil pits, and ground temperatures. Summer soil temperatures adjacent to and within Snowbed #1 were measured by two methods: with thermistors and recording thermographs described previously; and, secondly, with 66 thermistors and a direct temperature read-out, non-recording meter built by the Carleton University Science Workshop. Accuracy of the meter was $\pm 0.2^\circ \text{C}$. Thermistors for this meter were installed in August, 1972, at depths of 0, 5, 10, 15, 30 and 50 cm in the ground. Those at 0 cm were placed either next to the soil surface beneath any live leaves or under the first 0.5 cm of the litter layer. Those thermistors at lower depths were inserted into the ground with a 0.6 cm diameter aluminum probe, thereby minimizing disturbance to the soil structure. During the 1973 season, readings were normally taken in the morning, at noon and at 18:00 hours local time. At the end of the summer, the thermistors were recalibrated in an ice bath.

Precipitation was measured with standard 12.7 cm (5 inch) diameter, 30 cm high rain gauges (Casella Model WJ002), placed on the ground to avoid splash-up from surrounding vegetation. For comparison purposes, one gauge was located at the upper edge of Snowbed #1 and another at the upper edge of Snowbed #2 between May 15 - July 2, 1972. As #2 rain gauge could not be visited every day, evaporation rates during warm weather invalidated some results. The rain gauge was then located next to the anemometer at the base of Snowbed #1 in such a position as not to be sheltered from the prevailing northwesterly winds. A tipping-bucket rain gauge was used between July 22 - September 12, 1972, on the ridge behind Snowbed #1. This instrument functioned poorly under conditions around freezing, as the bucket was inclined to freeze in place. Total winter snowfall was not recorded due to instrument destruction.

During each field season, readings for wind run, precipitation, snow melt and snow depth were taken in the morning. Average daily values for temperature, relative humidity, and total incoming shortwave radiation were calculated from midnight to midnight. Profiles of albedo, incoming shortwave radiation, windspeed, and snowdepth were taken as close as possible to solar noon.

Mean values were calculated by averaging data over two week or monthly intervals. In the case of limited records, values were averaged over shorter time periods. Standard deviations were calculated as a measure of variation (Burns, 1973), with tests for significant differences (5% level) conducted using the standard Student's "t" test, analysis of variance, and Duncan's Multiple Range F-test.

B. Vegetation

Information on plant communities within and adjacent to snowbeds was collected using both surveys of snowbeds in the area and detailed examination of Snowbeds #1, 2 and 3. Forty-eight permanent quadrats (1m^2) were established at Snowbed #1 along sample grids at intervals representing horizontal retreat of snow over 4-7 days. At Snowbeds #2 and #3, twenty-one and ten quadrats respectively were placed both along profile lines perpendicular to the retreating snow borders and within major vegetation types. These quadrats were used for systematic recordings of phenological events, percentage cover, frequency, abundance, growth rates and standing crop. Further samples were taken at 5 m intervals along sample grids.

Plant specimens were identified by the author and verified by Dr. J. Lambert, Biology Department, Carleton University, and by W. Cody, Plant Research Institute, Ottawa. Nomenclature of species and plant associations follows those of Hulten (1968) and Lambert (1968) respectively. Voucher specimens have been deposited at the Carleton University Herbarium.

Above-ground biomass for Snowbeds #1, 2 and 3 was obtained by clipping a total of 72 quadrats (0.25m^2) to soil level at the end of the growing season. Material was sorted to species, then divided into current season's growth, secondary woody tissues, evergreen leaves, bases and attached dead organic. Unattached dead organic material, sampled in a total of 90 quadrats (0.25m^2), was divided by species into local and imported litter, woody tissue and animal droppings. All material was dried at 85°C for 24 hours before weighing.

Biomass for each species within a major plant community was obtained by averaging total biomass over the number of sample quadrats within each community. Net primary productivity was estimated from current season's growth. No attempt was made to measure harvest by animals. Densities of microtines did not exceed 10 animals/snowbed in July and August during snap-trap sampling. Harvesting also preceded the major autumn influx of ground squirrels into snowbed sites from the surrounding ridges. Measurement of circumference growth of woody species was considered beyond the scope of this study, as was growth of lichens, which occur with limited biomass within chionophilous communities and have low annual growth rates (Bliss, 1966). Annual net primary productivity for bryophytes was estimated from ratios of current year: previous year's

growth in members of the Polytrichaceae within each quadrant.

Estimates for below-ground biomass at Snowbed #1 were obtained from 35 cores, 5.0 cm in diameter and 20 cm deep, in addition to samples to permafrost in two soil pits. Roots and dead organic material greater than 5mm long were sorted out of core samples by hand and sieve, but not separated into living and dead material. Values were recalculated to a per m^2 basis.

Relative frequency and average heights of species in each plant community were obtained from 153 m^2 quadrats, in addition to transect surveys. Vegetation maps were drawn from detailed surveys of snowbeds. Phenological observations were obtained every 3-7 days both in permanent quadrats and along transect samplings. Growth rates were measured every day for 10 plants of each species within each plant community. Length was taken either to the top of the growing bud on such plants as Petasites frigidus or at the tip of the furthest leaf along the stem on grasses such as Arctagrostis latifolia. Significant differences at the 95% confidence level were determined by analysis of variance.

C. Soils

Soil characteristics were determined from 24 soil pits dug to permafrost level in a transect across Snowbed #1. Distinct soil horizons were sampled separately, with observations recorded on depth to water table, permafrost level, root and rock zones, colour, and continuity of layers. An additional 127 surface soil samples were gathered from snowbeds in the region to provide further data on pH, organic content and particle sizes.

Total snow debris accumulations were calculated from the analysis of dead organic litter in 90 quadrats (0.25 m^2) located in three separate snowbeds. Mineral accumulations were sieved out of the debris and muffled for organic content. Yearly depositions of snow debris were measured from accumulations in late melt zones of 4 different snowbeds. Litter, which normally lies in almost wind-free snowbed hollows, was removed from 0.25 m^2 quadrats when less than 5 cm of snow or ice remained over the surface. These samples were analyzed for plant species and mineral contents.

Determination of soil textures was undertaken by sieving rock and pebbles from the less than 2 mm fraction. The less than 2 mm fraction was wet-sieved to remove sand (2mm-50microns). Silt (50-20 microns and 20-2 microns) and clay-sized minerals (less than 2 microns) were measured by the falling drop method (Day, 1965, as modified by K. Torrance, Geography Department, Carleton University). The portions of all particle sizes were expressed by percentages of oven-dry weight for each sample.

Dr. G. Y. Chao, Geology Department, Carleton University, identified the chemical composition of clay-sized particles.

Organic contents of both the greater than and less than 2 mm fractions were determined by loss of weight after soils were heated at 450°C for 8 hours in a Dubuque IV Thermolyne Muffle Furnace. Percent organic contents were calculated on a basis of oven-dry weights. Soil horizons were divided on the basis of organic content characteristics (2mm fraction) into surface organic (organic content 20%, recognizable plant remains present), organic-mineral (organic content 20%, abundant streaking and staining by organic material) and mineral layers (organic content 8%, organic streaking rare, dominance of colluvium and/or mineral particles). Values were averaged for each major vegetation type.

Chemical characteristics of the <2mm soil fraction were obtained by following methods outlined by Jackson (1970). Soil pH was determined in the field using a Lamotte-Morgan Soil Testing Kit. Additional pH values were derived by standing 10 grams of soil in 10 ml of water for 24 hours, with pH values taken at the top of the soil pellet by a Fisher Accumet Portable pH Meter (Model 150).

Exchangeable cations (K, Mg, Na and Ca) were extracted from 1 g samples in 100 mls of ammonium acetate. Cation exchange capacities were calculated from the replacement of exchangeable cations by calcium chloride, then ammonium acetate. Analysis of cation concentrations were undertaken in a Jarrell-Ash Atomic Absorption Spectrophotometer (Fisher Scientific Co.). All values were transformed to milliequivalents/100 g (1 m.e. = the amount of an ion required to displace or react with 1 milligram of hydrogen). Total nitrogen determination (percentage by weight) was undertaken using a modified Kjeldahl digestion procedure (Jackson, 1970).

Cation contents of water samples from surface and spring water flows were obtained using the flame emission spectrometer described above.

A. Patterns of Snow Accumulation.

Patterns of wind speed and snow accumulation were measured at Snowbeds #1, 2, 3, and A, and over adjacent ridge and hummocky terrain. As illustrated by Table 2, redistribution of snowfall in the winter of 1972-1973 began during the initial autumn storms. By September 19, 1972, snow from the snowstorm of September 16-17 had been blown off exposed ground, filling small depressions and hollows between solifluction hummocks to depths of 20-60 cm. Larger drifts had formed to the lee of major obstacles or steep drops in elevation where wind speeds were reduced. For example, between Points 5 and 20, northwesterly winds encounter a change in gradient from 5° to 30° over 2.5 m of elevation, producing an 80% drop in wind speed under snowfree conditions. This topographic change, in combination with 1-1½ m high willows (Salix pulchra) growing across the slope, acts as a snow trap. Within 6 hours of the start of the blizzard from September 16-17, 1972, snow had accumulated to depths greater than 1.2 m in this zone along the upper edge of Snowbed #1. Accumulations began in the willows and, by September 17, extended 5 m downslope, reaching 10 m downslope by September 19. The face of the drift was at a 70-80° angle across most of the slope. Downhill from the drift, snow ranged from 10-20 cm in depth. Up to 30 cm of snow rested on the leafy branches of willows at the base of the snowbed. Prevailing northwesterly winds normally accelerate on the steep NW-facing slope forming the southern border of Snowbed #1. By September 19, wind had removed most of the snow from this slope, leaving a snowfree zone at the top of the bank. Beyond the snowbed basin, the 3-5° easterly-facing slope at the next ridge also experienced strong winds. Most snow deposition here was limited to 10-20 cm of snow in hollows between hummocks.

The pattern of snow accumulation changed over the winter (Table 2). By November 24, 1972, snow above Snowbed #1 was from 0-15 cm deep. Some snow from the upper snowbed had been redeposited further downslope, decreasing the snow depth here from 120 to 74 cm. The main drift of Snowbed #1 now extended down the upper slopes with depths in the range of 140-200 cm. The lower, flatter slopes were covered with snow from

Table 2

Patterns of Snow Accumulation
Snowbed #1

Distance along transect (m)	Location	Slope (°)	Aspect	Wind (% of Maximum) (Snow- free basin)	Snow Depth (cm)			
					Sept 19 1972	Nov 24 1972	May 18 1973	May 17 1972
0	exposed tundra	5	S	100	0-2	0-15	0	0
5	snowpatch	2	S	100	20-60	20-60	8-33	14-157
10	upper willows	5	SE	69	60	75	84	197
15	upper willows	20	SE	50	120	74	175	278
20		30	SE	19	120	200	276	305
25	upper	30	SE	25	20	140	348	423
30	meadows	30	SE	31	20	138	417	487
35		30	SE	46	20	160	496	552
40	reduced	30	SE	62	20	70	509	641
45	vegetation	20	SE	58	20	70	485	661
50	cover	10	SSE	54	10	75	452	688
55		5	SSE	50	10	70	408	646
60	lower	3	SSE	65	10	70	358	658
65	meadows	3	SSE	50	10	60	249	606
70	lower willows	3	SSE	12	20	74	159	450
75	lower willows	3	SSE	23	20	100	196	127
80	creek	2	SSE	19	10	100	378	200
85	steep slope	45	NW	54	0	0	0	100
90	top of slope	5	NW	100	0	0	0	0
95	hummocky terrain	3	SSE	100	10-20	10-20	10-15	10-15

60-75 cm deep, and the lower willows, with a ground snow cover of 74-100 cm, had 20-30 cm of snow caught on branches and leaves. From a steep-faced drift at the top of the slope in September, the snowbank changed shape by the end of November, with snow being redeposited downslope from the upper drift and new snow accumulating within the bottom of the basin.

Between November and May, the snowdrift tripled in depth. By May 18, 1973, the main drift had measured depths from 84-510 cm. Ridge areas above the snowbed were still mostly free of snow, with less than 30 cm of snow in shallow snowpatches. The drift of Snowbed #1 now extended at a 10-20° angle across the upper and lower slopes of the snowbed basin, ending in a 2-2½ meter high face at the front of the willows. The deepest snow was recorded at the base of the steep upper slope. Snow extended up the NW-facing slope about 10 m, but was swept off the upper slopes. Depressions between hummocks and shallow drainage pathways on the gentle slopes at the front of Ridge #2 remained snow covered, but hummock tops were exposed.

Patterns of snow accumulation within Snowbed #1 differed between 1972 and 1973. A much larger accumulation of snow occurred in Snowbed #1 by May, 1972, compared to May, 1973 (Figures 2A and 2B). Although the upper boundary of Snowbed #1 and adjoining snow patches remained the same between 1972 and 1973, as defined by topographic features which control snow accumulation, snow over most of the snowbed was 40-50% deeper than in 1973, with the main drift almost filling the basin. In 1972, the drift extended at a similar 10° slope as the exposed ground above the basin, ending in a face 400-750 cm high. The eastern portions of the lower willows were buried under 300-400 cm of snow and the upper willows under 200-250 cm of snow. This variation in total snow accumulation within Snowbed #1 was a product of significant year-to-year variations in snowfall which can occur in the western Arctic, depending on both the location of the Arctic High and the influx of moist Pacific air during the winter months. Compared to a mean total winter snowfall (September to May inclusive) of 183± 38 cm for Inuvik between 1957-1973, the winter of 1972-1973 had a significantly greater

Figure 2A. Snow Depths (cm), Snowbed #1
May 17, 1972

* - profile lines: See Methods, page 23

Figure 2B. Snow Depths (cm), Snowbed #1
May 18, 1973

snowfall of 279 cm, the product of an unusually high snowfall of 118 cm in October, 1971- (Table 3):

At Snowbeds #2 and #3, snow accumulated around different topographic features than Snowbed #1 (Figure 3). Snowbed #2, at the terminus of a SE-oriented ridge, forms on the side of a steep, 45° 25 m high bank along a S-SE flowing stream. The gully below fills with snow each year, in common with most relatively narrow creek valleys in the area, but the main large drift of Snowbed #2 normally forms along the sidehill. In 1972, the deepest snow depths were recorded in the gully, but during 1973, maximum snow accumulation was further upslope (Appendix 1). Snow depths in 1973 were 10-25% deeper on the easterly-facing slope than in 1972. The location of Snowbed #2 did not vary between 1971-1973, but the crest of the drift and amount of snow did. Snowbed #3 is typical of most smaller snowbeds in the Richardson Mountains. Located along a SSE-flowing creek on a SSE-facing slope, the gully is completely snow covered each year. Snow depths are determined by the depth of the gully itself and varied little between 1972 and 1973 (Appendix 1).

Table 3
Snowfall Records , Inuvik, N.W.T.*

Date	Snowfall (cm)					Total Snowfall (cm) September-May		
	<u>1957 - 1973</u>	<u>1970</u>	<u>1971</u>	<u>1972</u>	<u>1973</u>	<u>Years-</u>	<u>Total</u>	
Jan.	21.3 ± 13.4	10.4	12.5	20.3	30.7	1957 - 1973	183 ± 38.1	-
Feb.	14.1 ± 6.4	16.0	21.1	16.3	7.1	1959 - 1960	173.5	-
March	16.8 ± 10.1	11.2	13.2	21.8	15.2	1960 - 1961	167.4	-
April	18.2 ± 12.9	13.2	15.0	39.1	11.7	1961 - 1962	176.8	-
May	13.8 ± 11.1	9.4	5.3	10.2	24.1	1962 - 1963	179.8	-
June	2.1 ± 4.8	17.5	2.3	0.0	T	1963 - 1964	154.7	-
July	0.1 ± 0.6	0.0	0.0	0.0	T	1964 - 1965	193.0	-
Aug	3.6 ± 11.1	0.0	T	0.0	T	1965 - 1966	179.1	-
Sept.	11.5 ± 8.3	20.6	5.8	29.0 high	T	1966 - 1967	194.3	-
Oct.	39.2 ± 24.2	54.4	117.6 high	40.6	18.5	1967 - 1968	191.0	-
Nov.	21.1 ± 7.4	24.6	29.7	27.9	18.3	1968 - 1969	118.4	-
Dec.	22.0 ± 10.8	22.9	21.1	41.9	6.9	1969 - 1970	146.8	-
						1970 - 1971	189.5	-
						1971 - 1972	279.4	high
						1972 - 1973	228.4	-

* Source of data: Monthly Records, Atmospheric Environment Services

High: significantly higher than climatic mean (95% confidence level).

Figure 3. Profiles of Snowbeds #1, 2 and 3

B. Winter Climatic Conditions

Winter climatic conditions were recorded at Snowbed #1 from September, 1972 to May, 1973. Air temperatures over snowfree tundra adjacent to the snowbed and at two heights over the snowbed did not vary significantly during this time (Table 4). Temperatures recorded at Snowbed #1 between September, 1972 and May, 1973 were comparable to Upper Air Data from Inuvik, N.W.T., for similar elevations and averaged 3.3°C warmer than the Inuvik weather station. Over the winter, air temperatures at Canoe Lake underwent extreme fluctuations. Eight periods of cold temperatures lasting from 4-32 days and averaging from -19.1°C to -29.7°C were broken by five major sessions of near or above freezing temperatures (Figure 4). Air temperatures reached a maximum of $+0.5^{\circ}\text{C}$ on December 6 and a minimum of -35°C on March 9.

Snow and ground temperatures at Snowbed #1 showed important differences from air temperatures (Figure 5). Average temperatures increased with depth in the snowpack. For example, on January 1, air temperatures were -16°C , whereas temperatures at the base of 180 cm of snow were -0.5°C . The insulating effect of snow was most dramatic during periods of temperature extremes. Air temperatures on March 9 were -35°C , yet temperatures at 50 cm in the snow were -15°C and at ground level were -2°C . During periods of temperature inversions such as on December 6, above-freezing temperatures ($+0.2^{\circ}\text{C}$) were recorded at the snow surface, with freezing temperatures (-6.1°C) recorded at 50 cm in the snowpack. Such above-freezing temperatures within the upper layers of the snowpack produced melt water which refroze at lower levels in the snow. Many ice layers, varying from 1-10 cm thick, with networks of ice veins and columns between layers, were noted within the snowpack before the commencement of spring thaw. With the return of spring, temperatures at all depths through the snowpack were within 0.5° of freezing, as illustrated by the profile for May 13.

Ground temperatures within Snowbed #1, measured to 80 cm depth, fluctuated little over the winter of 1972-1973, remaining within 0.5°C of freezing under more than 200 cm of snow, and dropping to -4.0°C at ground level under 180-200 cm of snow (Figure 6). In comparison, ground temperatures

Table 4
Average Winter Air Temperatures (°C)
Inuvik and Canoe Lake, N.W.T.

Year	Date	Inuvik* (58 m a.s.l.)	Upper Air Data* (at 0:00 GMT or 17:00 local time)	Exposed Tundra	Canoe Lake ** (425 m a.s.l.)		
					Height above snow level (cm)		
			950 m b alt.		0	100	150
1972	Oct. 6-15	-2.5 ± 3.2	-4.4 ± 3.8	517	-2.5 ± 3.2	-	-
	Oct. 16-31	-5.4 ± 4.1	-5.1 ± 5.1	493	-3.6 ± 5.5	-	-
	Nov. 1-15	-15.6 ± 3.4	-13.5 ± 4.7	509	-14.9 ± 5.3	-	-
	Nov. 16-30	-23.8 ± 5.5	-19.2 ± 2.9	484	-20.5 ± 3.6	-	-
	Nov. 25-30	-27.5 ± 3.8	-18.0 ± 3.6	500	-19.5 ± 3.5	-18.5 ± 3.9	-19.2 ± 3.8
	Nov. 1-30	-19.7 ± 6.2	-16.3 ± 4.8	497	-17.7 ± 5.3	-	-
	Dec. 1-15	-12.6 ± 8.0	-10.8 ± 8.0	582	-10.4 ± 8.6	-8.9 ± 8.2	-9.0 ± 8.2
	Dec. 16-31	-31.1 ± 5.4	-24.5 ± 4.2	491	-25.6 ± 4.4	-25.7 ± 3.3	-26.0 ± 3.3
	Dec. 1-31	-22.1 ± 11.6	-17.9 ± 9.3	535	-18.2 ± 10.3	-17.6 ± 10.5	-17.8 ± 10.5
	Jan. 1-15	-19.2 ± 12.0	-15.1 ± 12.3	542	-14.7 ± 11.2	-13.6 ± 10.6	-13.9 ± 10.9
	Jan. 16-31	-31.2 ± 10.5	-26.4 ± 11.3	414	-26.4 ± 9.9	-25.0 ± 9.5	-25.2 ± 9.6
	Jan. 1-31	-25.6 ± 12.6	-20.9 ± 12.6	474	-20.8 ± 12.0	-19.4 ± 11.6	-19.7 ± 11.6
1973	Feb. 1-15	-22.5 ± 8.9	-17.7 ± 8.9	563	-18.7 ± 10.6	-17.9 ± 9.9	-17.8 ± 11.6
	Feb. 16-28	-24.3 ± 6.1	-20.4 ± 5.7	531	-18.9 ± 5.5	-20.3 ± 4.6	-20.7 ± 6.0
	Feb. 1-28	-23.0 ± 7.6	-19.0 ± 9.2	548	-18.8 ± 8.5	-19.0 ± 7.9	-19.2 ± 9.3
	Mar. 1-15	-29.1 ± 2.8	-26.4 ± 3.6	473	-26.1 ± 4.5	-27.1 ± 2.2	-29.3 ± 3.2
	Mar. 16-31	-21.4 ± 9.1	-19.2 ± 7.6	513	-20.0 ± 9.1	under	-19.6 ± 9.1
	Mar. 1-31	-25.0 ± 7.8	-23.4 ± 7.5	494	-23.0 ± 7.7	snow	-24.3 ± 8.1
	Apr. 1-15	-6.8 ± 5.5	-7.2 ± 5.7	549	-	-	-10.3 ± 6.3
	Apr. 16-30	-11.1 ± 6.0	-11.2 ± 4.6	554	-	-	-13.8 ± 6.9
	Apr. 1-30	-9.0 ± 6.0	-9.2 ± 5.5	551	-	-	-14.5 ± 6.5
	May 1-13	-0.9 ± 5.5	-1.5 ± 7.1	498	-	-	-13.0 ± 6.5
					-	-4.7 ± 4.7	-6.0 ± 4.3

* Source of data: Monthly Bulletins, Atmospheric Environment Service

** Complete data can be found in Appendices 3 and 4

Figure 4. Daily Air Temperatures During the
Winter of 1972-1973, Canoe Lake, N.W.T.

Figure 5. Temperature Profiles through the Snow Cover

— - upper surface of snow cover

C

Figure 6. Winter Temperatures at Ground Level

* - complete data can be found in Appendix 2

at the tundra site were close to ambient air temperatures and underwent rapid fluctuations in temperature (Appendix 2). Some surface heating of exposed tundra occurred in October. For example, ground temperature data contained in Appendix 2 show that on October 22-23, air temperatures were -8.5°C , while surface ground temperatures on exposed tundra were 0.5 to 3.5°C . In comparison, ground temperatures to 80 cm depth under 200 cm or more of snow remained between -1 and 0.5°C . Surface heating of tundra vegetation to above-freezing temperatures occurred on 50% of recorded days in October.

C. Patterns of Snow Ablation

Ablation patterns in Snowbed #1 were not uniform between 1971-1973. As illustrated in Figures 7 A, B, and C, the timing of exposure from snow cover for a point within the snowbed varied drastically from year to year. For example, ED105, a point in the lower portion of the snowbed basin, was exposed from snow on June 20, 1971, July 18, 1972, and June 5, 1973, a variation of 43 days. This variation in exposure dates resulted from differences in weather conditions, snow depths and snow deposition patterns between the three years. The melt season in 1972 began 10 days later than in 1973, with melt along the upper borders of Snowbed #1 reaching CD35 by May 29 in 1973 and June 7 in 1972. Snow within the basin remained longer in 1972, the last snow that year melting out after August 1, compared to July 10, 1973 and July 20, 1971. This variation was due in part to greater snow accumulation over the winter of 1971-1972. For example, the deepest snow measured in Snowbed #1 was 759 cm in 1972 compared to 509 cm in 1973. The pattern of drift formation also varied, with the main drift extending further over the basin in 1972 than in 1973. For example, areas in the lower basin which melted out between July 8-18, 1972, were covered with 400-500 cm of snow in May, 1972, compared to a snow cover of 150-200 cm in May, 1973 and exposure dates of June 5-10, 1973.

Within Snowbed #1, variations in the relationship of snow depth to date of exposure occurred throughout the snowbed basin (Table 5). For example, 100-120 cm of snow around the willow bands at the top and base of the snowbed melted out by June 5, compared to 80 cm of snow on the NW-facing slope which melted out a week later. Snow melt in willow zones was accelerated due to lower albedos and radiation of heat from protruding willow branches. Snow on the NW-facing slope did not receive any direct solar radiation. Melt was subsequently slower along this slope. Within the snowbed basin, points adjacent to willow bands melted out faster than points at the centre of the basin; for example, 182 cm of snow next to the upper willow band melted out by June 8, compared to 170 cm of snow on a comparable slope in the lower snowbed which melted out by June 11.

Figure 7A. Date of Exposure
Snowbed #1
1971

Figure 7B. Date of Exposure
Snowbed #1
1972

Figure 7C. Date of Exposure
Snowbed #1
1973

Table 5

Variations in the Relationship of Snow Depth
to Date of Exposure*

Snowbed #1

Point	Snow Depth (cm) May 15 1973	Date of Exposure	Albedo (%)	
			May 26	June 10
Upper Willows	103	June 3	60	--
Lower Willows	118	June 5	50	--
NW-facing Slope	80	June 12	72	44
Adjacent to Upper Willows	182	June 8	62	--
Lower Snowbed	170	June 11	70	45
Adjacent to Creek	378	June 21	72	27
Main Snowbed	358	June 25	70	48

* - For complete data, see Appendices 4 and 5

Disappearance of snow along the lower portions of the snowbeds was affected each year by the pattern of spring runoff. The rise of air temperatures to above freezing levels was rapid. Melt water flowed off tundra slopes into hollows and gullies which were still filled with snow. The sudden flow of water and saturated snow along drainage channels was dramatic, with runoff alternately dammed by the snow, then breaking through in floods. On May 25, 1973, water began to flow over the surface of the snow at Snowbed #1. Within one day, a gully 1-3 m deep and 1 m wide had been cut into the snowpack. This gully continued to increase in size until either the surrounding snow melted or the creek had worked its way under the snow to its natural bed. Caverns up to 60 cm high were opened under the snow and sections of snow were coated with silt. Snow melt was significantly affected in these areas. For example, 378 cm of snow which had been coated with silt (reducing the snow albedo to 27%) melted out by June 21, compared to 358 cm of snow on a comparable slope in the main snowbed which melted out by June 25. Other examples of such variations in the relationship of snow depth to date of exposure can be found by comparing Figures 2A and B, and Figures 7B and C.

D. Summer Climatic Patterns

Variations in above-ground microclimate were measured as snowpatches and snowbeds were exposed from snow.

1. Solar Radiation

Radiation totals for Inuvik during the summers of 1971-1973 did not vary significantly from the climatic norms (Burns, 1973) or from values recorded at Canoe Lake during 1973 (Table 6).

Solar radiation striking the ground varied considerably within the snowbed basin due to local topography (Figure 8). Profiles taken at solar noon showed shading of the steep, 45° northwest-facing slope. Compared to values for the $3-5^\circ$ slopes of snowpatches, hummocky terrain and the base of the snowbed basin (CD75-100), higher values were received on the steep SE-facing slope (CD 45-70) after snow melt in July revealed the underlying 30° slope.

Recorded profile values reflect potential values at that latitude for incoming solar radiation on slopes of various aspects and angles. At all solar altitudes throughout the summer, sloping terrain at certain aspects receives higher intensities of radiation than level ground (Figure 9). For example, under cloud-free conditions maximum intensities are received on south-facing slopes of 48° when the sun is at its maximum altitude of 42° above the horizon. The aspect of a slope also affects total radiation values. From May 28 to July 16, slopes facing SE to SW receive direct radiation when the sun is at altitudes between 42° and 35° . Intensities at these solar altitudes are greater than those at lower sun angles due to decreased atmospheric interference. When the solar azimuth is north of west, southerly-facing slopes steeper than 20 to 25° are shaded until the sun appears again in the east 12 hours later. Some southerly slopes can receive sunlight at midnight if they are not steeper than 1 to 3 degrees. North-facing slopes, on the other hand, can receive sunlight at noon (between May 28-July 16) if they are at grades less than 35 to 42° . In order to receive maximum radiation intensity at midnight, though, N-facing slopes must be steeper than 80° . Unobstructed N-facing slopes of 20° can receive direct sunlight 24 hours a day and may potentially

Mean Daily Solar Radiation - Inuvik and Canoe Lake, N.W.T.

Table 6

(cal cm⁻² day⁻¹)

Station	Year	May 1-31	May 17-31	June 1-15	June 16-30	June 1-30	July 1-15	July 16-31	July 1-31
Inuvik*	1971	510	556±94	602±133	558±140	580±138	504±166	420±92	461±138
	1972	546	574±112	567±172	462±209	515±196	594±149	423±132	506±163
	1973	445	456±144	505±148	479±142	492±143	478±134	398±50	436±106
Snowbed #1**	1973	-	466±163	524±167	491±128	507±147	482±138	541±103	508±118
Station	Year	Aug 1-15	Aug 16-31	Aug 1-31	Sept 1-15	Sept 16-30	Sept 1-30	May 17- Aug 15	May 17- Sept 15
Inuvik	1971	280±98	230±142	254±124	161±57	145±57	124±57	486±162	412±197
	1972	294±136	251±65	272±106	202±103	115±53	158±92	485±184	420±164
	1973	331±146	248±92	292±129	188±70	133±68	161±73	440±141	388±161
Snowbed #1	1973	366±132	-	-	-	-	-	477±157	-

Key: * -Source of data: Monthly Radiation Summaries, A.E.S.

** -Complete data can be found in Appendix 6

Figure 8. Incoming Solar Radiation Profiles
Snowbed #1, 1973

* taken at Solar noon

Figure 9. Slopes receiving maximum radiation intensities at various solar altitudes

receive more total incoming solar radiation than south-facing slopes greater than 3° . Within the valleys around Canoe Lake, though, few slopes are unobstructed. Topographic barriers shade most N-facing slopes after the sun drops below 20° above the horizon. Most S-facing slopes are shaded when the sun is in the east or west due to the N-S trending ridges.

2. Winds

Winds during the three years of study were representative of average conditions. Compared to mean hourly wind speeds given by Burns (1973) for Inuvik, the summers of 1971, 1972, and 1973 did not vary significantly from climatic norms. Windspeeds recorded at Canoe Lake on the ridge or upper snowbed in 1972 and 1973 did not differ significantly from those recorded at Inuvik or from those recorded at Snowbed #2 between May 19-June 25, 1972 (Table 7).

Daily average wind speeds at Canoe Lake varied considerably, ranging from a low of 2.3 km/hr on May 19, 1973 to a high of 32.4 km/hr on June 15, 1973 (Appendix 7). This range in average wind speeds over the three seasons resulted from the influence of major weather systems, with the strongest winds occurring when low pressure areas moved across the mountains from the northwest, and the lowest winds resulting from air flows off the Mackenzie Delta to the east.

Wind speeds recorded at Canoe Lake were strongly influenced by local topography (Table 7). Average values recorded at the base of Snowbed #1 were significantly lower than those recorded at the upper lip of the snowbed and on the exposed ridge above.

The effect of the snowbed basin upon storm winds passing down the SE-facing slope of Ridge #1 is illustrated in Figure 10. For example, on July 5/73, northwesterly winds averaged 33 km/hr with gusts over 50 km/hr on slopes above the snowbed. An immediate decrease in speed to 11 km/hr occurred when the wind passed over a 3 m drop in elevation associated with a band of willows. Wind speeds remained very low (5-7 km/hr) in the lee of this barrier, increasing slightly along the flat base of the gully, but decreasing to 4-5 km/hr in a lower band of willows. Across the entire extent of the snowbed, winds remained at speeds less than one third of those on the tundra above.

Table 7

Mean Daily Wind Speeds (km/hr)

Inuvik and Canoe Lake, N.W.T.

Dates	Inuvik*		Ridge **	Snowbed #1 - Upper		Snowbed #1 - Lower	
	1972	1973		1972	1973	1972	1973
May 17-31	--	--	8.0 ± 4.0	8.3 ± 4.4	6.8 ± 3.3	--	5.2 ± 2.4
June 1-15	--	--	13.7 ± 7.9	5.4 ± 1.5	11.0 ± 6.3	--	6.7 ± 2.3
June 16-30	--	--	12.0 ± 5.6	12.9 ± 8.9	8.7 ± 3.7	--	3.5 ± 1.1
June 1-30	13.4	7.4	12.9 ± 6.8	9.2 ± 7.3	9.9 ± 5.2	--	5.1 ± 2.4
July 1-15	--	--	11.5 ± 3.8	8.6 ± 2.4	9.2 ± 2.9	5.1 ± 1.4	2.9 ± 0.8
July 16-31	--	--	13.8 ± 4.1	8.3 ± 2.5	11.3 ± 2.9	3.6 ± 0.7	3.0 ± 1.0
July 1-31	12.6	11.6	12.7 ± 4.1	8.4 ± 2.0	10.3 ± 3.1	4.4 ± 1.4	3.0 ± 0.9
Aug. 1-15	--	--	17.8 ± 7.1	9.7 ± 4.8	12.7 ± 5.8	3.0 ± 1.3	3.8 ± 1.6
Aug. 16-31	--	--	--	7.1 ± 4.3	--	2.5 ± 1.2	--
Aug. 1-31	10.8	11.9	--	8.3 ± 4.6	--	2.8 ± 1.2	--
Sept. 1-15	--	--	--	7.0 ± 3.7	--	2.9 ± 0.9	--
May 17-Aug. 15	--	--	13.0	8.9	9.9	--	4.2
May 19-Jun. 25	--	--	--	7.3 ± 2.4	--	Snowbed #2 7.7 ± 1.9	--

* Data based on Monthly Summaries, Atmospheric Environment Service
 ** Complete data can be found in Appendix 7

Figure 10. Wind speed along CD Transect, Snowbed #1

3. Air Temperatures

The summers of 1971-1973 showed few significant variations from climatic norms (Table 8). Only June, 1971, was significantly warmer than normal. The remainder of the summers fell into regular climatic patterns although some differences were apparent: August, 1971, and May, 1972 were below normal temperatures while May, 1973 was warmer.

Summer air temperatures over the western Arctic are controlled by very different influences than winter air temperatures. The marked inversion over the land disappears in summer, with temperatures tending to decrease with height at a rate of $-1.8^{\circ}\text{C}/300$ meters in July (Burns, 1973). Adiabatic cooling of air rising over the mountains contributes to lower temperatures in the Richardson Mountains than in lower lying Delta stations. From June 1 - September 15 (1972 and 1973), Canoe Lake averaged $1.2 - 2.7^{\circ}\text{C}$ colder than Inuvik (Table 9). Patterns of air temperatures corresponded closely to major weather systems, with the lowest air temperatures occurring during storms from the Beaufort Sea, and the warmest temperatures during southwesterly to northeasterly air flows off the Delta.

Within the Richardson Mountains, air temperatures at 30 cm above ground level varied little between slopes of different aspects and wind exposures (Table 9). No significant differences in mean daily, mean maximum or mean minimum air temperatures occurred between the three snowbeds studied or between snowbed, exposed ridge, and NE-facing locations. Differences between years were significant only for August 1-15, 1971 and May 15-31, 1972, which were colder than comparable months. Between May 15-31, 1973, the ridge and NE-facing slope recorded above-freezing air temperatures, while the snowbeds were still recording sub-zero air temperatures. For example, average minimums between May 15-31 were $+1.1^{\circ}\text{C}$ for the former two sites, and -2.8°C over the snowbeds. This difference was not due to elevation, as the values for Snowbeds #2 and #3 show, but more likely due to heating and re-radiation from the bare rocks and exposed tundra patches on the ridge and NE-facing slope.

Table 8

Summer Air Temperatures, Inuvik, N.W.T. (°C) *

	Month	1957-1973	1971	1972	1973
Mean Maximum	May	4.1 ± 1.6	4.3	1.4	5.8
	June	16.4 ± 2.0	19.3	16.3	17.1
	July	19.4 ± 1.6	20.3	20.6	19.7
	August	15.7 ± 3.0	11.7	17.0	15.1
Mean Minimum	May	-5.8 ± 1.3	-5.3	-7.4	-3.9
	June	4.2 ± 1.8	7.4	4.8	5.7
	July	7.7 ± 1.3	8.8	8.7	8.3
	August	5.3 ± 2.1	3.2	7.0	6.2
Mean Daily	May	-0.8 ± 1.4	-0.5	-3.0	0.9
	June	10.3 ± 1.5	13.4h	10.6	11.4
	July	13.6 ± 1.4	14.6	14.6	14.0
	August	10.6 ± 2.5	7.4	12.0	10.7
Maximum	May	18.0 ± 3.6	20.0	11.7	21.7
	June	26.3 ± 2.1	27.8	26.1	25.6
	July	28.1 ± 1.7	26.7	27.8	30.6
	August	26.6 ± 2.6	23.9	25.0	23.9
Minimum	May	-19.0 ± 5.7	-23.3	-18.9	-12.2
	June	- 3.1 ± 2.0	- 1.7	0.0	0.6
	July	0.1 ± 2.0	1.7	1.7	2.2
	August	- 0.9 ± 2.6	- 1.7	0.6	- 1.7

* source of Data: Monthly Records, Atmospheric Environment Services
 h significantly higher than climatic mean (95% confidence level)

Table 2
Mean Summer Air Temperatures (°C) Inuvik and Canoe Lake, N.W.T.

Dates	Daily Temp	Inuvik*		Snowbed #1**		Snowbed #2		Snowbed #3		Ridge		NE Slope	
		1972	1973	1971	1972	1973	1972	1973	1972	1973	1973	1973	1973
May 15-31	Max	1.1±5.7	9.1±6.7	-	1.1±5.9	4.1±4.5	2.2±6.1	5.4±5.4	2.1±6.4	5.4±5.4	6.7±4.4	6.6±4.3	
	Min	-8.1±5.9	-1.0±4.3	-	-8.1±5.8	-2.7±3.8	-8.6±4.5	-2.8±4.5	-9.1±5.2	-2.8±4.5	1.1±5.5	1.1±5.5	
	Av	-	-	-	-2.6±5.7	0.1±4.2	-2.6±5.3	0.4±4.8	-2.8±5.2	0.7±5.0	4.8±5.4	4.6±5.3	
June 1-15	Max	17.4±5.3	16.9±6.2	-	14.4±5.3	13.4±6.3	13.1±4.5	13.0±6.3	14.1±5.9	13.1±5.8	12.6±4.2	11.7±4.4	
	Min	4.4±4.4	4.7±4.4	-	4.8±3.9	3.9±4.0	3.8±2.6	2.8±3.1	3.9±3.7	2.9±3.1	6.6±2.9	6.2±3.2	
	Av	-	-	-	9.6±4.3	8.2±5.1	8.9±4.1	7.9±5.0	9.4±5.1	8.4±4.7	9.6±3.6	9.2±3.8	
June 16-30	Max	15.2±6.5	17.2±4.5	-	11.8±6.8	13.7±3.8	11.7±7.1	14.3±4.5	12.0±7.7	13.6±4.5	13.6±3.3	12.6±3.7	
	Min	5.1±3.7	6.6±3.1	-	4.5±4.0	7.1±3.4	3.7±3.8	3.8±3.8	3.1±4.1	3.1±3.5	7.3±2.6	6.7±3.5	
	Av	-	-	-	7.9±5.2	10.4±3.7	7.4±5.0	9.2±4.4	7.9±5.9	8.4±4.2	10.2±2.9	9.6±3.5	
June 1-30	Max	16.3±5.9	17.1±5.3	-	13.1±6.1	12.4±5.9	12.4±5.9	13.7±5.4	13.1±6.8	13.4±5.1	13.1±3.7	12.2±4.0	
	Min	4.8±4.0	5.7±3.9	-	4.7±3.9	5.6±3.9	3.7±3.2	3.3±3.5	3.5±3.9	3.0±3.2	6.9±2.8	6.4±3.3	
	Av	10.6	11.4	-	8.8±4.8	9.3±4.6	8.1±4.5	8.6±4.7	8.7±5.5	8.4±4.4	9.9±3.2	9.4±3.6	
July 1-15	Max	20.7±4.4	18.8±3.6	-	18.5±4.6	14.7±3.6	17.6±4.7	16.2±5.1	18.9±5.6	14.3±4.7	14.2±3.1	13.9±3.6	
	Min	7.8±3.4	7.4±2.5	-	7.3±3.8	7.8±1.9	6.8±4.0	4.8±2.8	5.9±4.1	4.3±2.8	8.1±1.8	7.7±1.7	
	Av	-	-	-	13.3±4.1	11.4±2.9	12.5±4.2	9.7±3.7	13.3±4.7	9.4±3.5	11.0±2.5	10.9±2.8	
July 16-31	Max	19.4±6.8	20.6±6.7	-	16.5±5.0	17.5±6.4	15.3±4.2	19.7±6.6	18.3±6.3	19.4±5.5	16.0±5.0	16.8±6.3	
	Min	9.5±5.5	9.1±5.0	-	8.1±3.4	10.2±5.4	6.5±3.7	6.6±7.2	6.4±4.2	8.7±4.4	9.7±4.2	10.2±5.6	
	Av	-	-	-	12.3±4.1	14.2±6.3	11.5±3.7	12.4±7.0	12.4±4.4	14.0±5.3	12.9±5.0	12.7±6.1	
July 1-31	Max	20.0±5.7	19.7±5.5	-	17.5±4.8	16.3±5.3	16.4±4.5	18.0±6.1	18.6±5.9	17.0±5.7	15.1±4.2	15.4±5.3	
	Min	8.7±4.6	8.3±4.0	-	7.7±3.6	9.0±4.2	6.7±3.8	5.7±5.5	6.2±4.1	6.6±4.3	8.9±3.3	9.0±4.3	
	Av	14.6	14.0	-	12.8±4.1	12.8±5.1	12.0±3.7	11.1±6.0	12.8±4.5	11.7±5.0	12.0±4.0	11.8±4.8	
Aug. 1-15	Max	17.2±4.5	15.6±6.5	7.1±4.7	13.4±4.8	13.5±5.1	13.2±4.5	12.5±6.7	14.5±6.0	11.9±6.1	12.6±4.4	12.7±5.1	
	Min	7.0±2.8	6.6±3.9	-1.5±2.7	5.0±2.4	8.2±3.6	5.4±3.2	4.1±4.6	4.4±3.7	3.9±3.9	7.7±2.8	8.0±3.4	
	Av	-	-	2.9±3.0	9.9±3.4	10.9±4.5	9.6±3.6	8.8±5.5	9.6±3.9	8.0±4.9	10.2±3.6	10.5±4.2	
Aug. 16-31	Max	16.9±5.0	-	-	14.1±5.5	-	14.3±4.9	-	15.4±5.6	-	-	-	
	Min	7.1±3.3	-	-	7.0±3.8	-	5.3±3.2	-	5.2±3.3	-	-	-	
	Av	-	-	-	10.5±3.9	-	10.0±3.7	-	10.2±3.8	-	-	-	
Aug. 1-31	Max	17.0±4.7	-	-	13.7±5.1	-	13.8±4.7	-	15.0±5.7	-	-	-	
	Min	7.0±3.0	-	-	6.0±3.3	-	5.4±3.2	-	4.8±3.5	-	-	-	
	Av	12.0	-	-	10.2±3.6	-	9.8±3.6	-	10.0±3.7	-	-	-	
Sept. 1-15	Max	7.3±3.8	-	-	4.6±3.8	-	3.9±3.9	-	4.5±4.6	-	-	-	
	Min	0.1±2.1	-	-	-2.3±3.0	-	-2.2±2.7	-	-4.0±3.1	-	-	-	
	Av	-	-	-	1.2±3.2	-	0.9±3.1	-	0.2±3.5	-	-	-	
May 15- Aug 15	Max	15.1±8.6	16.3±6.8	-	12.5±7.8	12.4±6.5	12.1±7.1	13.5±7.2	13.3±8.4	12.9±6.7	12.6±5.0	12.4±5.5	
	Min	4.2±7.4	5.6±5.1	-	3.5±6.8	5.7±5.7	2.8±6.5	3.2±5.4	2.4±6.8	3.4±5.0	6.7±4.4	6.6±4.9	
	Av	-	-	-	8.4±6.8	9.9±6.4	7.8±6.5	8.1±6.6	8.3±7.8	8.1±6.6	9.8±4.4	9.5±4.8	

Key:

* Source of data: Monthly

Records, Atmospheric

Environment Services

** Complete data in Appendix 8

The lack of statistically significant variations in air temperatures between years and between locations of varied slope, aspect, topographic location and wind regime resulted in part from large oscillations in summer air temperatures, with resultant high standard deviations. Variations in daily air temperature between snowbed and exposed sites were masked by wide fluctuations in temperatures due to changing weather systems.

Diurnal fluctuations in air temperatures at the various sites showed that the NE-facing slope, which is shaded from receiving any direct sunlight, remained the most constant in temperature, while the south-facing snowbed, #3, underwent the greatest variation (Table 10). Snowbeds #2 and #3, at higher elevations and further from Canoe Lake, normally had greater diurnal fluctuations in temperature than Snowbed #1. The ridge site, on exposed felsenmeer at the top of the ridge, had lower diurnal fluctuations than Snowbed #1, located on a SE-facing slope.

4. Relative Humidity

During 1971, 1972 and 1973, the determining factor for relative humidity in the Canoe Lake area appeared to be the air mass characteristics of weather systems occupying the region, as differences between the snowbed, ridge and NE-facing slope sites were generally not significant (Table 11).

Relative humidities at the snowbed locations varied little from year to year or within each season. Mean daily averages over two-week periods ranged between 61% (Snowbed #1 from July 21-31, 1973) to 82% (Snowbed #3 from September 1-15, 1972), but average values throughout the summers normally fell between 65% and 75%. The maximum relative humidities recorded, 95-100%, occurred often during the summer, especially during the frequent fogs. The minimum recorded was 21%. Relative humidities recorded at the ridge and NE-slope sites were similar to those recorded for the snowbeds. The exposed ridge top consistently recorded the lowest relative humidities, while the sheltered NE-facing slope recorded consistently and occasionally significantly higher relative humidities than snowbed sites.

Table 10

Diurnal Air Temperature Fluctuations (°C)Canoe Lake, N.W.T.

Dates	Year	SB#1	SB#2	SB#3	Ridge	NE Slope
May 15 - 31	1972	9.2	10.8	11.2		
	1973	6.8	8.2	8.2	5.6	5.6
June 1 - 30	1972	7.0	8.7	9.6		
	1973	6.8	10.4	10.4	6.2	5.8
July 1-31	1972	9.8	9.7	12.4		
	1973	7.2	12.3	10.4	6.2	6.4
August 1 - 15	1971	8.6				
	1972	8.4	7.8	10.1		
	1973	5.3	8.4	8.0	4.9	4.7
August 16 - 31	1972	7.1	9.0	10.2		
Sept. 1 - 15	1972	6.9	6.1	8.5		

SB: Snowbed

Table 11
Mean Daily Relative Humidity (%) - Cance Lake, N.W.T.*

Dates	Snowbed # 1		Snowbed #2		Snowbed #3		Ridge	Slope
	1971	1972	1972	1973	1972	1973		
May 16-31	-	75 ± 8	71 ± 10	77 ± 11	76 ± 8	75 ± 11	75 ± 11	79 ± 9
June 1-15	-	69 ± 12	65 ± 14	72 ± 13	70 ± 11	74 ± 10	67 ± 16	76 ± 11
June 16-30	-	76 ± 14	71 ± 17	75 ± 7	79 ± 15	75 ± 6	69 ± 10	77 ± 6
June 1-30	-	72 ± 13	68 ± 19	73 ± 10	74 ± 14	75 ± 8	68 ± 13	77 ± 9
July 1-15	-	64 ± 11	61 ± 12	75 ± 10	67 ± 12	77 ± 10	72 ± 14	80 ± 9
July 16-31	-	72 ± 8	72 ± 10	65 ± 13	77 ± 7	67 ± 11	65 ± 15	75 ± 10
July 21-31	71 ± 11	74 ± 6	74 ± 9	61 ± 11	78 ± 6	64 ± 9	60 ± 13	72 ± 9
July 1-31	-	68 ± 11	67 ± 13	70 ± 12	72 ± 11	72 ± 11	68 ± 15	77 ± 10
Aug. 1-15	81 ± 7	77 ± 12	74 ± 14	69 ± 11	79 ± 11	73 ± 10	67 ± 17	77 ± 10
Aug. 16-31	-	79 ± 10	78 ± 11	-	80 ± 9	-	-	-
Aug. 1-24	80 ± 9	77 ± 11	75 ± 13	-	79 ± 10	-	-	-
Aug. 1-31	-	78 ± 11	76 ± 13	-	80 ± 10	-	-	-
Sept. 1-15	-	79 ± 10	78 ± 14	-	82 ± 10	-	-	-
May 15- Aug. 15	-	70 ± 12	69 ± 14	72 ± 11	75 ± 11	74 ± 10	69 ± 15	77 ± 9
May 15- Sept. 15	-	74 ± 12	71 ± 14	-	76 ± 11	-	-	-

* Complete data in Appendix 9

5. Precipitation

Total precipitation between May and September for 1971, 1972 and 1973 at Inuvik did not vary significantly from climatic means (Table 12).

Although the relationships between years was comparable between Inuvik and Canoe Lake (eg. precipitation in July, 1972, was half that of July, 1973 for both Inuvik and Canoe Lake), Canoe Lake received almost 50% more rainfall than adjacent lowland areas for a total of 19.6 cm from June 1 - September 15, 1972 (Table 13). Precipitation over the Richardson Mountains in summer is dominated by two primary sources-- warm air rising off the Mackenzie Delta bearing thunderstorms or moist air that forms clouds over higher elevations, and, more important, low pressure systems from the Beaufort Sea borne on strong, northwesterly winds. Between May 17 and August 15 at Canoe Lake in 1972 and 1973, 45% and 57% of the days respectively had rain, 6% and 9% had snow, 29 and 43% had fog, and 56 and 68% had rain, snow, fog or combinations of these (Appendix 10). Days without precipitation averaged 60-80% cloud cover, which, especially during 1973, was often at ceilings within 300 metres of the ridge tops.

Precipitation variations between habitats were difficult to measure in the mountains. Rain gauges in windswept areas normally record less precipitation than actually falls (Benson, 1969). Rain gauges placed on a SE-facing slope and at the base of a snowbed did not record significantly different totals despite locations with very dissimilar wind regimes. A tipping bucket rain gauge placed on a windswept ridge recorded 40% less precipitation than the former two gauges (Table 13). It is unlikely, though, considering the high total rainfall, strong winds, and cloud/fog frequency of the Canoe Lake area, that summer precipitation variations form important microclimatic differences between snowbed, snowpatch and snowfree environments.

Table 13

Summer Precipitation Totals (cm)1972 and 1973Canoe Lake, N.W.T.

Dates	Inuvik*		Upper** Snowbed		Lower Snowbed		Ridge 1972
	1972	1973	1972	1973	1972	1973	
May 22-31	-	-	-	3.32	-	3.01	-
June 1-15	2.24	0.76	2.35	0.24	-	0.18	-
June 16-30	2.03	3.02	4.54	3.97	-	4.32	-
July 1-15	0.76	1.75	0.58	1.76	0.53	1.80	-
July 16-31	1.65	2.64	5.04	8.84	5.01	8.88	-
Aug. 1-15	2.08	2.44	2.54	2.42	2.40	2.37	1.87
Aug. 16-31	3.20	1.98	3.11	-	3.33	-	2.43
Sept 1-15	1.75	-	1.45	-	1.75	-	-
May 15-Aug 15	9.58	12.79	-	20.55	-	20.67	-
June 1-Aug 15	8.41	10.61	15.05	17.23	-	17.66	-
June 1-Sept 15	13.36	-	19.61	-	-	-	-

Source of Data: Monthly Reports, Atmospheric Environment Services

** Complete data in Appendix 10

E. Variations in Above-Ground Climatic Conditions during the Thaw Season

The gradual retreat of snow borders within Snowbed #1 did not expose the ground to significantly different average weather conditions during June and July of any one year (Figure 11). Due in part to large standard deviations, which were the product of extreme fluctuations in weather, and conditions of continuous daylight modified by high cloud/fog covers and frequent storms, average daily values over the length of exposure for such climatic factors as incoming solar radiation and air temperatures did not vary significantly through the growing season. For example, air temperatures showed little variation for points exposed in June and July, with daily averages between 10.8 and 12.7° C. Differences did arise, though, with exposure after early to mid-August under decreasing solar radiation and lower air temperatures eg. CD80-90, 1972.

Major differences were the product of variations in number of days exposed. For example, daily average radiation values showed minimal differences, ranging between 449-493 cal/cm²/day across the snow depth gradient. In contrast, total incoming solar radiation received over the length of exposure (calculated on a basis of maximum thaw season exposure of 92 days for snow-free points) varied from 44,800 cal/cm² for snow-free sites, to as low as 17,800 cal/cm² for late melt zones. Although this potential incoming radiation was modified by topographic location, sites exposed by mid to late July in 1973 received only 50% of the energy available for points on the same slope exposed by June 1. Exposure date in June or July did not affect the percentage of days receiving precipitation. In June, 1972 and 1973, 53 and 67% of days respectively had some form of precipitation. In July the percentages were 42 and 52%. In contrast, though, ground exposed after the end of July experienced a higher frequency of precipitation. Between August 1-15, the percentage days receiving precipitation were 87 and 80% respectively for 1972 and 1973. Total precipitation received was a direct product of number of days exposed. For example, a site exposed on June 1 received totals of 15 cm of precipitation to August 15, 1972, and 17 cm to August 15, 1973, in contrast to a site exposed July 10 which received only 8 and 11 cm respectively.

Figure 11. Average Weather Conditions
over Length of Exposure
Snowbed #1

F. Summer Ground Conditions

1. Runoff Patterns

Flow patterns of melt-water within Snowbed #1 were determined by topographic features and location of remaining snow (Figure 12). Sites exposed in June along the lower edge of the snowbank received runoff water over 55-70% of the length of their exposure. Those points in this zone which were raised 0.3 - 0.5 m above surrounding ground levels (mesic lower meadows) were not subjected to the flow of cold melt water over the surface, although water tables matched the surrounding ground levels. As exposure lengths decreased, sites received meltwater over a decreasing percentage of their exposure time, due to the short duration of the remaining snow. Those late melting areas in Snowbed #1 located at the base of the steep upper slope, though, were saturated over the length of their exposure with water from flow of precipitation runoff and ground water which emerged at the base of the slope.

In contrast, the upper slopes of Snowbed #1 and snowbeds such as #2 and #3, did not receive flow of melt-water during exposure as remaining snow lay downslope to exposed ground. Precipitation runoff did not form pools on these slopes due to slope angles of 10-45°. The presence of hydric zones due to melt-water runoff was limited to snowbeds on lee slopes where ground on the downhill side of the retreating snowbank was at slope angles of 0-5°.

2. Albedos

Albedos of snow-free surfaces did not show significant variations throughout the summer (Table 14). Differences between locations were less than 10%, with most snow-free sites reflecting 23-25% of the incident short-wave radiation.

3. Active Layers

Depth to permafrost varied considerably along the snow-depth gradient (Figure 13). In mossy snowpatches and hollows between solifluction lobes, active layers reached 45-60 cm by mid-August, an average rate of thaw of 0.7 cm/day in 1973 and 0.5 cm/day in 1972. In contrast, thaw on rocky ridge slopes reached 100 cm by the end of July.

Figure 12. Patterns of Melt-Water Runoff,
Snowbed #1, 1973 : Percent days
receiving Runoff over Length of Exposure.

Table 14Average Albedos of Snow-free Surfaces (%)Snowbed #1

Surface	Albedo		
	June	July	August
Hummocky terrain	25	28	25
Rocky terrain	23	25	25
Snowpatch	23	25	24
<u>Snowbed</u>			
Willows (ground level)	21	22	21
Meadows on steep upper slopes	23	27	25
Wet, mossy meadows	21	21	23
Tall grass	26	27	27
Late melt areas	24	25	23
NW-facing slope (tundra)	-	-	20

Figure 13. Active Layer Depths
Snowbed #1

At the edge of Snowbed #1, active layers were 70-76 cm deep under a peripheral band of shrubby birch (Betula glandulosa), increasing to 132 cm under shrub willows. A 10-14 day delay in snowmelt during 1972 left active layers 20-30 cm shallower in this zone. Thaw was rapid in the upper willows; 35 cm in 11 days at the beginning of June, with rates as high as 7.5 cm/day for the first few days of exposure. Rapid thaw also occurred on shrub-free steep upper slopes of the snowbed basin. Rates as high as 8 cm/day were measured over the first 3 days of exposure, with averages of 45 cm of thaw over the first 12 days after snowmelt. Total depths of thaw on these slopes in 1973 reached 115-120 cm. Values in 1972 were almost 50% less due in part to a 1-3 week delay in exposure between 1972 and 1973, but also due to freezing of the soil during the previous August when below-freezing temperatures were recorded on 18 days between August 1-25, 1971. Soil was frozen before the fall accumulation of snow began, in contrast to 1972 and 1973 when unfrozen soils were buried under the first snows of autumn.

Decreased active layer depths in 1972 were even more pronounced in late-melt zones. Depths of 45-75 cm in 1972 were considerably less than those of 122-130 cm in 1973. In addition to the cold autumn of 1971, delayed exposure of late melt zones in 1972 until the end of July placed soils under conditions of decreasing solar radiation and air temperatures. Compared to 10-30 cm of thaw between July 25-August 15, 1972, only 1-5 cm of thaw occurred between August 15-30. In contrast, late melt soils in 1973 which were exposed by July 11, had thawed to 100 cm by July 27. Rates up to 9 cm/day were measured over the first 3 days of exposure in 1973. Hydric late melt zones thawed at a slower rate than late melt zones on the upper slopes. For example, by July 11, 1973, sites exposed on July 8 had thawed to 20 cm in hydric zones, compared to 50 cm on upper slopes. Maximum thaw in hydric zones was only 38-44 cm in 1972 compared to 110-115 cm in 1973. An anomalous 67 cm drop in active layer at one sample point between August 15-30, 1972, coincided with 6 days of heavy rain between August 25-30 and very heavy runoff through this zone.

Meadow areas adjacent to the lower willow zone had active layers that averaged 80 cm in 1972 and 123 cm in 1973. Exposure was not until July 25-31, 1972, compared to June 15-25, 1973. In contrast to the meadows,

active layers under the lower willow zone were not as affected by the 40 day delay in exposure between 1972 and 1973, averaging 110 cm in 1972 and 130 cm in 1973. Rates of thaw were rapid under the lower willow band. For example, in 1973 active layers of 30 cm by June 15 increased to 60 cm within 12 days. Rapid rates of thaw were recorded before lower willows leafed out - up to 8-11 cm/day over the first week of exposure. The deepest active layer recorded in 1973, 168 cm, occurred within the lower willows at a site disturbed by creek erosion. Adjacent active layers under grassy creek banks averaged only 80-90 cm deep. Active layer determinations below the stream bed itself and on the NW-facing slope were prevented by bedrock near the surface.

4. Ground Temperatures

Considerable variation in summer ground temperatures occurred between sites adjacent to and within Snowbed #1 (Table 15). On the snowfree tundra site, the upper 5 cm of soil was unfrozen after May 18, but thaw did not reach 50 cm until early July, averaging only 1.8° C at this depth by the end of the season. Within snowpatches, the same slow thaw below the upper few centimeters of soil was noticeable. Moist upper surfaces were cooler than at the drier tundra site, but thaw to 50 cm was not reached until July, with average temperatures of 1.6° C by August 1-17. At both sites, cold temperatures which originated in winter under thin snow cover, lasted into the summer, with average temperatures over length of exposure at 50 cm being -0.1 and -0.2° C for the tundra and snowpatch sites respectively.

Willow borders, with over 100 cm winter snow cover, were warmer at depth than snowpatch or tundra sites. For example, average temperatures at 50 cm were 1.3 and 4.3° C in July for upper and lower willows respectively, compared to 0.2 and 0.8° C for snowpatch and tundra sites. The temperature of the upper 5 cm of soil under the upper willows was warmer than under the lower willows, which received melt-water and ground-water runoff over most of the summer.

Table 15

Average Summer Ground Temperatures (°C) Snowbed #1*

Dates			Depth	Late melt		Meadow			Willows		Snow- patch	Tundra
			(cm)	Upper	Hydric	Upper	Lower		Upper	Lower		
						Hydric	Mesic					
1972	Aug 13-31	5	8.0	5.8	6.4	6.1	5.1	5.7	5.0	6.4	6.4	
		30	7.7	3.8	4.6	3.4	3.1	4.0	3.2	2.7	3.0	
		50	6.3	3.4	2.7	2.2	1.0	2.6	2.0	2.2	2.6	
	Sept 1-14	5	4.5	1.9	1.8	1.2	1.2	2.6	0.9	1.2	1.6	
		30	3.1	1.3	1.7	0.6	0.9	1.5	1.4	0.9	0.7	
		50	2.6	1.6	1.3	0.8	0.3	0.8	0.9	0.5	0.6	
	Sept 15-19	5	0.6	0.1	0.1	-0.6	-0.2	0.3	-0.5	-0.1	-0.2	
		30	0.9	0.0	0.5	-0.9	-0.3	0.6	0.1	0.1	0.1	
		50	0.7	0.1	0.2	-0.7	-0.6	-0.1	0.0	-0.2	-0.3	
1973	May 18-31	5	-	-	-	-0.9	-	-0.1	-	-0.2	8.5	
		30	-	-	-	-1.4	-	-0.8	-	-1.6	-1.2	
		50	-	-	-	-1.5	-	-1.8	-	-2.8	-2.0	
	June 1-17	5	-	-	-0.3	0.1	0.6	6.7	0.6	4.4	9.6	
		30	-	-	-0.1	-1.4	-0.5	-0.3	-0.2	-0.7	0.2	
		50	-	-	-0.5	-1.4	-0.9	-1.1	-0.8	-1.3	-0.8	
	June 21-30	5	-	0.1	5.9	2.9	4.3	6.1	5.9	4.5	10.6	
		30	-	-0.7	2.6	-0.9	0.5	0.1	1.3	-0.2	0.9	
		50	-	-0.3	0.3	-1.1	0.0	-0.9	-0.1	-0.1	-0.4	
	July 1-31	5	9.8	5.0	9.5	8.9	9.1	12.0	9.1	8.8	19.0	
		30	5.3	3.1	6.1	4.2	5.3	3.4	6.0	0.8	2.8	
		50	3.4	2.6	4.1	2.0	2.6	1.3	4.3	0.2	0.8	
	Aug 1-17	5	12.3	6.8	7.2	6.5	6.3	11.7	5.7	9.0	12.5	
		30	9.1	5.4	6.4	4.8	5.0	4.7	5.4	2.5	3.4	
		50	7.8	5.2	4.9	4.3	3.4	3.2	4.4	1.6	1.8	
	Over length of Exposure (1973)		5	12.9	6.9	7.7	5.5	6.5	10.0	6.6	5.8	11.8
			30	8.6	4.3	5.4	2.4	3.6	2.3	4.2	0.5	1.2
			50	7.2	4.0	3.5	1.6	1.9	0.9	2.9	-0.2	-0.1

* For complete data, see Appendix 11

Ground temperatures of shrub-free meadow zones in the snowbed basin were also affected by location above or below the flow of melt water from the retreating snowbank. Temperatures on upper slopes, although averaging 2-3° C cooler at 5 cm in July and early August compared to upper willows, were 1-3° C warmer at 50 cm. Above-freezing temperatures at 50 cm in upper meadows occurred within 1 week of exposure, compared to 28 days required for the upper willows. In comparison to upper meadows, lower meadows recorded significantly lower temperatures while subjected to flow of cold melt-water eg. from June 21-30, temperatures at 5 cm and 30 cm in the lower meadow were 2.9° C and -0.9° C respectively, compared to 5.9° C and 2.6° C in the upper meadow. Temperatures at the lower meadow site, raised 30-50 cm above melt-water flow (mesic lower meadows), were 4.3° C and 0.5° C at 5 cm and 30 cm during this same period of time. With cessation of melt-water flow, differences in temperature between the upper meadow and lower meadow sites were not as pronounced e.g. from August 1-17, the upper meadow averaged 7.2° C and 6.4° C at 5 and 30 cm, compared to 6.5° C and 4.8° C, and 6.3° C and 4.0° C for the hydric and mesic lower meadows respectively.

Late melt zones showed more pronounced temperature differences between upper slopes and hydric sites both during melt-water flow and during the later summer under flow from ground water and precipitation runoff. Over the length of exposure, upper late melt zones averaged 12.9, 8.6 and 7.2° C at 5, 30 and 50 cm respectively, compared to 6.9, 4.3, and 4.0° C in the hydric late melt zone.

Temperature differences between sites were less pronounced under conditions of lower incoming solar radiation and reduced air temperatures. For example, ground temperatures at 5, 30 and 50 cm for all sites except the upper late melt zone were comparable between August 13-September 19, 1972. In August, the upper late melt zone, on a steep, SE-facing, vegetation-free slope, recorded average temperatures 1.5-3° C warmer than other snowbed sites, and 1.5-2.5° C warmer during the first two weeks of September. With the first autumn snowfall on September 16-17, temperatures at all sites dropped to within 1° C of freezing.

The portion of cryptogams changed along the snow depth gradient. Compared to snowpatch and ridge areas where cryptogams formed 45-83% of the living biomass, moss and lichens formed less than 15% of the living biomass in most snowbed zones. The exceptions to this were hydric and late melt zones, where moss content formed 20-86% of the living biomass, and immediately downslope to upper willow zones. In this zone, Polytrichum juniperinum formed large mats averaging 81% of living biomass.

In contrast to above-ground biomass values, total below-ground biomass (upper 20 cm of soil), showed an increase in snowbed areas compared to values obtained for ridge and snowpatch sites. An increase also occurred between upper slopes and comparable zones receiving runoff. For example, below-ground biomass averaged 2781 g/m^2 in the upper willows compared to 4618 g/m^2 in the lower willows. The ratio of above to below ground biomass, low in ridge and snowpatch zones, dropped to a 1:1 ratio under well-drained shrub areas. In comparison, the ratios were high across the snowbed basin. Meadows, where 68-76% of plant species recorded had some form of underground storage organ, averaged 1:11 above to below-ground biomass. The highest value, 1:62; in the hydric late melt zone, was primarily a product of organic snow debris which had accumulated within upper soil horizons. As shown in Table 18, the distribution of roots throughout the soil horizons varied between upper slope areas and hydric zones. Over 90% of roots in the upper willows occurred in the upper 5 cm of soil, whereas 37% of roots in the hydric lower meadow grew below 4 cm in the ground.

The amount of biomass produced each year varied considerably along the snow depth gradient (Table 19). Willow and birch shrub zones had high net primary productivity ($194-196 \text{ g/m}^2/\text{year}$) and faster rates of production over their length of exposure ($2.2 - 2.8 \text{ g/m}^2/\text{day}$) compared to adjacent snowpatch and ridge areas ($62.8 - 112.3 \text{ g/m}^2/\text{year}$ and $0.7-1.4 \text{ g/m}^2/\text{day}$). Most upper meadows produced comparable biomass to snowpatch or ridge communities, but at a faster rate ($1.1-2.2 \text{ g/m}^2/\text{day}$). Very high net and daily productivity occurred adjacent to ground squirrel burrows and along creek banks, where almost pure swards of Calamagrostis

5. Erosion Processes

Slope instability was apparent in all snowbed sites examined. Although survey pegs placed across upper late melt slopes at Snowbed #1 did not show any detectable surface movement over two years, collapses of earth along the steep banks of this zone were frequent. Most upper snowbed slopes showed scars of recent and past mudslides. For example, during 1972 and 1973, two small slides 5-10 m in width occurred on the steep, NE-facing upper meadow zone of Snowbed #2 and the 45°, NW-facing bank of Snowbed #1. Three old slide scars crossed the upper SE-facing slope of Snowbed #1, the largest being 85 m wide. Well developed snowpatch vegetation and willows (maximum age: 123 years) occupied the upper sections of this scar. A buried organic layer, 10-20 cm thick and 20-25 cm below the surface, was found within two soil pits in willow and meadow areas below the scar. Organic contents of the layer were as high as 36%, compared to 5-8% for adjacent mineral horizons.

Groundwater flow during and after snow melt caused removal of soil from snowbed areas. For example, two major springs on the upper slopes of Snowbed #1 had flows sufficient to form 5-10 cm deep drainage channels. Other springs at the bases of Snowbeds #1 and #2 created pools in excess of 30 cm deep. These springs did not result from movement of water along the permafrost-active layer interface as free water was not detected in any pipes or soil pits dug to this level on upper slopes. Movement of precipitation from upper ridge areas through channels within permafrost and bedrock layers was suspected to occur during the frequent rainfalls of the region.

Both erosion and deposition resulted from floods during spring runoff. Soils of the lower willow area are built up in part by deposition of alluvial material over organic litter (Lambert, 1968). Flood waters also caused mass erosion of snowbed soils. The most dramatic example occurred at Snowbed #1 during the spring of 1973. An underground creek channel was cut through the lower willow band, emerging 20 m downstream through a 1.5 m wide hole 3 m from the natural creek bed. This channel, most likely formed by melt of a large ice lens, collapsed in June to 2 m below normal ground level. Scars from similar mass removals of soil were found along all creek channels examined in the region.

Gully and rill erosion were found in late melting zones of those lee snowbeds surveyed in the region, but were found less frequently in snowbeds confined to creek gullies. Water flow here was normally retained within well-defined stream beds. Soil erosion from melt and rain runoff was not common in well-vegetated upper and lower snowbed slopes. Flow in these cases either passed directly over vegetative mats or was channelled along depressions.

The autumn activities of the arctic ground squirrel (Citellus undulatus) also have an impact on soil stability. In the Richardson Mountains, ground squirrels over-winter under large snowbeds but leave these areas in early May to summer in burrows on well-drained ridge tops and exposed slopes. With the onset of autumn weather in August, they return to snowbed areas, re-excavating old winter burrows and gathering vegetation. The distribution of ground squirrel holes in the Canoe Lake area (Table 16) shows a preponderance of holes in SE-facing upper meadows (68/72 recorded) — Similar distributions were found at Snowbeds #2 and #3 where all ground squirrel burrows, 32 and 18 respectively, were located in snowbed meadows on S- to SE-facing slopes. None occurred on SW or NE-facing meadows.

Other animals had limited impact on the stability of snowbed soils. Excavations by wolverines and barren-ground grizzly bears pursuing ground squirrels resulted in patches of upper meadows up to 2 m by 3 m being overturned to depths of 0.5 m. The frequency of these activities averaged less than 1 per large snowbed over the study area. During August of 1971 and 1972, large sections of upper and lower late melt zones suffered considerable churning as caribou herds in excess of 100 animals moved across snowbed basins each day over a period of 2-3 weeks. Permanent game trails were apparent through the upper willow zones: 5 at Snowbed #2, 2 at Snowbed #3 and 3 at Snowbed #1.

Table 16

Distribution of Ground Squirrel Burrows
along Ridge #1

Zone*	Aspect	Slope (°)	Holes (#)
Ridge-S-facing	SSE	5-10	16
-N-facing	NE	25-35	0
Hummocky Terrain	S	0-10	0
Snowpatch	S	0-10	0
Upper Border of Birch	SE	10-15	0
Upper Willows	SE	2-15	0
Upper Meadows	SE	20-30	68
Upper Late Melt	SE-S	20-40	4
Hydric Late Melt	S	0- 5	0
Lower Meadow	S	0- 8	0
Lower Willows	S	0-10	0
Along Creek	S	0- 5	0
NW-facing Slope	NW	30-45	0

*Sample area: Snowbed #1 basin and Ridge #1 immediately upslope
to Snowbed - total area = 500m x 500 m

G. Vegetation Patterns Across the Snow Depth Gradient

Increases in winter snow depths and decreasing lengths of summer exposure across Snowbed #1 were accompanied by changes in the underlying vegetation cover (Table 17).

In contrast to the exposed ridge which often had bare patches of rock or frost-churned soil, snowpatches above Snowbed #1, peripheral shrub zones and snowbed meadows exposed during June (1973) normally had a continuous mat of vegetation. As length of exposure decreased towards the centre of the basin, the percentage plant cover also decreased to a low of 25% average cover in hydric late melt areas.

Reflecting, in part, the decrease in plant cover, above-ground biomass also decreased towards the centre of Snowbed #1. The highest biomass values were found in peripheral shrub zones where standing crops reached $2,500 \text{ g/m}^2$ for upper willow thickets, and $1,500 \text{ g/m}^2$ for willows subjected to melt-water runoff. The lowest values, less than 10 g/m^2 , occurred in hydric late melt zones. The portion of the biomass formed by local dead organic material also changed across the snow depth gradient. Forty percent of biomass on exposed ridges and in snowpatches consisted of dead material. About 25% of the biomass in peripheral shrub communities was dead, much of this being woody material. Leaf litter, plentiful under well-drained birch and willow bushes, occurred infrequently on the wet, mossy floors of the lower willow zones. The percentage of dead organic in meadow zones showed some variations with location relative to flow of runoff. Close to 50% of local biomass in lower meadows was dead. Although dead organic material averaged 54% of biomass in upper meadow zones, values as high as 85% of total biomass were recorded for well-drained Calamagrostis canadensis meadows near old ground squirrel burrows. Mats of grass stems accumulated to depths of 5-15 cm under these conditions. The amount of local litter was highly variable in late melt zones, ranging from 4-63% of total local biomass. The large range in values was a product of both the variability in percentage plant cover and in species composition within late melt areas. For example, Phippsia alga accumulated thick mats of dead stems and leaves, whereas sites dominated by mosses such as Pohlia drummondii or Drepanocladus fluitans retained a limited amount of dead material.

Table 17
 Vegetation Characteristics Across the Snow Depth Gradient*
 Snowbed #1

Zone	Point (m)	Average 1973			Above Ground Biomass			Total Biomass		
		Snow Depth (cm)	Expo- sure (Days)	% Plant cover	g/m ² Live	Local Dead	Cryp- togams % Live	g/m ² Above Ground	Below Ground	Ratio
Ridge-S-facing	0	0	92	75	169	185	83	729	2347	1:3
	5	0	92	85	519	283	47			
	10	0	92	80	314	416	69			
Snowpatch	15	24	79	100	749	411	45			
	20	20	79	100	915	457	55			
Birch	25	5	85	100	1403	470	3	2039	3567	1:2
	27	18	81	100	1791	414	6			
Upper Willows	30	103	74	100	1582	751	<1	2404	2781	1:1
	33	110	73	100	1990	482	<1			
Upper Meadows	35	182	68	100	393	443	81			
	40	195	64	100	251	337	11	385	4352	1:11
	45	262	61	100	173	266	15			
	50	360	51	95	144	77	8			
Upper Late Melt	55	450	41	40	80	46	20			
	60	454	38	40	87	9	40	148	2732	1:18
	65	485	37	35	50	2	86			
Hydric Late Melt	70	485	37	25	7	1	29	69	4272	1:62
	75	449	40	80	47	52	11			
Lower Meadows -hydric -mesic	80	350	49	100	209	218	21	428	4742	1:11
	85	360	49	100	471	456	8	982	4603	1:5
Lower Willows	90	118	71	100	705	339	9	1259	4618	1:4
	95	105	73	100	1138	325	3			
Meadows next to Creek	100	300	56	100	215	558	<1			
	105	170	65	100	300	180	<1			
NW-facing Slope	110	80	64	100	722	331	38			
	115	85	62	100	657	374	39			

* For complete data, see Appendices 12, 13 and 14

The portion of cryptogams changed along the snow depth gradient. Compared to snowpatch and ridge areas where cryptogams formed 45-83% of the living biomass, moss and lichens formed less than 15% of the living biomass in most snowbed zones. The exceptions to this were hydric and late melt zones, where moss content formed 20-86% of the living biomass, and immediately downslope to upper willow zones. In this zone, Polytrichum juniperinum formed large mats averaging 81% of living biomass.

In contrast to above-ground biomass values, total below-ground biomass (upper 20 cm of soil), showed an increase in snowbed areas compared to values obtained for ridge and snowpatch sites. An increase also occurred between upper slopes and comparable zones receiving runoff. For example, below-ground biomass averaged 2781 g/m^2 in the upper willows compared to 4618 g/m^2 in the lower willows. The ratio of above to below ground biomass, low in ridge and snowpatch zones, dropped to a 1:1 ratio under well-drained shrub areas. In comparison, the ratios were high across the snowbed basin. Meadows, where 68-76% of plant species recorded had some form of underground storage organ, averaged 1:11 above to below-ground biomass. The highest value, 1:62; in the hydric late melt zone, was primarily a product of organic snow debris which had accumulated within upper soil horizons. As shown in Table 18, the distribution of roots throughout the soil horizons varied between upper slope areas and hydric zones. Over 90% of roots in the upper willows occurred in the upper 5 cm of soil, whereas 37% of roots in the hydric lower meadow grew below 4 cm in the ground.

The amount of biomass produced each year varied considerably along the snow depth gradient (Table 19). Willow and birch shrub zones had high net primary productivity ($194\text{-}196 \text{ g/m}^2/\text{year}$) and faster rates of production over their length of exposure ($2.2\text{--}2.8 \text{ g/m}^2/\text{day}$) compared to adjacent snowpatch and ridge areas ($62.8\text{--}112.3 \text{ g/m}^2/\text{year}$ and $0.7\text{-}1.4 \text{ g/m}^2/\text{day}$). Most upper meadows produced comparable biomass to snowpatch or ridge communities, but at a faster rate ($1.1\text{-}2.2 \text{ g/m}^2/\text{day}$). Very high net and daily productivity occurred adjacent to ground squirrel burrows and along creek banks, where almost pure swards of Calamagrostis

Table 18

Distribution of Roots with Depth in Ground
(% of Total Roots)

Location	Depth (cm)	%
Upper Willows	0- 5	93
	5-20	2
	20-45	1
	45-60	4
Lower Meadow (hydric)	0- 4	63
	4-15	12
	15-30	12
	30-40	9
	40-55	4

Table 19

Estimates of Net Above-Ground Primary Productivity
(Average g/m²/year)

Community	Year	Length of exposure: May 15 - August 15	Herbaceous Growth	New Woody Growth	Moss-New Growth	Total	Average daily g/m ²
Exposed Ridge	72	92	51.0	5.2	6.6	62.8	0.7
Snowpatch-S-facing	72	78	50.0	8.5	32.8	91.3	1.3
	73	82	68.9	8.7	34.7	112.3	1.4
-N-facing	72	80	47.1	11.1	25.9	84.1	1.0
Birch	72	87	149.6	36.4	7.8	193.8	2.2
Upper Willows	72	66	176.0	20.0	0.4	196.4	2.8
Upper Meadow-within 5m of Willows	72	61	80.3	9.7	0.1	90.1	1.5
	73	74	33.6	2.5	44.9	81.0	1.1
-ground squirrel burrows	72	59	176.0	14.6	0.8	192.3	3.2
-SE facing	72	59	112.1	4.8	2.6	119.5	2.0
	73	64	98.6	4.8	1.3	104.7	1.7
-#2-NE facing	73	41	53.6	3.6	7.8	65.2	1.6
-#3	73	55	111.6	4.0	3.6	119.2	2.2
Late Melt-upper: #1	72	18	2.9	0.0	0.6	3.5	0.2
	73	40	33.8	1.0	4.1	38.9	1.1
: #2	73	26	15.3	n	2.9	18.2	0.7
: #3	73	31	15.9	n	2.3	18.2	0.6
-hydric #1	72	18	3.9	n	n	3.9	0.2
Lower Meadow-hydric	72	21	39.7	0.2	2.4	42.3	1.8
	73	52	68.7	0.6	6.7	76.0	1.5
-mesic	72	61	109.5	15.1	4.0	128.6	2.2
	73	60	102.4	15.6	2.1	120.1	1.9
Lower Willows	72	38	80.3	20.7	6.4	107.4	2.6
Meadow adjacent #1 to creek #2	72	49	257.5	0.0	0.1	257.6	5.0
	73	34	71.9	0.8	20.4	93.1	2.7

n-negligible

canadensis or Carex podocarpa reached values of 192.3-257.6 g/m²/year and 3.2-5.0 g/m²/day. Yearly primary productivity dropped as plant cover decreased both upslope on exposed ridges and downslope into late melt zones. The lowest net yearly biomass production, 3.9 g/m²/year, and daily production, 0.01 g/m²/day, was found on the sparsely vegetated, saturated soils of late melt zones subjected to melt water runoff.

H. Soil Patterns Across the Snow Depth Gradient

1. Deposition Patterns of Snow Debris

Snowbed soils in the Canoe Lake area received significant amounts of wind-blown material from bordering vegetation communities (Table 20). The amount and composition of the debris, deposited in the winter snow accumulation, varied both between and within snowbeds. The zones of highest accumulation were normally late melting or hydric zones, where debris, forming over 50% of the total biomass, averaged 84.1 g/m^2 on the upper slopes and $21.2\text{-}23.0 \text{ g/m}^2$ in hydric zones. The highest total accumulation of snow debris recovered was 1070.5 g/m^2 in the late melt zone of Snowbed #2. Debris here was up to 15 cm thick. In contrast to these high values, snow debris accumulations in snowpatch and early melting snowbed zones, normally 5 g/m^2 or less, accounted for less than 1% of total biomass.

Annual input of organic snow debris along the late melting bases of three creek gullies and in the late-melt zone of Snowbed #1 ranged between $107\text{-}677 \text{ g/m}^2$, for an average of 234 g/m^2 . This debris was highly variable in composition, containing leaves of many chionophobous species, in addition to the snowbed border species, Salix pulchra. An average of 39% of the debris was $> 2 \text{ mm}$ in length, with a further 32% between $2\text{-}0.7 \text{ mm}$.

The mineral contents of snow debris sampled in the Canoe Lake area showed substantial differences between snowbeds, ranging from 19-71%. Peak organic contents (81%) occurred in snowdrifts downslope from hummocky terrain, with snowbeds below barren ridges receiving more mineral material (59-75%).

The size of inorganic debris moved by wind also varied. Thin fragments of sandstone and shale weighing from $0.07\text{-}0.52 \text{ g}$ were found in 6% of debris samples. In contrast to aeolian deposits which are dominated by silt-sized particles, an average 83% of the mineral content of snow debris samples from late-melt zones and within litter layers was sand-sized particles from upslope felsenmeer fields. Yearly accumulations of inorganic snow debris in the late-melt zones of four different snowbeds ranged from $39.8\text{-}159.5 \text{ g/m}^2$ (average 90.8 g/m^2). Total accumulations of sand in moss and litter layers of upper meadow zones averaged 37.7 g/m^2 .

Table 20

Distribution of Organic Snow Debris in Snowbed Basins(g/m²)

<u>Zone</u>	<u>Total Accumulation</u>	<u>% Total Dead Organic</u>	<u>% Total Biomass</u>
Exposed Ridge	n	n	n
Snowpatch-S-facing	0.4	0.1	n
-N-facing	0.0	0.0	0.0
<u>Snowbed #1:</u>			
Birch	0.1	0.1	0.1
Upper Willows	1.4	0.2	0.1
Upper Meadow-within 5m			
of willows	1.6	0.3	0.1
-SE-facing	2.4	1.6	0.6
Late Melt -upper	84.1	75.5	50.3
-hydric	21.5	92.0	69.9
Lower Meadow-hydric	23.0	33.5	17.0
-mesic	21.2	5.6	2.4
Lower Willows	5.5	1.6	0.4
Meadow adjacent to creek	1.5	0.5	0.3
<u>Snowbed #2:</u>			
Upper Meadow-NE-facing	16.0	5.5	1.8
-SW-facing	2.0	0.6	0.4
Late Melt -NE-facing	92.0	49.0	20.0
-flat	410.7	91.1	71.6
<u>Snowbed #3:</u>			
Upper Meadow	5.2	2.0	0.9
Late Melt	12.0	19.2	8.1

n-negligible

2. Soil Fraction > 2 mm

The soil component composed of particles > 2 mm in diameter, such as large roots, dead branches, stones and bedrock fragments, changed across the snow depth gradient (Table 21). The shallow organic mats of exposed ridges, often interrupted by large protruding bedrock boulders, were composed, by weight, of an average of 70% particles > 2 mm, of which 24% were organic. Rock contents were likewise high in organic-mineral and mineral zones. Less than 1% of the > 2 mm fraction was organic. Snowpatches, which developed organic mats in excess of 15 cm, had less than 10% particles > 2 mm in any horizon. The development of mineral layers underneath snowpatches was variable. Sites close to exposed tundra often had 10-20 cm thick organic mats over large plates of sandstone bedrock, whereas other snowpatches with deeper winter snow covers overlay sandy colluvium of low rock content.

Peripheral willow zones also had limited rock content, with 63% of the > 2 mm fraction being organic in the upper horizon. Upper meadow communities were variable in the > 2 mm content. Rock contents, in mineral horizons averaged 30-65%, with the > 2 mm fraction decreasing in most organic-mineral and organic horizons. Large > 2 mm rock contents up to 55% were found in the organic horizons of some steep meadows. Upper late melt slopes were also very rocky, but over 50% of the > 2 mm fractions in the hydric late melt zone were large fragments of snow debris. In contrast to upper slope soils which were dominated by fragments of sandstone, lower meadow and willow zones were underlain by a solid layer of rounded gravel 63-95 cm below the surface. The rock content of mineral horizons in these areas reached as high as 85% by weight.

3. Soil Fraction < 2 mm

The organic contents of the < 2 mm soil fraction changed significantly across the snow depth gradient (Table 22). Vegetated ridge sites, hummocky terrain and snowpatches normally had a distinct organic mat 6-16 cm deep with a 54-76% organic content. Organic contents of the underlying organic-mineral layers were less than 10%. Although upper willow zones did not have a distinct organic mat, upper horizons were highly organic (49-62%), compared to 19% for lower willow zones. Downslope from the upper willows, the organic contents

Table 21
Characteristics of the > 2 mm Soil Fraction

Zone	Percent of soil > 2mm			Fraction of soil > 2mm: Percent Organic		
	Organic	<u>Horizons</u> O-Mineral	Mineral	Organic	<u>Horizons</u> O-Mineral	Mineral
Ridge	70	58	40	24	1	0
Snowpatch	8	2	3	90	12	0
Upper Willows	11	8	15	63	21	11
Upper Willows- edge	17	6	16	70	8	7
Upper Meadows-						
distance) 5m	20	15	60	33	1	0
from) 8m	8	3	65	27	28*	0
upper) 10m	16	8	30	33	1	7
willows) 15m	18	20	40	42	2	0
Upper late melt	-	50	50	-	8	3
Hydric late melt	-	50	65	-	52	3
Lower Meadow - hydric						
distance)	30	20	30	12	0	0
from) 5m	30	15	40	37	25	0
l. willows) 3m	25	20	25	45	3	0
Lower Willows	15	28	85	24	13	0
Hummocky Terrain	60	70	58	91	1	0

*Buried organic horizon

2

of upper layers decreased with reductions in length of exposure. In late melt zones, organic layers were absent. The organic content of surface organic-mineral layers in late melt zones was formed primarily of snow debris. The organic contents of soil horizons in all snowbed zones decreased rapidly with depth, averaging less than 10% in mineral layers.

The particle size composition of the < 2 mm soil fraction also changed across the snow depth gradient (Table 22). Exposed ridge soils, which developed directly on weathered sandstone colluvium, showed a high percentage of sand at all depths, with less than 17% clay-sized particles. Snowpatches also had high sand contents in mineral layers, but willow zones showed some increase in silt and clay content in the organic-mineral layers. The silt and clay-sized fractions were higher in upper meadow zones, decreasing in late melt areas, but increasing again in lower meadow and lower willow soils. Distinct patterns of particle size distribution for the < 2 mm soil fraction were not apparent in the snowbed basin due to highly variable soil characteristics.

4. Chemical Characteristics

The chemical characteristics of soils changed along the snow depth gradient (Table 23). Soils at all depths were strongly acidic. The highest cation exchange capacities, concentrations of exchangeable cations and nitrogen contents in all soils were found within the surface organic layers, with values decreasing within organic-mineral and mineral horizons. Snowpatch communities with well-developed organic mats had higher soil nutrient values than meadow and lower willow zones. Southeast-facing upper meadows had higher CEC and nutrient values than other meadow areas. The lowest CEC and nutrient values were found in the rocky upper meadow and upper late melt soils. High values of sodium and calcium were found in hydric late melt soils.

Patterns of nutrient enrichment through animal activity, especially additions of organic material, varied considerably throughout the snowbed basin (Table 24). Caribou droppings were most prevalent in upper willow zones, averaging 10.6 g/m^2 , whereas microtine droppings, averaging $0.9\text{--}2.1 \text{ g/m}^2$, occurred most frequently in overwintering areas within the lower mesic meadow and willow zones. Ground squirrel burrows were most

Table 23

Soil Chemical Characteristics
Snowbed #1

Zone	Layer	pH	CEC (meq)	Cations meq/100gm				N(%)
				K	Mg	Na	Ca	
Ridge-S-facing	O	4.4	46.7	1.42	7.03	0.43	14.2	0.82
	O-M	4.5	11.4	0.14	1.50	0.09	3.9	0.11
	M	4.8	9.8	0.13	1.21	0.09	4.1	0.06
Snowpatch- SE-facing	O	4.8	90.8	0.87	13.00	0.49	40.5	0.93
	O-M	4.9	13.5	0.14	1.64	0.10	4.0	0.11
	M	5.3	12.7	0.14	1.88	0.16	5.9	0.90
Birch	O	4.7	66.5	0.70	10.70	0.22	24.0	1.06
	O-M	5.2	31.5	0.49	7.38	0.13	11.0	0.22
	M	5.0	11.0	0.22	2.50	0.13	4.3	0.06
Upper Willows	O	4.6	78.6	1.96	9.13	0.39	40.3	1.48
	O-M	4.7	28.1	0.16	3.92	0.33	15.2	0.42
	M	4.8	19.8	0.21	2.33	0.15	7.4	0.15
Upper Meadow- SE-facing	O	4.8	56.2	0.85	8.43	0.24	29.1	0.81
	O-M	4.8	17.6	0.19	3.56	0.14	7.9	0.14
	M	4.9	14.4	0.27	2.78	0.14	6.6	0.08
rocky	O	4.8	40.0	0.23	3.12	0.13	8.0	0.42
	O-M	4.8	18.0	0.25	4.39	0.13	6.5	0.09
	M	5.0	10.8	0.23	2.89	0.15	4.9	0.02
Upper late melt	O	-	-	-	-	-	-	-
	O-M	4.1	17.1	0.34	1.35	0.09	4.4	0.28
	M	4.4	13.0	0.20	0.88	0.08	2.8	0.13
Hydric late melt	O	-	-	-	-	-	-	-
	O-M	5.0	46.3	0.47	6.72	0.43	29.8	0.28
	M	4.8	15.4	0.22	2.62	0.12	8.4	0.11
Lower Meadow- hydric	O	5.2	39.3	0.48	8.20	0.22	17.0	0.70
	O-M	4.8	20.3	0.26	4.06	0.18	6.7	0.20
	M	4.8	15.2	0.30	2.79	0.16	5.2	0.10
mesic	O	4.7	35.0	0.44	3.61	0.17	10.0	0.60
	O-M	4.8	11.7	0.21	2.30	0.13	3.6	0.06
	M	4.8	15.3	0.18	1.64	0.23	4.0	0.06
Lower Willows	O	5.2	59.7	0.61	7.16	0.31	28.5	0.87
	O-M	4.6	23.1	0.25	2.71	0.13	6.7	0.27
	M	4.6	15.0	0.19	2.10	0.12	5.1	0.12
Hummocky Terrain	O	4.6	82.0	2.11	13.1	0.32	35.5	1.29
	O-M	4.7	29.5	0.23	7.4	0.13	16.5	0.29
	M	5.5	13.5	0.23	3.1	0.09	7.0	0.09

O - Organic
O-M - Organic-Mineral
M - Mineral layer

Table 24

Distribution of Animal Droppings
Across the Snow Depth Gradient

Snowbed #1

Zone	Droppings (average g/m ²)			
	Microtine	Caribou	Ptarmigan	Total
Ridge-S-facing	0	0	0	0
Snowpatch-				
SE-facing	0.2	0	0	0.2
Birch	0.1	0	0	0.1
Upper Willows	0.1	10.5	0	10.6
Upper Meadow-				
SE-facing	0.3	0.9	0.3	1.5
rocky	0.1	0.3	0.1	0.5
Upper late melt	0.2	0.3	n	0.5
Hydric late melt	0	0	0	0
Lower Meadow-				
hydric	0.4	n	0	0.4
mesic	0.9	0.3	0.1	1.3
Lower Willows	2.1	0	0.3	2.4

n-negligible

frequent on upper meadow slopes.

Movement of cations into the snowbed basin was measured in samples of surface runoff and groundwater (Table 25). In June, high levels of cations were found in surface runoff on tundra plant communities upslope from Snowbed #1. Surface water flow within the upper willows recorded the highest levels of all cations, especially after intense rainfall. For example, on June 27, after 3.2 cm of rain over the preceeding 6 days, values for Ca, Mg, Na and K in surface runoff through upper willows were 8.25, 2.2, 1.7 and 0.4 meq respectively. Runoff which passed over meadow zones downslope from the willows had values of 1.45 and 0.75 meq for Ca and Mg, and 1.87 and 1.21 meq for Na and K. These values suggest some retention of cations such as Ca and Mg on upper meadow slopes. Nutrient input into hydric zones also occurred in ground-water flow. Values of cations comparable to surface water runoff were recorded in spring water which flowed from the base of Snowbed #1 over the hydric late melt and hydric lower meadow zones.

Table 25

Chemical Characteristics of Groundwater and Runoff
 Snowbed #1
 (milliequivalents/100 mls)

Date (1973)	Cation	Surface Runoff			Groundwater Spring
		Tundra above Snowbed #1	Upper Willow Zone	Upper Meadow Zone	Lower Hydric Zone
June 8	Ca		0.80		
	Mg		0.38		
	Na		0.11		
	K		0.17		
12	Ca	2.60	3.85		
	Mg	0.56	1.00		
	Na	1.38	1.26		
	K	0.46	0.29		
27	Ca	0.90	8.25	1.45	
	Mg	0.79	2.24	0.75	
	Na	0.60	1.65	1.87	
	K	3.28	0.41	1.21	
29	Ca	0.65	4.10	2.05	
	Mg	0.93	1.12	0.79	
	Na	2.24	1.13	0.09	
	K	4.00	0.18	0.10	
July 22	Ca				2.15
	Mg				1.91
	Na				0.42
	K				0.08
Aug. 1	Ca				2.90
	Mg				1.66
	Na				1.35
	K				0.27
8	Ca				1.40
	Mg				1.91
	Na				1.09
	K				0.09
20	Ca				1.30
	Mg				1.74
	Na				0.15
	K				0.56

I. Plant Species Responses to the Snow Depth Gradient

Plant species responses to microclimatic and soil conditions along the snow depth gradient varied considerably. Results for biomass distribution, phenological responses and growth rates of selected plant species are presented in Figures 14, 15 and 16.

1. Willows (Salix sp.)

Of 56 willow species occurring in Alaska and adjacent territories, 17 are found in the tundra plant communities of the Richardson Mountains (Hultén, 1968). Most of these are restricted to stream and lake banks, but some prostrate forms are able to grow under severe conditions. In the Canoe Lake area, the dwarf prostrate willow, Salix arctica, found on exposed ridges, attained peak average biomass of 27.9 g/m^2 on SE-facing lee slopes, but did not grow in the organic mats of snowpatch areas or under deep snow accumulations. Although exposed from snow prior to May 15, S. arctica did not flower until the first and second weeks of June on both N-facing and S-facing slopes. In comparison, S. pulchra, a shrub species which can grow to $2\frac{1}{2} \text{ m}$ in height, is limited to sites with a protecting winter snow cover. Peak biomass values, averaging $1,870 \text{ g/m}^2$, occurred in the upper willow zones of Snowbed #1. Most bushes flowered from the first to third weeks in June, but individual branches which protruded above snowcover in May flowered 4-7 days earlier than lower branches. Bushes in upper and lower meadows, exposed 7-20 days later than those in willow zones, did not flower during 1971-1973.

Both S. Chamissonis and S. polaris subsp. pseudopolaris, found only under deep snow covers, were able to adjust flowering by more than 30 days. Blossoms in August, though, did not produce mature seed. Salix Chamissonis, which forms large mats in meadow zones, attained highest biomass (403.3 g/m^2) in mesic lower meadows. Scattered individuals found in late-melt zones did not flower. Those found in hydric lower meadows flowered after the flow of cold melt-water had ceased. S. polaris subsp. pseudopolaris, found throughout mesic upper meadows, reached maximum biomass on upper late melt slopes. Leaf development in upper meadows occurred 7-18 days after snow melt, depending upon date of exposure. Flowering did not occur before the last week in June, despite exposures up to 17 days earlier. In comparison, plants melting out in July and August flowered within 7-10 days. Those found in hydric late melt areas did not flower.

Figure 14. Biomass Profiles for
Selected Plant Species %

Percent of Maximum
Above-Ground Biomass

Figure 15*. Phenological Time-Tables
for Selected Plant Species,
1972 and 1973
Snowbed #1

* - see pocket on back cover

Figure 16. Comparison of Growth Rates
in Different Melt Zones,
1973
Snowbed #1

2. Forbs, Horsetails

Herbaceous flowering plants found within snowbed plant communities range from those limited solely to snowbeds, to those found in almost all terrestrial tundra environments. Of 26 forbs in the *Salicetum Chamissonis* plant association (Lambert, 1968), 12 are restricted to snowbeds, compared to 9/15 in the *Salicetum pseudopolaris* association.

The composite, *Petasites frigidus*, occurring in both snow-free and snow-dominated environments, develops leaves and flowers separately along a thick creeping rootstock. In snow-free and snowpatch areas, *P. frigidus* flowered from the second to third weeks in June. Although flowering within snowbed meadows was delayed by 1-3 weeks, growth was rapid, averaging 1.4 cm/day from exposure to maximum flower height. Length of flowering, and in some cases, time to flowering was shortened within snowbeds compared to tundra areas. For example, flowering in upper meadows occurred over 6 days compared to 16 days in snowpatches. Flowering did not occur in all meadow zones each year. Plants in late melt and hydric zones were vegetative only. Biomass was highest in mesic lower meadows (24.8 g/m^2), but the relative flowering frequency here was from 14-28% of quadrats.

Similar distributions within both snowpatch and snowbed areas are found for other species. The horsetail, *Equisetum arvense* also occurs across the snow depth gradient, with the highest biomass values (39.4 g/m^2) found within the moist lower willows, and the lowest biomass values (less than 1 g/m^2) on the ridge slopes. *Artemisia arctica*, a composite of wide environmental tolerance, obtained peak biomass (80.1 g/m^2) on upper meadow slopes. Within snowbed basins, it often flowered but rarely set mature seed before the end of August. Growth rates of flowering stems, 0.6-0.8 cm/day, did not vary significantly between sites of different exposure length. Flowering occurred 25-30 days after initial exposure except in zones saturated by cold melt-water where flowering occurred 20-25 days after saturated conditions ceased.

In contrast to widely-occurring species, *Dodecatheon frigidum* grows only on upper snowbed slopes, with peak biomass (7.5 g/m^2) in meadows within 5 m of the upper willow zone. Growth of flower stems was rapid: 1.0-1.4 cm/day after bud initiation, with flowering within 15 days after exposure. Mature seed was produced within 35 days of snow melt. This

rapid development was suitable for growth in upper meadow zones, but within late melt zones, phenological events were not speeded up. Seeds did not mature if exposure was after July 1st.

The majority of plants occurring within late melt zones were unable to finish flowering and set seed before the onset of autumn snows. Some forbs, though, were able to complete their reproductive process under much reduced growing seasons. Ranunculus pygmaeus, R. nivalis, Oxyria digyna, Antennaria monocephala, and Saxifraga rivularis, which produced mature seed during the 1-1½ snow-free months in 1972, flowered within 6, 6, 5, 12 and 13 days of exposure respectively. These species, which experienced near-zero winter temperatures, had winter green leaves capable of photosynthesis immediately upon snow melt. Flower and leaf buds developed the previous autumn grew quickly after exposure. No growth was noted under the snow, except for Equisetum arvense which emerged through 5 cm of ice in the upper late-melt zone of Snowbed #2. Species such as Ranunculus pygmaeus and R. nivalis went from flower buds to dispersal of seed within 30 days on well-drained soils. Development was delayed by melt-water -- 15-20 days for R. pygmaeus and 5-10 days for R. nivalis.

C. Monocots

Monocots found in snowbeds include few strictly snowbed species, although some obtain peak biomass within snow-dominated environments. Three sedge species, Carex lugens, C. podocarpa, and C. Lachenalii, occur in both tundra and snowbed environments but attain maximum biomass within different exposure zones. } C. lugens is most common on exposed soils which are snow-free before the end of May. It flowered during the second to fourth weeks of June, 1973, with snowpatch and snow-free sites flowering within 5 days of each other. C. podocarpa, on the other hand, does occur on exposed ridges, but the highest biomass values (261.7 g/m^2) occurred in snowbed meadows, especially along the margins of creeks. Growth in upper meadows, averaging 0.6 cm/day, was similar to Artemisia arctica but slower than the 1.0-1.4 cm/day recorded for Dodecatheon frigidum. Carex podocarpa flowered within 30 days when exposed in early June, but flowering was speeded up by 4-12 days under conditions of delayed exposure.

For example, in 1973, an average of 17-25 days elapsed between exposure and flowering in upper meadows compared to 13 days in upper late melt zones. Despite faster flowering times, C. podocarpa did not set mature seed in late melt areas. Growth appeared to be slowed by the presence of cold melt-water -- C. podocarpa did not exceed 2 cm in height in lower meadows until saturated conditions ceased. Development of C. Lachenalii, which can occur in both snowbed and snowpatch areas, also appeared to be slowed by the presence of melt water and accelerated under upper late melt conditions. C. Lachenalii, tolerant of saturated conditions, reached peak biomass of 61.0 g/m^2 in hydric lower meadows.

Graminoids found in snowbed meadows are circumpolar species of wide ecological tolerance. Festuca altaica and Calamagrostis canadensis, common in exposed tundra areas, were found only within early melting zones of snowbed basins. C. canadensis, which reached peak biomass values of 243.3 g/m^2 growing in lush stands along creeks and near ground-squirrel burrows, did not set seed during the years of study. Festuca altaica, with peak biomass of 15.9 g/m^2 on upper slopes, flowered at the end of July and, in 1972 and 1973, produced seed by the end of August. It did not occur in late-melt or hydric zones. In contrast, Phippisia algida occurred only in late-melt areas, preferentially in hydric zones where it reached maximum biomass of 4.1 g/m^2 . Despite its circumpolar distribution in similar habitats (Hultén, 1968), P. algida continued to flower up to burial by snow in autumn and failed to set mature seed during the years of study. Other grasses had wider distributions within the snowbed basin. Trisetum spicatum, Poa arctica and Arctagrostis latifolia, with maximum biomass values of 2.5, 37.6 and 26.8 g/m^2 respectively, showed progressive decreases in time required to flower after snow melt as length of the growing season was reduced. The extent of exposure in late-melt zones, though, was insufficient for these species to produce mature seed.

In contrast to changes in flower times showed by some grass species, the growth rates of Arctagrostis leaves did not appear to adjust to length of exposure. Although growth was slower in the presence of cold melt-water, leaves in unsaturated conditions did not have significantly different rates of elongation despite

differences in exposure of 2 or more weeks. Upon release from snow or melt-water flow, growth rates averaged 0.7 cm/day until leaves were within 2-4 cm of maximum growth. Delays due to late exposure reduced leaf heights from an average of 24.1 cm in upper mesic zones to 17.7 cm at the edge of upper late-melt vegetation. A. latifolia, which averaged 35 cm (maximum 61 cm) in meadows adjacent to the upper willow zone, was reduced to 5 cm in height at the edge of hydric late-melt areas (Appendix 12).

A. Regional Climate

Microclimate, or climate near the ground, varies between locations due to the modification of regional climate by such site characteristics as topography, vegetation and moisture regime. In order to characterize a particular microclimate, it is important to assess the degree to which measurements for one site are unique to that physical setting, common to other sites of a similar setting, or can be used to characterize all microclimates in an area. Furthermore, as climate is variable through time and space, one must determine if observations fall within climatic norms, or represent abnormal conditions. In the study of environmental gradients, it is important to determine whether or not the yearly variations in regional climate and subsequent microclimate responses are greater in magnitude than the range of values obtained across a gradient during any one year.

The climate of the Richardson Mountains is poorly documented. Detailed records have been kept by the Atmospheric Environment Service, Environment Canada, for Inuvik, Aklavik, and Fort MacPherson in the Northwest Territories, and for Shingle Point in the Yukon Territory, but all these locations lie outside the foothill zone of the Richardson Mountains. Summaries and interpretations of available climatic records have been made by Thompson (1967), the Meteorological Branch, Department of Transport (1970), and Burns (1973, 1974), but their values for the mountainous regions were derived by extrapolation. The only existing data on the Richardson Mountains were recorded by Lambert (1968) at Canoe Lake, Northwest Territories. His records are limited to air temperature and relative humidity over two months in 1966. Further visual weather observations were made in 1965 and 1966.

As records for Aklavik ceased in 1960 and those for Fort MacPherson and Shingle Point had many missing values, Inuvik represented the only station close to the Richardson Mountains with continuous weather records. Assessment of the normality of the climate during 1971-1973 was made by averaging Inuvik data between 1959 and 1973. Data collected in the Canoe Lake area were compared to weather records for Inuvik. As prior microclimatic studies have been based on data from subarctic stations (Drew and Shanks, 1965; Gill, 1973; Smith, 1975) as well as sites on the Arctic Coastal Plain (Benson, 1966, 1969; Brown et al, 1975; Bunnell et al, 1975), the High Arctic Islands (French, 1971; Williams, 1975) and alpine areas

(Klikoff, 1965; Bliss, 1966; Gardiner, 1969; Kuramoto and Bliss, 1970; Douglas, 1972; and, Graf, 1976), it was important to characterize the regional climate of the Richardson Mountains before climatic and biological data from Canoe Lake could be compared to results from other subarctic, arctic and alpine areas.

Table 26 presents a summary of significant variations from climatic means during the years of study, as well as significant differences between Canoe Lake sites and Inuvik. Weather patterns generally fell within climatic norms except for snowfall, which was abnormally heavy in the winter of 1971-1972. Wind speeds recorded at Canoe Lake were comparable to those at Inuvik. Summer precipitation was double that recorded at Inuvik over the same period of time. Winter snowfall, not recorded at Canoe Lake, was estimated to be in the range of 200-400 cm. Air temperatures, although not differing significantly from those of Inuvik due to large standard deviations, averaged 3.3°C warmer in winter and $1.2\text{-}2.7^{\circ}\text{C}$ colder in summer (Tables 4 and 9), reflecting mean lapse rates for the region of $-2.7^{\circ}\text{C}/300\text{ m}$ in winter and $+1.8^{\circ}\text{C}/300\text{ m}$ in summer (Burns, 1973).

Climatic variations recorded at Snowbed #1 between 1971-1973 determined differences in the length of the thaw season: air temperatures for August, 1971, were colder than either 1972 or 1973; the end of July, 1973, was warmer than 1971 or 1972; and May 15-31, 1973, was warmer than the same time period in 1972. Precipitation and windspeed variations throughout the summer corresponded to the passage of major storms e.g. June 16-30, 1972 was windier and wetter than in 1973 due to a major storm in the area from June 25-29. These climatic variations set the basis for extreme differences in some microclimatic patterns between the three years of study.

Table 26

Summary of Weather, 1971-1973

Significant Differences* (between 2 week or monthly averages)	Climatic Factor				
	Wind Speed	Precipitation.		Air Temp	
	Mean Daily	Snowfall (Sept-May)	Monthly Snowfall	Total May-Sept	Mean Daily
A. Inuvik vs Climatic Mean					
1971-sig. higher	none	no	October	none	June
-sig. lower	none	no	none	none	none
1972-sig. higher	none	yes	September	none	none
-sig. lower	none	no	none	none	none
1973-sig. higher	none	no	none	none	September
-sig. lower	none	no	none	none	none
B. Inuvik vs Snowbed #1					
1971-sig. higher	none				none
-sig. lower	none				none
1972-sig. higher	none			none	none
-sig. lower	none			May-Sept., June, July	none
1973-sig. higher	none			none	none
-sig. lower	June-ridge			May-Sept., July	none
C. Snowbed #1					
1971 vs 1972					none
-sig. higher					August 1-15
-sig. lower					none
1971 vs 1973					July 22-31
-sig. higher					August 1-15
-sig. lower					July 1-15
1972 vs 1973	June 16-30				May 15-31,
-sig. higher	June 1-15			June	July 16-31
-sig. lower	July 16-31			July	

*Significant differences at 95% confidence levels

B. Microclimatic, Soil and Vegetation Patterns along Snow Depth Gradients

Late lying snowbeds are a common feature in arctic and alpine regions (Bird, 1967; Embleton and King, 1968). Comprehensive work in Alaska by Benson (1966, 1969) has shown that the size and shape of drifts formed by prevailing winds varies little from year to year. Deep snow accumulations, several kilometers long, up to 20 m wide and 6-8 m deep, form along the edges of rivers and lake banks, in small valleys, and in any other topographic depression large enough to hold snow. Small gullies are nearly drifted in with snow during years of heavy snowfall.

Deep snow accumulations are also a common feature in the northern Richardson Mountains, forming in depressions greater than one meter deep, in narrow creek gullies, on southerly to easterly-facing stream banks, and on SE-facing lee slopes. As long as the prevailing wind direction (NW) remains unchanged, snowbeds occur year after year in the same topographic locations, occupying the same surface areas as limited by surrounding topographic features. Many snowbeds, found in narrow stream valleys completely buried with snow each year, vary little in amount of accumulated snow. In contrast to these snowbeds and to Benson's findings (1966, 1969) in Alaska, snowbeds on lee slopes in the Canoe Lake area can vary by as much as 50% in volume, with snow depths reaching maximums of 5-8 m during years of unusually high snowfalls. During these years, lee drifts may extend on to ground which is normally snowfree in winter, as shown in Figures 2A and 2B.

Variations in the distribution of snow cover form the patterns of winter microclimatic conditions. Important differences exist between sites with deep snow covers and snow-free or snowpatch environments.

Snow is an excellent insulator. Comparable to data from other arctic and mountainous areas (Dahl, 1956; Bergen, 1968; and Benson, 1969), temperature gradients within the first meter below the snow surface can be very steep (Figure 5), with temperature oscillations in the snowpack decreasing with depth. The snowbed winter microclimate, under 2 or more meters of snow, offers a stable environment of near-freezing temperatures with limited fluctuations (Figure 6). In comparison, snow-free terrain is subjected to severe cold, extreme temperature oscillations, and

the full force of winter winds. Snowpatches, although sheltered from winds by shallow snow covers, also experience severe frosts.

Ablation of the winter snow cover is an important process in determining the microclimatic characteristics of sites during the thaw season. Ablation patterns define the boundaries between exposed, snowpatch and snowbed micro-environments. Modification of the snow cover begins in winter with redistribution of snow by wind, and by the melting of snow and formation of ice layers during influxes of warm Pacific air. The early appearance in spring of the ground surface on ridges and windward slopes is primarily the product of snow removal throughout the winter. Intermittent snow cover over snowpatch and hummocky terrain may also disappear before the main spring thaw through melt and sublimation enhanced by continuous daylight, wind and unequal heating around vegetation protruding through snow (Trabant et al, 1969). Comparable to results in other arctic areas (Saville, 1972, Benson et al, 1975), the low albedo of exposed tundra or snowpatch vegetation at Canoe Lake allowed heating which raised surfaces above 0°C when air temperatures were still at freezing. Growth is able to commence in chionophobous plant communities 2 to 4 weeks before snow begins to melt in snowbed areas.

When daily average temperatures rise above 0°C at the end of May, ablation is accelerated. Variations in ablation rates occur both between years and within each snowbed basin. As shown in Figures 7A, B and C, a snowbed does not always melt out in an identical pattern or at the same time each year. These differences are due to variations in winter snowfall, drift patterns and summer weather conditions. Similar snow depths on different slopes within the same snowbed do not necessarily complete melt at identical dates due to variations in albedo, radiation and physical removal of snow by creek runoff. The length of each melt season is determined by the return of cooler temperatures and reduced incoming solar radiation at the end of July to early August. Ablation normally stops altogether in September with the onset of below-freezing temperatures, new snow and short hours of daylight.

Above-ground climatic differences between snow-free, snowpatch and snowbed areas are not pronounced in the Canoe Lake area. As summarized in Tables 9, 11 and 13, air temperatures, relative humidity and precipitation vary little between slopes of different aspects and wind regimes. The dominant influence on these three characteristics

is the frequency of major weather systems passing through the region. Within the snowbed basins, average weather conditions over length of exposure, such as air temperatures, percent days with precipitation and daily incoming solar radiation, do not show significant variations between sites melting out during June and July, as shown in Figure 11. Variations in above-ground climatic factors such as total incoming solar radiation and total precipitation between similar slopes in all but the latest melting zones are the product of differences in number, not quality, of days exposed. This is in contrast to snowbeds in the alpine-subalpine zone of the Western United States where changing weather conditions through June and July have significant impacts on microclimatic conditions (Billings and Bliss, 1956; Kuramoto and Bliss, 1970).

Microclimatic, soil and vegetation patterns in snowbed basins during the summer are influenced both by length of exposure and topographic differences between sites. As summarized in Figure 17 and Table 27, topographic location within the snowbed basin also determines patterns of runoff. Those zones in lee snowbeds which lie downslope to the melting snowbank are subjected to flow of cold melt-water as long as the retreating snowbank remains upslope from them. Some of these zones, also subjected to runoff flow from precipitation and groundwater springs after the snowbank has melted, experience hydric soil conditions over most of their exposure. In contrast, the upper slopes of lee snowbeds and snowbeds confined to gullies where the retreating snow is downslope from exposed vegetation, are not subjected to flow of melt-water runoff. Although hydric zones in lee snowbeds represent an extreme in water availability, variations in soil moisture which could exist in snowbed basins due to differences in slope and drainage are lessened by the wet, cloudy weather typical of most summers in the Richardson Mountains. During limited sessions of warm weather, the upper surface of the ground can dry out, but such conditions seldom persist beyond 3-4 days duration during the growing season (Appendix 10). In normal years, high frequencies of rain, snow, and fog provide moisture at frequent intervals. Only during unusually dry seasons would deficiencies in soil moisture limit growth in upper snow-

Figure 17. Map of Vegetation
and Drainage Patterns,
Snowbed #1

See Table 27

Table 27

Summary of Vegetation Zones
Snowbed #1

No.	Name	Vegetation Community*	Plant Cover (%)	Slope (°)	Aspect	Expo- sure (a) (1973)	% days with (b) runoff
1	Lower Ridge	Lupino-Dryadetum alaskensis	60-80	5-10	S	92	0
2	Hummocky Terrain	Vaccino-Betuletum glandulosae	90-100	0-10	S or NNE	92	0
3	Transition	Betulo-Chamaemoretum-alnetosum crispae	100	10-20	S	78	0
4	Snowpatch	Betulo-Eriophorum to Betula- Chamaemoretum	100	0-10	S	80-78	0
5	Upper Birch	Vaccinio-betulosum glandulosae	100	10-15	SE	85-78	0
6	Upper Willows	Salicetum pulchrae	100	2-15	SE	73-71	0
7	Upper Mesic Meadow	Salicetum Chamissonis	100	20-30	SE	66-56	0
8	Upper Meadow	Affinities with Salicetum Chamissonis	80-100	30-45	S-SSW	68-51	0
9	Upper Late Melt	Salicetum pseudopolaris	3-40	20-40	S-SE	50-35	0
10	Hydric Late Melt	Salicetum pseudopolaris	0-20	0-5	S	50-35	100
11	Lower Hydric Meadow	Affinities with Salicetum Chamissonis	90-100	0-8	S	61-49	100
12	Lower Mesic Meadow	Salicetum Chamissonis	100	0-10	S	66-49	25
13	Lower Willows	Salicetum pulchrae	100	0-10	S	71-61	100
14	Creek Meadow	Affinities with Salicetum Chamissonis	100	0-5	S	66-56	0
15	N-facing Slope- Snowpatch	Betulo-chamaemoretum to Vaccino-Betuletum glandulosae	80-100	30-45	NNW- NW	78-62	0
16	Exposed broken bedrock	Colluvium	0	45	NW	92	0
17	Exposed	Lupino-Dryadetum alaskensis	20-40	5-10	NNW	92	0

* - based on Lambert (1968).

a - between May 15-August 15

b - from upslope melting snow or ground water seepage; data from 1973

bed plant communities. This is in sharp contrast to studies in alpine areas of the Western United States where yearly drought on upper slopes in July is an important characteristic of snowbed environments (Billings and Bliss, 1959; Klikoff, 1965; Chabot and Billings, 1972).

Topographic differences and length of exposure in snowbed basins define the amount of energy available for plant growth. Variation in absorbed solar radiation at ground level is the product of slope angle, aspect, and surrounding topography, rather than albedo, which changes little between vegetation types. As shown in Figure 8, on sunny days, snowbed meadows on steep SE-facing slopes receive higher intensities of incoming solar radiation than adjacent snowpatch or hummocky terrain lying on gentler slopes, or than northerly-facing slopes which often do not receive direct sunlight. Differences between slopes are decreased under conditions of thick cloud cover or fog. Differences in the total amount of energy received during the thaw season for similar slopes or sites on the same slope are a function of length of exposure. For example, in 1973, on the upper SE-facing slopes of Snowbed #1, an upper meadow site exposed on June 12 received $31,500 \text{ cal/cm}^2$ compared to $17,800 \text{ cal/cm}^2$ for the late melt zone on the same slope exposed on July 9. This decrease in available energy corresponds to a drop in percent plant cover across the snowbed basin.

Topographic location in the snowbed basin determines the wind regime of each site. As illustrated in Figure 10, winds decrease by 30-40% between exposed ridges and lee slopes, and by as much as 500% between exposed ridges and gullies. The upper borders of willows around snowbeds correspond to sudden drops in topography and subsequent rapid decreases in wind speeds. In snowbeds where a sudden drop in topography is absent, an upper willow band is either missing or restricted to a limited number of scattered bushes. Within snowbed basins, winds average less than 5 km/hr over the first 5 meters downslope from the upper willows, in the lower band of willows and in creek meadows to the lee of these willows. Speeds average 5-10 km/hr in the central portion of the basin and seldom exceed 10-15 km/hr. Plant cover within snowbed basins is not exposed to the high summer wind speeds, in excess of 50 km/hr during some storms, that are experienced by vegetation on exposed ridges.

Physical and chemical characteristics of soils along the snow depth gradient are also a function of topographic location. The boundaries between the three snowbed soils identified by Lambert (1968) are not always distinct within snowbed basins. Soil characteristics occur in gradients across snowbeds, reflecting changes in vegetation, slope, runoff patterns, erosion rates and snow debris deposition. The transition from arctic brown to meadow tundra and regosolic soils is influenced by the same snow-related factors which regulate microclimatic changes between snow-free, snowpatch and snowbed environments.

As noted in many other arctic-alpine studies (Warren Wilson, 1958; Powell, 1961; Savile, 1961; Brassard and Longton, 1970; Teeri and Barrett, 1975), the development and fertility of snowpatch and snowbed soils appear to be influenced by wind-blown dirt and organic debris which becomes incorporated into snowdrifts and is deposited on the ground when the snow melts. In the Canoe Lake area, comparable to results in other arctic and alpine sites (Osburn, 1963; Teeri and Barrett, 1975), the rates of accumulation and composition of snow-debris can vary, both between and within snowbeds, reflecting the characteristics of source areas for the detritus and drift patterns in the snowbed. As suggested by Oswald (1963), the greatest amount and most easily removed organic litter is available in autumn, as that remaining by spring is either firmly attached to plants or buried under snow. In Snowbed #1, the zone of highest debris accumulation, 84.1 g/m^2 average, corresponded closely to the lip of the snowdrift in November. Another zone of high accumulation in the lower meadows, $21.2\text{--}23.0 \text{ g/m}^2$ average, corresponded to the lower edge of the snowdrift from December to May. Debris was also noted being washed into this area in the summer from hydric late melt zones. Annual input of organic snow debris along the late melting bases of 4 snowbeds averaged 234 g/m^2 , compared to a maximum value of $23 \text{ g/m}^2/\text{year}$ obtained by Teeri and Barrett (1975) in a snowbank on Devon Island. Their source areas for detritus, though, were limited to narrow beach ridges in comparison to the large, 400-700 m high ridges and well-vegetated hummocky slopes that lie above the snowbeds studied in the Canoe Lake area.

Yearly accumulations of inorganic snow debris average 90.8 g/m^2 in late melt zones. Mineral contents of snow debris varied widely depending upon the degree of vegetation cover on slopes above the snowbed. An average of 83% of the mineral content of snow debris samples was sand-sized. The incorporation of predominantly sand-size particles into snowbed soils, although aiding drainage and aeration characteristics, has a minimal effect on soil fertility and water retention capacities, due to the inert characteristics of the quartzose sand particles themselves. If an average of only 17% of the mineral fraction of debris samples is silt to clay-sized, accumulations of these particles in late-melt zones would be in the range of $13 \text{ g/m}^2/\text{year}$. Deposition at this rate over the 10,000 years since the last glaciation (snowbed basins were most likely snow-filled during the cold temperatures of the Wisconsin--Barry et al, 1975) would result in 130 kilograms of silt and clay-sized particles, as well as 780 kilograms of sand, being deposited per m^2 at the base of snowbed basins. At an estimated silty loam bulk density of 1.6 g/cc or 16 kilograms in an area 1 m^2 by 1 cm deep (Buckman and Brady, 1969), total deposition, without removal by erosion processes, would have resulted in an accumulation of 57 cm of inorganic snow debris particles over the last 10,000 years. Actual depths of soil in the lower zones of Snowbed #1 are similar to this value, ranging from 39-95 cm of mineral soil over stream-washed rocks and gravel in the lower meadows and 68 cm of mineral soil at the lower edge of the hydric late-melt zones.

Disruption of soil horizons can occur due to the activities of such animals as arctic ground squirrels. Studies in the Ruby Range of the southern Yukon (Price, 1971) have shown that the volume of material removed from ground squirrel burrows each year can reach 36 g/m^2 on over-wintering slopes. Although the densities of burrows around Snowbed #1 averaged 16% of those in the Ruby Range, the impact of burrowing activities is important for scattered locations where 3-7 burrows occur in close proximity. Burrowing activities can also cause slope instability by production of tunnels which may be used by melt-water flow during runoff, and by weakening of the soil structure (Price, 1971). Soil particles pushed to the surface are easily removed by erosion. Ground squirrel holes in the Ruby Range occur most frequently in snowbed plant communities at the fronts of solifluction lobes, similar to Canoe Lake snowbeds where most burrows occur in well-drained, SE-facing snowbed meadows. The greatest impact from burrowing activities is within these zones, with soil particles

being washed downslope into late-melt areas.

Other processes affect the accumulation and removal of soil materials in snowbed basins. "Nivation," a term introduced by Mathes in 1900 to describe processes associated with a patchy alpine snow cover, includes both movement of the snow itself and snow-related impact on surrounding terrain (Embleton and King, 1968). Although not directly measured in Canoe Lake snowbeds, many erosional processes associated with snowbeds are worth noting, as they aid in understanding important processes in the formation and distribution patterns of snowbed soils. Movement of large stones can occur during snow slippages on steep slopes (Bird, 1967; Costin et al, 1973). Freeze-thaw cycles along the edges of melting snowbanks sort materials, with coarse particles moving up and fines moving down. The degree of sorting, as manifested by uprighted stones and stone stripes, increases as moisture increases and plant cover decreases (Benedict, 1970). The slow flow of saturated materials downslope over permafrost layers, "solifluction," is a common process in the Arctic. Solifluction rates increase downslope from snowbeds, with movements up to 25 cm in spring as saturation by melt-water reduces the internal friction and cohesion of snowbed soils (Williams, 1962). Snow-melt runoff and ground-water carry debris away from snowbeds through rill erosion across bare ground, and by gullying in unconsolidated material. Mudflows and slumping during or soon after heavy rains or runoff occur along steep changes in topography which often accompany snowbank formation (Lambert, 1968; Price, 1969). Asymmetry in snowbed gullies and basins results from increased erosion processes on snow accumulation slopes, which, through movement of colluvium and aeolian deposits downslope, force stream flow against opposing banks (French, 1971).

Snowbeds in the Canoe Lake area showed the effects of erosion processes, for example, two small mudflows occurred at Snowbeds #1 and #2 during the years of study. Several large slide scars at Snowbed #1 showed extension of the basin into former snowpatch or tundra zones. Asymmetry of snowbed basins was common throughout the area. Along drainage pathways, snow accumulated on 20-30°, SE-facing slopes, with creeks flowing against steep, 35-40°, W to NW-facing snowfree banks. The erosion processes associated with snowbeds in the Richardson Mountains have led to a gradual widening of snowbed basins towards the SE,

with a lowering of slope angles on the N sides of basins as upslope material erodes into late melt zones.

The physical and chemical characteristics of soils along the snow depth gradient reflect the patterns of deposition and erosion of inorganic and organic material. Soils on exposed ridges, subjected to removal of organic material and fine soil particles, show little development of soil structure - the major portion of material at all depths is rock. Soil in snowpatches, protected from erosion by wind, has thick organic mats over variable mineral layers that, in deeper snowpatches, show some deposition of silt and clay-sized particles. The mineral layers of all snowbed soils are dominated by large rock fragments. On upper slopes, the stones are sandstone colluvium, but in lower meadow and willow zones, they are a solid layer of rounded creek gravel. French (1971), from work on Banks Island, suggested that meadow soils are formed by upslope material progressively overriding streams at the base of snowbed gullies, forcing flow against steeper opposing banks. The same process appears to have taken place in the Canoe Lake area.

Interpretation of the gradients of sand to clay-sized particles across snowbed basins is difficult. Compared to soils on exposed ridges which develop directly on weathered sandstone and show a high percentage of sand at all depths, some snowbed sites, especially those in lower meadow zones, show increased silt and clay-sized fractions in the organic-mineral and mineral layers. Both deposition of snow debris and movement of material by runoff into these zones is similar to the results in alpine areas (Osburn, 1963; Kuramoto and Bliss, 1970). In these studies, lower meadow communities acted as concentrators of organic, mineral and radioactive fragments when material was trapped on thick vegetation mats.

The chemical composition of the sand to clay-sized fraction reflects both bedrock characteristics and low chemical weathering rates in the Canoe Lake area. Although the sandstone bedrock forming the ridges around Canoe Lake disintegrates easily, it releases up to 80% quartzose sand grains by volume, with the remainder being iron oxides and clay-sized particles (Lambert, 1968). The clay-sized fraction found in soils across the snow depth gradient is composed primarily of quartz-rock flour (Chao, personal communication), which is not a clay mineral and is not active in chemical processes. Chlorite, a weathering product of mica, is not present in snowbed soils, but kaolinite, formed by the decomposition

of silicates under acidic conditions; is present in only minor quantities. The greatest percentage of snowbed soils is composed of inert rock, sand, silt and rock flour, with only very small quantities of chemically active clay minerals. The nutrient content of soils reflects this--cation exchange capacity and concentrations of cations are directly proportional to the amount of organic material throughout soil horizons. The organic content of soils in the Canoe Lake area rises along moisture gradients, with decreasing drainage accompanied by accumulations of peaty material (Lambert, 1968). As shown in Table 22, snowpatch soils have thick organic mats and high nutrient values, compared to snowbed soils which are characterized by low surface organic contents. If decomposition rates were the sole reason for lack of organic mats in snowbed soils, then organic accumulations should form under the anaerobic conditions of hydric lower meadows. Surface mineral contents are high in these soils (66-77%). Significant amounts of mineral material deposited from snow debris and erosion, accompanied by predominately herbaceous growth, help maintain lower organic contents in snowbed soils. Organic horizons become less discernable as length of exposure and vegetation cover decrease towards the center of snowbed basins. Late melting zones average 16-19% organic content in surface horizons, much of this being wind-blown organic debris instead of local litter.

Despite the lower organic content of snowbed soils, the nutrient values are comparatively high. Accumulations of wind-blown debris, such as recorded in the Canoe Lake area (Table 20), are known to increase the fertility of the snow basin soils (Kuramoto and Bliss, 1970; Teeri and Barrett, 1975). Movement of cations into snowbed basins can also occur in surface runoff from tundra vegetation and ground-water springs as shown in Table 25. Price (1971) and Bunnell et al (1975) have suggested that soil nutrients are built up through the activities of ground squirrels and microtines which utilize snowbeds in the autumn and winter. These patterns of nutrient enrichment as well as soil organic contents are reflected in cation exchange capacity values and cation levels across the snowbed basin. The highest values are normally found in the upper willow band, with the highest values for meadow zones found in the upper meadows.

Patterns of soil nutrients are not always reflected in vegetation growth. Although snowpatches have higher soil nutrients than snowbed meadows, total net primary productivity is similar, averaging 96 and 95 $\text{g/m}^2/\text{year}$ respectively (Table 19). As suggested by Billings and Mooney (1968), energy and nutrients in snowpatch vegetation are only slowly released to the environment, being bound up in structural woody tissue, slowly decomposing plant remains, and mats of cryptogams. In comparison, nutrients in snowbed soils are made available quickly in spring, due to rapidly thawing, warm soils. Despite exposure 3-4 weeks later than snowpatch vegetation, snowbed meadows have faster rates of production ($2.2 \text{ g/m}^2/\text{day}$ compared to $1.2 \text{ g/m}^2/\text{day}$).

Within snowbed basins, both total and daily net primary productivity are influenced by length of exposure and flow of melt-water. In comparison to high values of daily production for wet sedge meadows in other arctic regions (eg. $2.8\text{--}3.4 \text{ g/m}^2/\text{day}$ in Devon Island - Bliss, 1975), sedge-dominated lower snowbed meadows in the Canoe Lake area recorded only $1.7 \text{ g/m}^2/\text{day}$. The lower value, as illustrated in Figure 12, is due in part to the suppression of growth by cold melt-water over the plants for most of the growing season, similar to results by Holway and Ward (1963). The highest productivity averages in the Canoe Lake area are found in meadows along creek banks, where a combination of shelter from wind, potential nutrient enrichment, snow removal by runoff in spring, and a long growing season allow an average productivity of $257.6 \text{ g/m}^2/\text{year}$ and $5.0 \text{ g/m}^2/\text{day}$. Similar to observations by Price (1971), high values also occur near nutrient enriched ground squirrel burrows ($192.3 \text{ g/m}^2/\text{year}$ and $3.2 \text{ g/m}^2/\text{day}$). The lowest values ($3.6 \text{ g/m}^2/\text{year}$ and $0.2 \text{ g/m}^2/\text{day}$), comparable to those of arctic deserts (Bliss, 1975), are found in late melt zones with low plant cover and short exposure.

Total plant biomass along the snow depth gradient does not totally reflect the patterns of yearly productivity, but does correspond closely to topographic location. Snowpatches in the Canoe Lake area have standing crops in the range of $900\text{--}1,300 \text{ g/m}^2$, values similar to those listed in the literature (Wielgolaski, 1972; Rosswell and Heal, 1975).

As suggested by Mick (1967) and Heal (1972), reduced decomposition rates in the saturated cold soils of snowpatches allows biomass accumulation. In contrast, the build-up of organic material on exposed ridges is slow,

as much of the annual production is removed by winter winds (Savile, 1972; Svoboda, 1973). The biomass composition of vegetation under deep winter snow cover varies with length of exposure and flow patterns of melt-water runoff. Willow zones along the outer edges of snow basins, with lower above-ground productivity than some meadow zones, have the highest above-ground biomass values of any chionophilous plant communities (2404 g/m^2), similar to those given for other arctic or alpine shrub associations (Wielgolaski, 1972). Over 80% of living biomass in willow zones is composed of structural woody tissue. Twenty-five percent of the total biomass is dead organic. Biomass values are lower in shrub zones subjected to melt-water runoff, due in part to larger shrub sizes and wider spacing. Inward from these shrub communities, decreasing lengths of exposure are accompanied by decreasing above-ground biomass. Values for total above-ground biomass in snowbed meadows, $65\text{--}258 \text{ g/m}^2$, are lower than those for wet sedge meadows at Point Barrow (Bunnell et al, 1975) and on Devon Island (Bliss, 1975). Values for late melt zones, 3.9 g/m^2 in hydric and $3.5\text{--}38.9 \text{ g/m}^2$ in well-drained late melt areas, are comparable to those for arctic deserts with similar low plant cover values (Bliss, 1975).

The broad patterns of vegetation characteristics across the snow depth gradient are also a function of the changes in plant species within each zone. Of the 43 vascular species listed as members of the *Salicetum Chamissonis* snowbed association (Lambert, 1968), only 19% are woody, whereas 76% are herbaceous. In the *Salicetum pseudopolaris* late melt association, of 25 vascular species, 92% are non-woody. These figures support the suggestion by Billings and Mooney (1968) that herbaceous growth in the arctic environments minimizes energy losses to non-photosynthetic tissues and allows more rapid responses to changes in growing conditions. The large percentage of living biomass allocated to green, non-woody growth in snowbed plant communities permits daily productivity rates, which calculated over the length of the growing season (40-75 days), average as high as $5.0 \text{ g/m}^2/\text{day}$ (Table 19), exceeding values recorded for deserts, grasslands and some cultivated crops (Bliss, 1966; Kuramoto and Bliss, 1970). Lack of evergreen leaves in snowbed meadows does not necessarily indicate that such leaves would not be suitable adaptations for rapid spring development. This lack may be the product of the damp, relatively

warm conditions in snowbeds in winter which allow the development of smut on evergreen leaves (Bell, 1974). As most fungi require two or more arctic summers to complete their life cycles (Savile, 1972), deciduous leaves represent unsuitable hosts. The herbaceous nature of snowbed vegetation is reflected in the number of species with underground storage organs. Within chionophilous plant communities (Lambert, 1968), 68-92% of the total species have some form of rhizome, caudex or perennial storage tissue, with 63-93% of these organs occurring in the upper 5 cm of soil. As outlined in Table 17, above to below-ground biomass ratios are high in snowbed communities. Upper meadows, dominated by rhizomatous forb species, have 1:7 to 1:11 ratios, similar to the 1:9.3 value for Norwegian snowbeds (Wielgolaski, 1972). As snowbed soils are within 0.5 to 4.0° C of freezing during winter, underground storage organs are in above 0° C temperatures within 1-3 days of exposure. Such subterranean storage structures allow rapid development of photosynthetic and reproductive organs upon exposure from snow, an important adaptation in snowbed environments with reduced lengths of exposure (Kuramoto and Bliss, 1970).

Distinct vegetation zonation across snowbed basins result from overlapping distributions of individual plant species along snow-dominated microclimatic gradients. Changes in species composition often mark environmental boundaries beyond which a species is unable to adjust patterns of growth sufficiently to survive. Although some species of broad ecological tolerance are able to grow continuously along ecological gradients, with peaks in biomass reflecting optima for growth, others are unable to adjust to environmental limitations. Their distributions occur in distinct zones with "sharp" boundaries.

Snowbed associations in the Richardson Mountains are a mixture of circumpolar species with high genetic variability and wide ecological tolerance, as well as species of limited geographic and ecological distributions (Hulten, 1968; Lambert, 1968). Of 25 vascular species in the *Salicetum pseudopolaris* late melt association and 43 in the *Salicetum chamissonis* meadow association (Lambert, 1968), only 14 and 12 species respectively are restricted to snowbed habitats. The remainder occur in many chionophobous plant communities.

Species of willows are limited by form and phenological responses to distinct ecological niches, with only minimal overlaps, as shown in Figures 14 and 15. Prostrate species are distributed according to tolerance to winter damage and to decreasing lengths of exposure. Salix arctica, restricted to exposed sites, flowers and develops leaves before most snowbed communities are exposed. S. Chamissonis, on the other hand, can have a 65 day flowering period but is unable to survive either the exposure of ridges or the $\frac{1}{2}$ -1 month growing season of late melt zones. Although S. polaris subsp. pseudopolaris is found within late snow areas, its peak productivity occurs at the lower edge of upper meadows where competition with tall herbaceous plants and S. Chamissonis is reduced. Dwarf decumbant growth with subsurface branches allows S. polaris to grow in zones of limited length of exposure and unstable soils, but with reduced biomass compared to earlier melting sites. As suggested by Billings and Mooney (1968), maintenance of woody tissues becomes difficult as the length of the growing season and energy available for growth are decreased.

The tall shrub species, S. pulchra, similar to many other erect woody species (Savile, 1972), is unable to grow in snow-free sites due to winter wind damage to exposed branches. The height of woody growth is determined by both the degree to which stems will compress under the weight of snow (e.g. lower willows are compressed 50-150 cm by snow accumulation on branches) and by the depth of snow which drifts over erect and compressed plants. Erect woody growth provides structural stability and eliminates the need to grow supportive structures for photosynthetic or reproductive tissue each season, thus allowing development of flowers within 2-4 days and leaves within 10-14 days of exposure. The presence of erect woody shrubs within snowbed basins is limited in part by the physical properties of snow itself. Snow on steep slopes creeps downhill with sufficient force to bend steel rods (Costin et al, 1973). Snow movement at Snowbed #1 was strong enough to snap 3 cm diameter wooden rods placed as snow depth markers along the upper slopes of the snowbed and across the lower meadow. S. pulchra seldom occurred on slopes greater than 10° or under snow covers greater than 2 m.

Forbs show a diverse range of responses to snowbed habitats. Some species occur as sporadics from adjacent chionophobous communities, while others are highly adapted to living and reproducing under shortened growing seasons. For example, storage of food in underground rootstock, combined with herbaceous growth, allows Petasites frigidus to grow within widely varying environments. Lack of mature seed and low biomass values in upper and late-melt snowbed zones suggest that these environments represent marginal habitats for P. frigidus. Similarly, due to a set phenological pattern, Artemisia arctica in late melt zones normally does not produce flowers, although flower buds may be initiated. Lush growth in upper meadows, up to 80 g/m^2 , results from vegetative growth along runners which spread sterile rosettes outwards from one main parent plant. Biomass dominance of A. arctica within snowbed meadows does not depend upon sexual reproductive success.

Other chionophilous plants show contrasting adaptations to the snowbed environment, despite similar restricted distributions within areas of deep snow accumulations. Dodecatheon frigidum, occurring only on well-drained slopes, is able to flower and set seed within 35 days of snow melt if exposed in June, but is unable to set mature seed if exposed after July 1st. Carex podocarpa and C. lachenalii, whose flowering times vary between June 26-August 21 and July 7-August 29, are also unable to set mature seed if exposed after July 1st. In contrast, forbs such as Ranunculus pygmaeus, R. nivalis, Oxyria digyna, Antennaria monocephala and Saxifraga rivularis are able to set mature seed within even the latest melting zones. Growth is rapid upon exposure, with flowering occurring from 6-14 days after snow melt. These species, similar to other arctic-alpine plants (Savile, 1972; Bell, 1974; Bell and Bliss, 1977), develop buds to an advanced state in autumn and retain semi-evergreen leaves throughout the winter. The maintenance of both is possible under a protecting snow cover and near-freezing ground temperatures. Winter-green leaves allow immediate photosynthesis upon exposure, whereas well-developed buds permit rapid initiation of floral and leaf growth. Although growth of arctic and alpine plants under snow cover has been reported by several authors (Billings and Bliss, 1959; Powell, 1961; Kuramoto and Bliss, 1970; and Bell, 1973), vegetation in Snowbeds #1, 2 and 3 did not initiate growth until after exposure, similar to plants in other arctic environments (Svoboda, 1972).

Many phenological responses to snowbed environmental gradients recorded in the Canoe Lake area are similar to those reported for other arctic and alpine areas. Comparable to results by Holway and Ward (1963), Svoboda (1973) and Fareed and Caldwell (1975), timing and duration of phenological events are closely related to length of exposure and presence of melt-water. Similar to Holway and Ward (1963), the presence of melt-water can slow plant development by as much as 20-25 days. Growth rates of chionophilous species are also reduced by periods of near-zero temperatures (for example, June 22-26, Figure 16), but they are similar to most arctic and alpine plants in that they are able to tolerate freezing temperatures during the growing season and continue to flower and set seed (Bliss, 1966; Savile, 1972). Development is not uniform over the summer. Rapid spring growth in early exposed plants often ceases by early July, but, in contrast to findings in many alpine studies (Klikoff, 1965; Bliss, 1966; Rochow, 1969; Canaday and Fonda, 1974), the same species, such as Artemisia arctica and Arctagrostis latifolia, can show high growth rates to the end of July in later melting zones. Reduction of growth in earlier exposed plants does not correspond to summer drought conditions, as found in alpine meadows (Billings and Bliss, 1959; Klikoff, 1965; Rochow, 1969; and Canaday and Fonda, 1974), but may correspond to translocation of carbohydrates to rhizome-root systems, as suggested by Bliss (1966) and Canaday and Fonda (1974).

As suggested by many authors (Dahl, 1956; Gjaervoll, 1956; Holway and Ward, 1963; Kuramoto and Bliss, 1970; Canaday and Fonda, 1974), and confirmed in this study, the snowbed environment has several advantages over exposed sites: plants are protected against wind damage both summer and winter; soil temperatures are close to freezing in winter; vegetation is not exposed to freeze-thaw cycles in autumn and spring; soils are enriched by wind-blown debris and runoff water; and ground temperatures are warm. Several environmental factors, though, represent significant limitations to growth within snowbeds: flow of cold melt-water in hydric zones, which saturates soil horizons and lowers soil temperatures; decreases in length of exposure towards the center of snow basins; increases in erosion processes in late melt and hydric zones; deterioration in growing conditions after the end of July; and significant variations in growing season length from year to year. Decreases in total

biomass and total net primary productivity along the snow depth gradient reflect the diminishing adaptive advantages of residing in snowbed environments as winter snow cover exceeds 2 meters in depth. In order to understand the relationship between gradients of microclimate, soil and vegetation within a snowbed basin, one must consider the stability of both the snowbed environment and the vegetation/soil patterns within snowbeds. Zones that exist under the climatic conditions of this decade are not only a product of those conditions, but also reflect events in the past that have influenced the size, melt patterns and ablation rates of snowbeds.

C. Variability of the Snowbed Environment and Its Effects on Snowbed Plant Communities

Areas of deep snow accumulation are sensitive to short and long-term fluctuations in climate (Embleton and King, 1968). Snow basins or nivivation hollows become the nuclei of snowfield and glacial build up with deteriorating climate (Graf, 1976). Under conditions of increased winter snowfall and warmer winter air temperatures, but decreased summer temperatures, the boundaries and duration of snowbanks expand (Bradley, 1973; Williams, 1975). During the Little Ice Age of the 17th to 19th centuries, extensive snowbanks covered sections of the Arctic Islands, a result of only minor summer cooling by 1.5°C and a doubling of winter snowfall (Barry et al, 1975).

Snowbeds in the Richardson Mountains show the same sensitivity towards oscillations in climatic conditions, but fluctuations in size are dependent upon snowbed type. Variations in area and volume are infrequent in those snowbeds formed by burial of topographic hollows such as narrow drainages. Surrounded by windswept terrain, snow depths are virtually independent of snowfall, similar to snowbeds studied by Canaday and Fonda (1974) and Benson (1969). In contrast, snowbeds formed along lee slopes can change by as much as 50% in volume, extending into low snow zones during years of heavy snowfall. Snow depths in lee snowbeds, a function of winter snowfall and wind patterns, are sensitive to any change in wind or precipitation characteristics of a region.

All types of snowbeds show significant variations in melt rates and patterns, a function of snow deposition patterns, snow type, summer weather conditions and spring runoff characteristics. Delays in spring melt are subsequently expressed by shortened exposure lengths across snowbeds. Variations in length and timing of exposure affect other micro-climatic factors in snow-dominated environments such as active layer depths and ground temperatures. Snow melt completed after mid-July exposes the ground to conditions of decreasing intensities of incoming solar radiation, lower air temperatures, and increasing precipitation and storm frequencies. Rates of ground thaw and plant productivity are reduced under such conditions. The timing of autumn snowfalls determines the length of exposure for plants and soil, not only to growth or thaw conditions, but also to sub-zero temperatures which may precede the establishment of an insulating snow cover. If temperatures are maintained below freezing

without a snow cover over snowbed basins, active layers can be reduced by as much as one-third the following summer, with late melt chionophilous plant species being exposed to freezing temperatures much below those normally experienced.

Plants growing in snowbed environments are faced with significant fluctuations in snow depth, timing and length of exposure, soil temperature characteristics and summer climatic conditions, yet, visually, snowbed communities appear to occur in well-defined zones. In actual fact, vegetation zones within snow-dominated environments oscillate with climatic change. Broad or minor shifts in community boundaries are proportional to the severity of the climatic perturbation.

The outer, upper, shrub borders of snowbed basins, which are found both in alpine and arctic snowbeds in North America (Billings and Bliss, 1959; Britton, 1967), are defined by topographic features which allow snow accumulation. These boundaries undergo little change. Shrub heights correspond to depth of snow cover, with growth rings often being compacted on windward NW sides. Willows in upper zones around Canoe Lake snowbeds averaged 123 years old, with large branches between 10-50 years. The edges of upper willow zones bordering on upper meadows normally correspond to steep changes in slope. Many dead branches and scattered dead and living bushes extend up to 5 m into meadow zones, suggesting previous extensions of willow borders into herbaceous snowbed communities when winter snow covers were decreased and/or snow melt was accelerated by one week or more. Sections through the 22-year old stem of one dead bush showed 14 years with an average year increment of 1.08 mm, followed by 7 years with an average yearly increment of 0.54 mm, indicating deteriorating growth conditions before death. In contrast, recently established young shoots 3-8 years old, suckers off adjacent Salix pulchra bushes, grew in dirt around ground squirrel burrows 2 m from present willow borders.

Delays in exposure or increases in snow cover are less likely to be as severe in willow zones along creek banks or the upper borders of lee snowbeds, where snow depth increases would be limited by wind removal of snow past a certain height, than in lower willow zones of lee snowbeds. Here, extensions of the main drift can drastically affect vegetation communities. In 1972, a total winter snowfall 152% greater than normal extended snow at depths of 5 m into lower willows. Melt was not until the middle to end of July in affected areas (compared to a normal exposure date

of June 7). In contrast, a patch of willows was buried under only 100-130 cm of snow in 1972-1973, leaving branches up to 80 cm high protruding above the snow surface. Due to low wind speeds in the basin, few branches were damaged, although many of the buds were eaten by overwintering ptarmigan.

Persistence of either low or high snow cover values would modify the boundaries of lower willow zones. Within major groves, lower willows averaged 97 years old, but most large stems were centered with wood rot. Larger branches peaked at 3 years of age, with the majority between 20-45 years. The boundary between lower willows and meadow communities is not as distinct as along upper slopes. Scattered small shoots averaging 5 years old and with well-developed root systems, as well as live and dead bushes 20 or more years old, extend 5-15 m into flat lower meadows.

Lower willow zones show evidence of considerable fluctuations in past extent. Continuation of melt seasons such as 1971 would allow extensions of willows, either by suckers or seeds blown in from upper willows, into meadow communities, whereas persistence of conditions such as during 1972 would eliminate many bushes. Total annihilation of Salix pulchra within snow basins would not lead to extinction of the species, as this plant is able to grow at reduced heights in hollows between hummocks and in small snowpatches. Only under the most severe climatic changes would snow remain in these sites, which normally require only 1-2 weeks to melt. Re-establishment back into snow basins would most likely occur through seed deposited in snow debris or blown into basins during late-summer storms.

In contrast to willow borders, shifts in the distribution of herbaceous snowbed plants do not leave as obvious a legacy as dead bushes. Past shifts in distribution are suggested by the distinct distribution of species along snowbed gradients, with late-melt plants extending outward into predominantly meadow communities and meadow species occurring sporadically in late melt zones. Should delays in exposure, such as in 1972, persist, late melt species would most likely increase in predominance in meadows where exposure was consistently limited to 1½ months or less. The abilities of some of these species to telescope phenological events, flowering and setting mature seed in less than one month, would allow them to colonize areas where meadow species, unable to complete reproductive cycles, would die out. The ability of late melt chionophilous species to withstand extreme

cold is not known, although they are similar to many arctic-alpine plants in their tolerance of sporadic freezing temperatures in summer and autumn. If intolerance to prolonged sub-zero temperatures is a limitation, then these species would require a minimum snow cover of 2 meters. With present climatic conditions, this depth of snow melts by mid-June. Only the most severe of climatic changes would prevent melt before the end of the thaw season or during more favourable years. Re-establishment of late-melting species into the centres of basins during climatic amelioration could occur through vegetative spread along runners, seedling establishment and germination of seed left in these zones. It is suspected that the seeds of many arctic species are able to persist for decades in the frozen state (Billings and Mooney, 1968).

Snowbed meadow communities show the same response to climatic change. Lengthening of exposure would allow more robust meadow plants, already sporadic in late melt zones, to increase vegetatively and reproductively. During conditions of decreasing growing seasons, meadow communities would move outwards into dying willow zones. Many snowbed meadow species are circumpolar arctic plants of wide ecological tolerance, persisting and setting mature seed in chionophobic plant association. Although producing high biomass values in snowbed meadows, they are unable to adjust phenological stages or growth rates to decreasing exposure lengths. Elimination of these plants within snowbeds would be compensated for by re-establishment of seed developed in adjacent chionophobic communities. According to Savile (1972), in the evolution of Arctic plant species, selection has favoured plants of wide tolerances. Species such as Arctagrostis latifolia and Artemisia arctica are able to cope with severe oscillations in the physical environment by wide distribution within many plant communities, rather than being specialized within certain habitats and facing extinction during short or long-term climatic changes. The snowbed environment, with its sensitivity to climatic fluctuations, offers highly variable growing conditions. Only a limited number of specialized chionophilous plants are able to adjust phenologically to the oscillations inherent to the snowbed environment.

Variations in snow cover and length of exposure between snow-dominated and snow-free or snowpatch terrain in the Richardson Mountains produce distinct microclimatic differences. The characteristics of the snowbed environment that distinguish it from the latter are:

1. Rapid accumulation of snow in autumn due to topographic location. Depths of snow often exceed 1.5 m on upper snowbed slopes within hours of the first snowfall.
2. Winter snow depths in excess of 1 meter, reaching measured maximums of 8 meters in lee snowbeds.
3. Protection of ground and vegetation surfaces during winter through reduced wind speeds and compacted snow covers (similar to snowpatches).
4. Winter ground and surface temperatures close to 0°C .
5. Reduced winter surface temperature oscillations--protection from destructive freeze-thaw cycles.
6. Exposure of ground surfaces after the first to second week of June, with decreasing lengths of exposure towards the centre of snowbeds.
7. Higher incoming solar radiation intensities than on gentler or north-facing slopes.
8. Lower wind speeds, seldom exceeding 10-15 km/hr.
9. Rapid soil thaw (4-11 cm/day), deeper active layers (110-170 cm), and warmer ground temperatures ($4.5-11.5^{\circ}\text{C}$ at 50 cm by August) than snowpatch or vegetated tundra sites.

Regional climate and yearly variations in weather, though, are dominant factors in all microclimates and determine:

1. Prevailing winds which set the pattern of snow distribution.
2. Total snowfall which affects snow accumulation in lee drifts--volumes may vary by as much as 50% between years.
3. Winter air temperatures which determine the degree of freezing in the ground at the borders of snowbeds and the characteristics of the winter snowpack.
4. Rates and patterns of snowmelt--exposure of the same ground may vary by as much as 3-6 weeks between years.
5. Moderation of total solar radiation received on slopes of different aspect or steepness by the frequency of cloud and fog cover.
6. Dampening of differences in air temperature, relative humidity and moisture between microhabitats due to the severity and frequency of storms from the Beaufort Sea.

The snowbed climate is the product of interactions between characteristics created by the unique physical setting of snowbeds and by the overwhelming influences of a regional climate with heavy precipitation, extremes in air temperatures, and highly variable annual weather conditions. In the formation of microclimate patterns, the most important factors along the snow depth gradient are topographic location and length of exposure, the latter being the direct product of variations in regional climate. Within snowbed basins, gradients are a function of the number of days exposed in June and July. Under the influence of frequent cloud and fog, mean climatic conditions through these months do not vary significantly within any one year. Microclimatic characteristics are further modified by slope aspect and runoff patterns of melt water and precipitation.

The resultant soil patterns within snowbed basins are characterized by:

1. Mineral soils built up by the deposition of inorganic and organic snow debris which averaged 325g/m^2 in 1973 within late melt zones of four snowbeds.
2. Soil nutrients levels which are lower than adjacent snowpatch soils but which are influenced by patterns of animal activity, runoff, ground-water flow and snow debris.
3. Active erosion processes which move and modify patterns of soil particle composition and nutrient contents.

The resultant vegetation in snowbed basins, in comparison to chionophobous communities, is characterized by:

1. The ability to withstand prolonged burial by snow at near-zero temperatures, shortened growing seasons, and wet soils.
2. Above-ground biomass values which are lower than chionophobous associations and decrease under hydric conditions or with reductions in length of exposure towards the center of snowbed basins.
3. Higher below-ground biomass values and above to below-ground biomass ratios (1:11 compared to 1:3 in chionophobous associations).
4. Higher daily productivity values than chionophobous associations ($2.3\text{g/m}^2/\text{day}$ average in well-drained meadows compared to $1.2\text{g/m}^2/\text{day}$ in snowpatches).
5. Net annual above-ground primary productivity in well-drained meadows (116g/m^2 average) lower than shrub zones (166g/m^2), but comparable to snowpatches (96g/m^2).

6. Specialized chionophilous plant species such as Ranunculus pygmaeus and Saxifraga rivularis which are able to develop mature seed within 30 days of exposure.
7. Species such as Ranunculus nivalis and Carex Lachenalii which are able to adjust phenological time-tables and growth rates to length of exposure.
8. Species such as Petasites frigidus and Artemisia arctica which are unable to adjust to shortened growing seasons and are limited to vegetative growth only in later melting zones.

The resultant zonations of plant communities within snowbed basins are determined by the reactions of individual plant species to:

- i) topographic location (which determines slope, aspect, snow cover, and microclimatic conditions),
- ii) number of days exposed (which determines total energy available for growth during June and July, and exposure to deteriorating weather conditions in August),
- iii) patterns and persistence of melt-water and precipitation runoff (which determines cold temperatures and hydric soils in runoff zones).

Although species are able to withstand short-term extremes in climatic conditions, larger fluctuations shift species distributions across changing patterns of length of exposure and melt-water runoff. The variability of the snowbed environment is manifested by oscillations in the boundaries of plant communities within snowbed basins.

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APPENDICES

Additional Snow Depth Data (cm). Canoe Lake, N.W.T.

Site	Year	Date	Sample Points and Snow Depths (cm)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																		
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Key:

Pt	- sample points, distance in meters	E1	- estimate from Snowbed #1, June 20-21, 1971
D'	- depth of snow in cm.	E2	- estimate from Snowbed #1, May 18-26, 1972
bN	- name of point		- May 17-20-no melt; May 20-26=8cm
		E3	- estimate from Snowbed #1, May 18-28, 1973
M	- May 1 - June 3	E4	- estimate from Snowbed #1, May 18-21, 1973

Appendix A
Air and Ground Temperatures (°C) for Canoe Lake, N.W.T.
A. October, 1972 to April, 1973

Month	Day	Exposed Tundra ^a					Snowbed Meadow ^a					Month	Day	Exposed Tundra ^a					Snowbed Meadow ^a				
		84cm	0cm	-20cm	-40cm	-60cm	0cm	-20cm	-40cm	-60cm	80cm			84cm	0cm	-20cm	-40cm	-60cm	0cm	-20cm	-40cm	-60cm	80cm
Oct.	6	-1.5	-1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Nov.	1	-16.0	-14.5	8.5	sr	5.0	0.0	0.0	0.0	0.0	0.0
	7	-6.5	3.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		2	-19.2	-16.9	9.2		5.5	0.0	0.0	0.0	0.0	0.0
	8	-3.0	2.5	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0		3	-21.2	-18.0	9.2		5.5	0.0	0.0	0.0	0.0	0.0
	9	-1.5	1.5	1.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0		4	-16.5	-13.5	8.5		5.5	0.0	0.0	0.0	0.0	0.0
	10	1.5	0.5	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0		5	-17.2	-13.5	8.5		6.0	0.0	0.0	0.0	0.0	0.0
	11	2.0	2.0	0.5	nr	0.0	0.0	0.0	0.0	0.0	0.0		6	-16.0	-14.5	9.2		6.0	0.0	0.0	0.0	0.0	0.0
	12	-4.5	0.5	0.5		0.0	0.0	0.0	0.0	0.0	0.0		7	-23.0	-19.2	10.2		6.5	0.0	0.0	0.0	0.0	0.0
	13	-3.5	1.0	0.5		0.0	0.0	0.0	0.0	0.0	0.0		8	-26.0	-21.0	12.5		7.5	0.0	0.0	0.0	0.0	0.0
	14	-7.5	4.5	1.0		0.0	0.0	0.0	0.0	0.0	0.0		9	-25.1	-20.1	11.0		7.5	0.0	0.0	0.0	0.0	0.0
	15	0.0	6.5	1.5		0.0	0.0	0.0	0.0	0.0	0.0		10	-22.2	-14.5	10.2		7.5	0.0	0.0	0.0	0.0	0.0
	16	7.5	8.0	1.0		0.5	0.5	0.5	0.5	0.5	0.5		11	-22.2	-13.5	9.2		7.5	0.0	0.0	0.0	0.0	0.0
	17	6.5	5.5	0.5		0.5	0.5	0.5	0.5	0.5	0.5		12	-22.2	-15.2	9.0		7.5	0.0	0.0	0.0	0.0	0.0
	18	2.0	2.0	0.5		0.5	0.5	0.5	0.5	0.5	0.5		13	-20.1	-15.2	9.2		7.5	0.0	0.0	0.0	0.0	0.0
	19	-4.0	2.0	0.5		0.5	0.0	0.5	0.0	0.0	0.0		14	-17.2	-14.5	9.2		7.5	0.0	0.0	0.0	0.0	0.0
	20	-1.5	9.5	0.5		0.5	0.5	0.5	0.0	0.0	0.0		15	-16.5	-14.5	9.2		7.5	0.0	0.0	0.0	0.0	0.0
	21	-5.5	3.5	1.5		0.5	0.0	0.5	0.0	0.0	0.0		16	-20.1	-15.2	9.2		7.5	0.0	0.0	0.0	0.0	0.0
	22	-8.5	0.5	2.0		0.5	0.0	0.5	0.0	0.0	0.0		17	-26.0	-18.9	9.9		7.5	0.0	0.0	0.0	0.0	0.0
	23	-8.5	3.5	2.5		0.5	0.0	0.5	0.0	0.0	0.0		18	-17.2	-15.2	10.2		8.0	0.0	0.0	0.0	0.0	0.0
	24	-11.5	7.5	2.5		0.5	0.0	0.0	0.0	0.0	0.0		19	-12.5	-13.5	10.2		8.5	0.0	0.0	0.0	0.0	0.0
	25	-9.0	6.5	3.5		0.5	0.0	0.0	0.0	0.0	0.0		20	-12.5	-14.0	12.0		8.5	0.0	0.0	0.0	0.0	0.0
	26	-3.0	2.5	1.5		0.5	0.0	0.0	0.0	0.0	0.0		21	-6.5	-7.5	9.0		9.0	0.5	0.5	0.0	0.0	0.0
	27	-6.5	5.5	2.5		0.5	0.0	0.0	0.0	0.0	0.0		22	-9.0	-8.5	8.0		8.0	0.5	0.5	0.0	0.0	0.0
	28	0.5	0.5	2.0		0.5	0.5	0.5	0.0	0.0	0.0		23	-1.5	-7.5	8.5		8.0	0.5	0.5	0.0	0.0	0.0
	29	-3.0	2.0	1.5		0.5	0.0	0.0	0.0	0.0	0.0		24	0.5	-3.0	7.5		7.5	0.5	0.5	0.0	0.0	0.0
	30	-5.5	0.5	3.0		0.5	0.0	0.0	0.0	0.0	0.0		25	-2.0	-3.0	5.5		7.5	0.5	0.5	0.0	0.0	0.0
	31	-7.5	1.5	3.5		0.5	0.0	0.0	0.0	0.0	0.0		26	-3.5	-5.5	6.0		6.5	0.5	0.0	0.0	0.0	0.0
Nov.	1	-7.0	-6.0	4.5		1.5	0.5	0.0	0.0	0.0	0.0	Dec.	1	-16.5	-13.5	10.2		8.5	0.0	0.0	0.0	0.0	0.0
	2	-13.5	-11.5	4.5		1.0	0.0	0.0	0.5	0.5	0.5		2	-12.5	-14.0	12.0		8.5	0.0	0.0	0.0	0.0	0.0
	3	-12.0	-9.2	5.5		1.5	0.0	0.5	0.5	0.5	0.5		3	-6.5	-7.5	9.0		9.0	0.5	0.5	0.0	0.0	0.0
	4	-3.5	-8.5	5.5		2.0	0.5	0.0	0.0	0.0	0.0		4	-9.0	-8.5	8.0		8.0	0.5	0.5	0.0	0.0	0.0
	5	-8.0	-10.2	5.0		2.5	0.5	0.0	0.0	0.0	0.0		5	-1.5	-7.5	8.5		8.0	0.5	0.5	0.0	0.0	0.0
	6	-17.0	-14.5	6.5		2.5	0.5	0.5	0.5	0.5	0.5		6	0.5	-3.0	7.5		7.5	0.5	0.5	0.0	0.0	0.0
	7	-19.0	-15.2	7.5		2.5	0.5	0.5	0.5	0.5	0.5		7	-2.0	-3.0	5.5		7.5	0.5	0.5	0.0	0.0	0.0
	8	-19.2	-15.4	7.5		3.5	0.0	0.5	0.5	0.5	0.5		8	-3.5	-5.5	6.0		6.5	0.5	0.0	0.0	0.0	0.0
	9	-20.5	-18.0	9.0		3.5	0.5	0.5	0.5	0.5	0.5		9	-5.5	-6.0	6.5		6.5	0.5	0.5	0.0	0.0	0.0
	10	-16.0	-13.5	8.0		4.5	0.0	0.5	0.5	0.5	0.5		10	-8.5	-9.0	7.5		6.5	0.5	0.5	0.0	0.0	0.0
	11	-14.5	-12.0	8.5		4.5	0.0	0.5	0.5	0.5	0.5		11	-4.5	-5.5	6.5		6.5	0.5	0.5	0.0	0.0	0.0
	12	-14.5	-12.0	8.5		5.5	0.0	0.5	0.5	0.5	0.5		12	-12.5	-12.5	7.5		6.5	0.5	0.5	0.0	0.0	0.0
Dec.	21	-23.0	-23.1	17.6	nr	-13.5	0.5	0.5	0.5	0.5	0.5	Jan.	30	-27.9	nr	nr	nr	nr	0.0	0.5	0.5	0.5	0.5
	22	-23.0	-24.2	18.4		-13.5	0.5	0.5	0.5	0.5	0.5		31	-30.5					0.0	0.5	0.5	0.5	0.5
	23	-24.2	-26.0	20.1		-14.5	0.5	0.5	0.5	0.5	0.5		1	-19.2					0.0	0.5	0.5	0.5	0.5
	24	-28.0	-28.0	20.9		-15.2	0.5	0.5	0.5	0.5	0.5		2	-19.8					0.0	0.5	0.5	0.5	0.5
	25	-27.9	-25.1	20.1		-16.0	0.5	0.5	0.5	0.5	0.5		3	-5.0					0.0	0.5	0.5	0.5	0.5
	26	-29.0	-24.2	18.4		-15.2	0.5	0.5	0.5	0.5	0.5		4	-3.0					0.0	0.5	0.5	0.5	0.5
	27	-20.5	-19.8	17.6		-15.2	0.5	0.5	0.5	0.5	0.5		5	-8.5					0.0	0.5	0.5	0.5	0.5
	28	-26.4	-22.6	16.9		-14.5	0.5	0.5	0.5	0.5	0.5		6	-12.0					0.0	0.5	0.5	0.5	0.5
	29	-26.9	-24.2	16.9		-14.5	0.5	0.5	0.5	0.5	0.5		7	-8.5					0.0	0.5	0.5	0.5	0.5
	30	-26.0	-23.0	18.0		-14.5	0.5	0.5	0.5	0.5	0.5		8	-8.0					0.0	0.5	0.5	0.5	0.5
	31	-28.0	-26.9	18.4		-14.5	0.5	0.5	0.5	0.5	0.5		9	-20.9					0.0	0.5	0.5	0.5	0.5
Jan.	1	-22.6	-24.2	20.1		-15.2	0.5	0.5	0.5	0.5	0.5		10	-32.0					0.0	0.5	0.5	0.5	0.5
	2	-6.5	-9.2	14.5		-15.2	0.5	0.5	0.5	0.5	0.5		11	-32.0					0.0	0.5	0.5	0.5	0.5
	3	-9.0	-9.9	12.5		-13.5	0.5	0.5	0.5	0.5	0.5		12	-27.2					0.0	0.5	0.5	0.5	0.5
	4	-7.5	-9.2	12.0		-12.7	0.5	0.5	0.5	0.5	0.5		13	-21.2					0.0	0.5	0.5	0.5	0.5
	5	-1.0	-3.5	10.5		-12.0	0.5	0.5	0.5	0.5	0.5		14	-30.5					0.0	0.5	0.5	0.5	0.5
	6	-7.5	-8.5	9.2		-11.0	0.5	0.5	0.5	0.5	0.5		15	-32.5					0.0	0.5	0.5	0.5	0.5
	7	-3.0	-5.5	10.5		-10.5	0.5	0.5	0.5	0.5	0.5		16	-25.1					0.0	0.5	0.5	0.5	0.5
	8	-0.5	-2.0	7.0		-10.2	0.5	0.5	0.5	0.5	0.5		17	-19.2					0.0	0.5	0.5	0.5	0.5
	9	-6.5	-7.5	7.5		-9.0	0.5	0.5	0.5	0.5	0.5		18	-12.5					0.0	0.5	0.5	0.5	0.5
	10	17.2	15.2	9.9		-9.0	0.5	0.5	0.5	0.5	0.5		19	-9.9					0.0	0.5	0.5	0.5	0.5
	11	-26.9	-23.5	12.7		-9.2	0.5	0.5	0.5	0.5	0.5		20	-18.4					0.0	0.5	0.5	0.5	0.5
	12	-28.2	-25.1	15.2		-10.5	0.5	0.5	0.5	0.5	0.5		21	-19.8					0.0	0.5	0.5	0.5	0.5
	13	-27.9	-26.0	16.0		-12.0	0.5	0.5	0.5	0.5	0.5		22	-19.2					0.0	0.5	0.5	0.5	0.5
	14	-25.1	-27.9	17.2		-12.7	0.0	0.5	0.5	0.5	0.5		23	-20.1					0.0	0.5	0.5	0.5	0.5

Key: + - no snow cover on May 15, 1972 and 1973
 ++ - exposed from snow June 25, 1973
 * - height above ground level
 ** - values partially estimated
 Equipment did not function properly after April 1st.
 nr - no record available

Appendix 3
Snowpack Temperatures ($^{\circ}\text{C}$) for Canoe Lake, N.W.T.
A. November, 1972, to May, 1973

Height above Ground (cm)										Height above Ground (cm)									
Year	Mon.	Day	0	50	100	150	200	300	350	Year	Mon.	Day	0	50	100	150	200	300	350
1972	Nov		snow	snow	snow	snow	air	air	air	1972	Dec	30	-1.2	-6.6	-5.6	-14.3	-25.2	-25.2	-24.9
		25	0.2	-0.8	-3.8	-12.2	-21.9	-22.2	-22.8			31	-1.2	-6.6	-5.6	-14.3	-28.3	-27.9	-28.3
		26	0.2	-1.2	-3.8	-14.3	-18.6	-19.0	-19.9	1973	Jan	1	-1.2	-6.1	-5.6	-13.6	-15.9	-15.1	-16.3
		27	0.2	-1.8	-5.1	-14.8	-14.3	-15.9	-15.1			2	-1.2	-6.6	-6.1	-14.3	-5.1	-5.6	-6.1
		28	0.2	-1.8	-4.6	-13.9	-13.1	-15.5	-13.9			3	-1.2	-6.6	-5.1	-11.9	-9.5	-9.0	-10.0
		29	0.2	-1.8	-4.6	-13.1	-21.9	-21.4	-21.4			4	-1.2	-6.1	-5.6	-10.0	-8.1	-7.6	-8.6
		30	0.2	-1.8	-4.6	-14.8	-21.0	-21.4	-22.2			5	-1.2	-6.1	-4.6	-8.5	-1.8	-0.8	-2.1
	Dec		snow	snow	snow	snow	air	air	air			6	-1.2	-5.1	-4.6	-6.1	-6.1	-5.1	-6.1
		1	0.2	-1.8	-4.1	-13.9	-8.1	-8.1	-8.1			7	-1.2	-5.1	-5.6	-8.1	1.2	1.8	1.2
		2	0.2	-1.2	-4.1	-10.9	-14.3	-14.3	-14.3			8	-1.2	-4.6	-5.1	-4.6	0.2	0.8	-0.2
		3	0.2	-0.8	-4.1	-10.9	-5.1	-5.1	-5.1			9	-1.2	-4.1	-4.1	-4.6	-6.1	-6.1	-6.1
		4	0.2	-0.8	-4.1	-8.1	-4.1	-4.1	-4.1			10	-1.2	-3.8	-3.8	-5.1	-19.0	-19.4	-19.4
		5	0.2	-0.2	-3.8	-6.6	-6.6	-7.1	-7.1			11	-0.8	-3.1	-3.8	-5.1	-26.1	-26.1	-26.1
		6	0.2	-0.2	-3.1	-6.1	0.2	0.2	0.2			12	-0.8	-3.1	-4.1	-6.1	-27.0	-27.0	-27.0
		7	0.2	-0.2	-3.1	-5.1	0.2	0.8	0.8			13	-0.8	-3.1	-4.1	-7.1	-26.6	-26.1	-26.1
		8	0.8	-0.2	-2.8	-3.1	-1.8	-1.2	-1.2			14	-0.2	-3.1	-5.1	-7.6	-26.6	-27.0	-28.3
		9	0.2	-0.2	-3.1	-3.1	-3.1	-3.8	-3.8			15	-0.2	-3.1	-6.6	-8.5	-27.0	-27.0	-27.0
		10	0.2	-0.2	-2.1	-3.1	-6.1	-6.1	-6.1			16	-0.2	-3.1	-6.1	-10.0	-27.0	-27.0	-27.0
		11	0.2	-0.2	-1.8	-3.1	-5.1	-5.1	-5.1			17	-0.8	-3.8	-6.6	-11.2	-27.0	-26.6	-27.0
		12	0.8	-1.2	-2.1	-4.1	-10.4	-10.9	-10.9			18	-0.2	-4.1	-7.6	-11.9	-32.8	-33.2	-33.2
		13	0.8	-1.2	-2.1	-6.6	-21.0	-21.0	-21.0			19	-1.2	-4.8	-6.1	-12.8	-31.9	-31.3	-31.3
		14	0.8	-1.2	-2.1	-10.0	-23.6	-23.6	-23.6			20	-1.2	-5.1	-8.1	-12.8	-28.3	-28.3	-28.3
		15	0.2	-2.1	-2.1	-10.4	-24.4	-24.4	-24.4			21	-1.2	-5.1	-8.1	-13.1	-33.6	-33.2	-33.6
		16	0.8	-2.1	-2.1	-10.4	-31.3	-30.5	-31.0			22	-1.2	-5.6	-8.5	-13.1	-29.8	-29.8	-29.8
		17	0.8	-3.1	-2.8	-11.2	-29.8	-30.5	-30.5			23	-1.2	-6.1	-9.0	-13.6	-29.2	-29.8	-31.3
		18	0.8	-3.1	-4.1	-12.8	-27.0	-27.0	-27.0			24	-1.2	-6.1	-9.0	-13.6	-31.0	-30.5	-31.3
		19	-0.8	-4.6	-4.6	-13.6	-20.2	-19.0	-19.9			25	-1.2	-6.1	-9.0	-13.6	-33.2	-33.2	-33.6
		20	-0.8	-5.1	-3.8	-13.1	-19.9	-20.2	-20.6			26	-1.2	-6.1	-9.5	-13.6	-18.1	-17.6	-18.1
		21	-0.8	-5.1	-4.1	-13.1	-23.5	-22.8	-24.4			27	-1.2	-6.1	-9.0	-13.6	-8.1	-7.1	-8.1
		22	-0.8	-5.6	-5.1	-13.6	-24.4	-24.4	-26.6			28	-0.8	-6.1	-8.5	-12.8	-0.8	-0.2	-0.8
		23	-0.8	-5.6	-5.1	-13.9	-24.4	-25.2	-25.2			29	-0.8	-6.1	-7.1	-10.9	-16.3	-16.2	-16.9
		24	-0.2	-5.6	-6.1	-14.3	-27.0	-27.0	-27.0			30	-1.2	-6.1	-7.1	-10.9	-26.4	-24.4	-24.4
		25	-0.8	-6.1	-6.1	-15.1	-27.0	-27.0	-27.0			31	-1.2	-6.1	-8.1	-11.2	-27.9	-27.9	-27.9
		26	-1.2	-6.1	-6.1	-15.1	-27.4	-27.9	-27.9		Feb	1	-1.2	-5.6	-8.5	-11.2	-15.5	-15.1	-15.5
		27	-1.2	-6.1	-6.1	-15.1	-21.0	-20.2	-20.6			2	-1.2	-5.6	-9.0	-10.9	-6.6	-5.6	-6.6
		28	-1.2	-6.6	-5.6	-14.8	-27.0	-27.4	-27.4			3	-1.2	-5.6	-8.5	-10.0	-11.2	-10.4	-11.2
		29	-1.2	-6.6	-5.1	-1.3	-27.9	-27.9	-27.9			4	-1.2	-5.1	-8.5	-9.0	-2.8	0.8	0.2
1973	Feb	5	-1.2	-4.6	-5.1	-8.5	-10.0	-4.6	-6.6		Mar	15	-2.8	-8.1	-12.8	-14.8	-30.5	-32.4	-32.8
		6	-1.2	-5.1	-7.6	-8.1	-6.6	-3.1	-3.6			16	-3.1	-8.1	-13.6	-15.1	-31.3	-31.3	-31.3
		7	-1.2	-4.6	-7.6	-8.1	-15.9	-20.0	-12.8			17	-3.1	-8.5	-13.6	-15.5	-27.4	-26.1	-27.0
		8	-1.2	-4.6	-7.1	-8.1	-10.0	-6.6	-8.1			18	-3.1	-9.0	-13.6	-15.9	-28.9	-27.0	-27.9
		9	-1.2	-4.1	-8.1	-8.1	-21.9	-23.6	-24.0			19	-3.8	-9.0	-13.6	-15.9	-27.9	-29.8	-31.0
		10	-1.2	-4.1	-7.1	-8.1	-20.2	-28.9	-28.9			20	-3.8	-9.0	-13.6	-15.9	-27.9	-31.0	-31.0
		11	-1.2	-4.1	-7.6	-9.0	-29.2	-33.2	-33.2			21	-3.8	-9.0	-13.6	-15.9	-29.8	-29.8	-31.3
		12	-1.2	-4.6	-9.1	-10.9	-31.3	-28.3	-29.8			22	-3.8	-9.0	-13.9	-15.9	-27.9	-23.1	-23.6
		13	-1.2	-5.1	-10.9	-11.9	-29.8	-31.3	-31.3			23	-4.1	-9.0	-13.6	-15.9	-23.6	-21.0	-21.4
		14	-1.2	-5.1	-11.9	-12.8	-27.0	-26.1	-27.0			24	-4.1	-9.0	-13.1	-15.5	-19.4	-7.6	-10.0
		15	-1.2	-5.6	-11.9	-13.1	-29.8	-28.9	-28.9			25	-4.1	-9.0	-12.8	-14.8	-16.9	-16.9	-16.9
		16	-1.2	-6.1	-11.9	-13.6	-31.3	-28.9	-28.9			26	-4.1	-9.0	-11.9	-13.9	-18.6	-21.4	-24.4
		17	-1.2	-6.1	-12.8	-14.3	-21.0	-21.9	-22.8			27	-4.1	-9.0	-11.9	-13.6	-13.9	-10.0	-11.2
		18	-1.2	-6.1	-12.8	-14.3	-26.1	-21.9	-21.9			28	-3.8	-8.5	-11.2	-12.8	-13.9	-10.4	-11.9
		19	-1.2	-6.6	-12.8	-13.9	-15.9	-5.1	-6.1			29	-3.8	-8.1	-10.9	-12.2	-11.2	-13.1	-13.1
		20	-1.2	-6.6	-11.9	-13.1	-13.9	-14.3	-15.9			30	-4.1	-8.1	-10.4	-11.2	-12.8	-8.5	-11.2
		21	-1.8	-6.6	-10.4	-12.2	-16.3	-20.2	-19.9			31	-4.1	-7.6	-10.4	-10.9	-11.2	-6.6	-7.1
		22	-1.8	-6.6	-10.4	-11.2	-17.2	-16.9	-16.3		Apr		snow	snow	snow	snow	snow	air	air
		23	-1.8	-6.1	-9.5	-11.2	-18.1	-24.9	-24.9			1	-4.1	-7.6	-10.0	-10.4	-10.9	-6.1	-7.6
		24	-1.8	-6.1	-10.4	-11.2	-19.0	-21.0	-21.9			2	-3.8	-7.6	-9.5	-9.5	-10.9	-12.2	-15.1
		25	-1.8	-5.6	-10.4	-11.2	-19.0	-17.6	-18.1			3	-3.8	-6.6	-9.5	-9.0	-11.2	-14.3	-14.8
		26	-1.8	-5.6	-10.4	-11.2	-19.0	-21.9	-21.9			4	-4.1	-7.1	-10.0	-8.5	-14.3	-15.9	-16.3
		27	-1.8	-6.1	-10.9	-11.2	-22.2	-24.4	-24.4			5	-4.1	-6.6	-9.5	-9.0	-13.1	-15.9	-18.6
		28	-2.1	-6.1	-10.9	-11.2	-24.4	-27.4	-27.4			6	-3.8	-6.1	-9.0	-8.5	-11.2	-6.6	-7.6
	Mar		snow	snow	snow	snow	+	air	air			7	-3.8	-5.6	-9.0	-8.1	-6.6	-3.2	-4.6
		1	-1.8	-6.1	-10.9	-12.2	-24.4	-26.1	-26.1			8	-3.8	-5.6	-8.5	-7.6	-7.6	-4.6	-5.6
		2	-1.8	-6.1	-11.2	-12.8	-27.0	-29.8	-29.8			9	-3.8	-5.6	-8.5	-7.6	-3.8	0.2	-0.2
		3	-2.1	-6.1	-11.9	-13.6	-27.9	-31.9	-31.3			10	-3.8	-5.6	-8.0	-6.6	-4.6	-4.6	-4.6
		4	-2.1	-6.6	-11.9	-14.3	-27.0	-27.0	-27.4			11	-3.8	-5.6	-7.6	-6.6	-5.6	-6.6	-10.4
		5	-2.1	-7.1	-12.8	-14.8	-28.7	-26.6	-27.0			12	-3.8	-5.1	-7.6	-6.1	-6.1	-12.2	-13.9
		6	-2.1	-7.1	-12.8	-15.1	-27.0	-22.8	-22.8			13	-3.8	-5.1	-8.0	-6.1	-8.5	-12.2	-13.1
		7	-2.8	-7.6	-12.8	-15.1	-23.6	-29.2	-29.2			14	-3.8	-4.6	-8.5	-6.1	-10.4	-21.4	-21.4
		8	-2.8	-7.6	-12.8	-15.1	-26.0	-32.4	-32.4			15	-3.8	-4.6	-8.5	-6.6	-10.4	-19.0	-19.9
		9	-2.8	-8.1	-12.8	-15.1	-31.0	-34.5	-34.5			16	-3.8	-4.6	-8.5	-6.6	-11.2	-24.0	-24.0
		10	-2.8	-8.1	-12.8	-15.1	-30.1	-31.9	-31.9			17	-3.8	-5.0	-9.0	-8.0	-12.8	-20.2	-21.0
		11	-2.8	-8.1	-13.1	-15.1	-26.1	-31.0	-31.0			18	-3.8	-5.0	-9.0	-8.0	-11.9	-18.1	-18.6
		12	-2.8	-8.1	-12.8	-15.1	-27.4	-29.8	-29.8			19	-3.8	-5.6	-9.0	-8.0	-10.9	-12.8	-14.3
		13	-2.8	-8.1	-12.8	-15.1	-26.1	-25.8	-25.8			20	-3.8	-5.6	-9.0	-8.0	-10.0	-10.0	-10.0
		14	-2.8	-8.1	-12.8	-15.1	-24.4	-28.3	-28.9			21	-3.8	-4.1	-8.5	-7.6	-8.5	-11.2	-11.2

Appendix 3 (continued)

2. May, 1973, to June, 1973

Year Mon. Day		Height above Ground (cm)										Mon. Day Time		Height above Ground (cm)										Mon. Day Time		Height above Ground (cm)												
		0	50	100	150	200	300	350	400	450	500			0	50	100	150	200	300	350	400	450	500			0	50	100	150	200	300	350	400	450	500			
1973 Apr 22		-3.8	-5.6	-9.0	-7.6	-10.0	-16.9	-16.9	-19.9	-21.0		10:10		0.2	2.0	12.0	10.3	10.0	8.1	8.1	3.2		10:10		0.2	2.0	12.0	10.3	10.0	8.1	8.1	3.2		10:10				
23		-3.8	-5.1	-8.5	-7.1	-10.4	-19.9	-21.0				13:00		0.2	2.0	14.8	13.1	10.0	7.8	8.1	4.4		13:00		0.2	2.0	14.8	13.1	10.0	7.8	8.1	4.4		13:00				
24		-3.8	-5.6	-8.5	-7.6	-10.9	-16.9	-16.9				30		9:40	0.2	2.5	7.8	8.1	6.9	5.6	4.9	2.9		30		9:40	0.2	2.5	7.8	8.1	6.9	5.6	4.9	2.9		30		
25		-3.8	-5.6	-8.5	-7.6	-10.4	-19.4	-20.6				13:00		0.2	2.5	11.0	12.0	7.8	7.2	6.5	3.2		13:00		0.2	2.5	11.0	12.0	7.8	7.2	6.5	3.2		13:00				
26		-3.8	-5.6	-8.5	-7.6	-9.5	-15.5	-15.1				17:35		0.2	2.5	9.0	10.3	7.2	7.2	6.5	4.9		17:35		0.2	2.5	9.0	10.3	7.2	7.2	6.5	4.9		17:35				
27		-3.8	-5.6	-8.5	-7.6	-9.5	-13.6	-13.6				31		10:40	0.2	1.8	6.9	6.5	6.9	5.2	5.2	2.9		31		10:40	0.2	1.8	6.9	6.5	6.9	5.2	5.2	2.9		31		
28		-3.8	-5.6	-8.5	-7.6	-8.0	-7.1	-9.0				12:30		0.2	1.2	9.0	9.0	7.8	6.5	6.0	3.2		12:30		0.2	1.2	9.0	9.0	7.8	6.5	6.0	3.2		12:30				
29		-3.8	-5.6	-8.0	-7.1	-6.6	-0.8	-2.1	Jun			1		9:10	0.2	2.5	7.2	5.6	5.6	4.4	4.4	1.2		1		9:10	0.2	2.5	7.2	5.6	5.6	4.4	4.4	1.2		1		
30		-3.8	-4.6	-7.6	-6.1	-4.1	-0.2	-2.8				12:50		-0.6	3.2	4.9	5.6	5.6	4.9	4.9	4.9		2		9:20	-0.6	3.2	4.9	5.6	5.6	4.9	4.9	4.9		2			
1		-3.8	-5.1	-7.1	-5.6	-3.8	0.8	-1.8				2		9:20	-0.6	3.2	3.2	3.2	3.2	1.8	1.8	3.2		3		13:20	-0.6	4.0	4.0	4.0	2.9	2.9	4.0		3			
2		-3.8	-4.6	-6.6	-4.6	-4.6	-12.2	-12.2				3		10:30	0.9	5.6	2.5	2.9	3.2	2.5	1.2	2.0		4		13:50	0.9	4.9	2.5	3.2	2.0	1.2	2.5		4			
3		-3.8	-4.1	-6.6	-4.6	-3.8	-5.1	-5.6				4		9:35	0.6	3.2	2.0	3.2	0.2	2.0	2.0	2.9		5		9:10	0.2	27.5	20.5	20.5	16.9	16.3	4.9		5			
4		-3.8	-4.1	-6.6	-4.6	-4.6	-11.2	-11.2				5		9:10	0.2	27.5	20.5	20.5	16.9	16.3	4.9		6		12:50	-0.2	14.1	13.1	14.1	15.2	14.1	14.8	9.0		6			
5		-3.8	-4.1	-6.6	-4.6	-4.6	-6.1	-7.6	-7.6			6		9:30	0.2	15.8	15.8	15.8	15.8	14.1	14.1	5.2		7		17:00	0.2	12.0	14.1	15.2	16.3	15.8	16.3	9.0		7		
6		-3.8	-4.6	-6.6	-4.6	-4.6	-6.6	-11.2				7		9:30	0.2	15.8	15.8	15.8	15.8	14.1	14.1	5.2		8		17:00	0.2	12.0	14.1	15.2	16.3	15.8	16.3	9.0		8		
7		-3.8	-4.6	-6.6	-4.6	-4.6	-6.6	-11.2				8		9:30	0.2	15.8	15.8	15.8	15.8	14.1	14.1	5.2		9		17:00	0.2	12.0	14.1	15.2	16.3	15.8	16.3	9.0		9		
8		-3.8	-4.6	-6.6	-4.6	-4.6	-6.6	-11.2				9		9:15	4.9c	7.2	6.9	9.0	8.5	8.1	7.2	7.8	4.9		10		17:00	0.2	12.0	14.1	15.2	16.3	15.8	16.3	9.0		10	
9		-3.8	-4.6	-6.6	-4.6	-4.6	-6.6	-11.2				11		10:00	0.2	12.6	14.1	14.1	14.8	14.1	14.1	8.1		12		17:00	0.2	12.6	14.1	14.1	14.8	14.1	14.1	8.1		12		
10		-3.8	-4.6	-6.6	-4.6	-4.6	-6.6	-11.2				12		10:45	0.2	18.1	18.8	17.5	18.8	17.5	18.8	9.0		13		17:00	0.2	18.1	18.8	17.5	18.8	17.5	18.8	9.0		13		
11		-2.8	-3.6	-0.2	-0.8	0.2	-2.8	-2.8				13		8:35	0.2	8.1	9.0	9.0	10.0	9.6	9.6	4.9		14		18:00	0.2	13.6	14.1	14.1	14.1	14.1	10.0		14			
12		-2.8	-4.1	0.2	-0.8	0.2	-1.8	-1.8				15		8:55	0.6	8.5	8.5	8.1	8.1	7.2	7.2	4.0		16		12:40	0.2	10.0	9.6	9.0	9.0	8.1	8.1	6.9		16		
13		0.2	-1.2	0.2	-0.8	0.2	2.2	1.8				16		8:55	0.6	8.5	8.5	8.1	8.1	7.2	7.2	4.0		17		17:30	0.9	11.0	12.0	11.4	12.0	10.0	11.0	8.1		17		
14		0.2	0.2	0.2	0.2	12.0	5.6	5.6				17		9:15	4.9c	7.2	6.9	9.0	8.5	8.1	7.2	7.8	4.9		18		13:00	7.2	9.6	9.0	8.5	8.1	7.2	7.8	4.9		18	
15		0.2	0.2	0.2	0.2	0.2	1.8	2.5				18		17:00	9.0	9.0	9.0	9.0	9.0	9.0	11.0	7.2		19		17:00	9.0	9.0	9.0	9.0	9.0	9.0	11.0	7.2		19		

Key: Mon. - month

+ - covered with snow on March 22nd to May 15

++ - exposed from snow on May 25

@ - exposed from snow on May 27

\$ - exposed from snow on May 28

c - exposed from snow on June 9

** - 2 cm into lichen mat; on tundra above snow

Key: Mon. - month

+ - covered with snow on March 22nd to May 15

++ - exposed from snow on May 25

@ - exposed from snow on May 27

§ - exposed from snow on May 28

c - exposed from snow on June 9

** - 2 cm into lichen mat; on tundra above snowbed

APPENDIX 4 (continued)

Location	Point (m)	Year	Date	ASH.	DSM.	Date	ASH.	DSM.	Date	ASH.	DSM.	Date	ASH.	DSM.	Date	ASH.	DSM.
WD	25	1972	July 10	470	3.0'	July 12	--	--	July 18	--	--	July 20	--	--	July 23	--	--
	30			460	15.5		485	12.5		505	3.7		--	--			
	35			441	15.5		471	15.0		577	17.7		603	13.0		--	--
	40			475	15.0		504	14.5		576	12.0		617	20.5		649	6.4
WD	40		Aug. 1	669	2.9'	Snow entirely melted by August 7, 1972 at Snowbed #1											
ED	0'	1972	May 23	4	0.7	May 29	23	3.8	June 2	--	--	June 7	--	--	June 11	--	--
	5			2	0.3		12	1.7		--	--		--	--		--	--
	10			2	0.3		26	4.0		39	3.3		--	--		--	--
	15			1	0.2		40	6.5		54	2.5		70	3.2		--	--
	20			0	0.0		20	3.3		50	7.5		94	8.8		106	3.0'
	25			0	0.0		20	3.3		61	10.3		99	7.6		126	6.8
	30			0	0.0		20	3.3		60	10.0		94	6.8		146	18.0
	35			3	0.5		23	3.3		73	12.5		105	6.4		179	18.5
	40			0	0.0		20	3.3		64	11.0		106	8.4		156	12.5
	45			2	0.3		22	3.3		67	11.3		120	10.6		175	13.8
	50			2	0.3		22	3.3		62	10.0		110	9.6		175	16.3
	55			2	0.3		22	3.3		62	10.0		110	9.6		177	16.8
	60			3	0.5		29	4.3		57	7.0		84	5.4		164	15.0
	65			3	0.5		29	4.3		57	7.0		84	5.4		118	8.5
	70			0	0.0		24	4.0		50	6.5		75	5.0		113	9.5
	75			0	0.0		28	4.7		53	6.3		83	6.0		128	11.3
	80			0	0.0		26	4.3		52	6.5		73	4.6		124	12.3
	85			0	0.0		20	4.0		46	6.5		78	6.4		126	12.0
	90			0	0.0		26	5.2		52	6.5		82	6.0		130	12.0
	95			0	0.0		26	4.3		46	10.0		74	5.6		117	10.8
	100a			0	0.0		23	7.7		54	7.8		78	5.8		121	10.8
	100b			0	0.0		20	3.7		48	7.0		81	6.6		96	3.8
	110			0	0.0		23	7.7		51	9.3		84	6.6		122	9.5
ED	30	1972	June 14	176	3.3	June 17	--	--	June 19	--	--	June 21	--	--	June 24	--	--
	35			181	0.7		--	--		--	--		--	--		--	--
	40			--	--		--	--		--	--		--	--		--	--
	45			--	--		--	--		--	--		--	--		--	--
	50			190	5.0'		--	--		--	--		--	--		--	--
	55			247	23.3'		--	--		--	--		--	--		--	--
	60			192	16.0		235	14.3		268	16.5		--	--		--	--
	65			151	11.0		189	13.7		239	25.0		263	12.0		293	10.0
	70			155	14.0		183	12.7		229	18.0		253	12.0		283	10.0
	75			168	13.3		196	9.3		239	21.5		265	13.0		298	11.0
	80			165	13.7		197	10.7		234	18.5		256	11.0		287	10.3
	85			163	12.3		195	10.7		232	18.5		259	13.5		295	12.0
	90			170	13.3		196	8.7		233	18.5		256	11.5		283	9.0
	95			150	11.0		182	10.7		218	18.0		239	10.5		264	8.3
	100a			154	11.0		188	11.3		277	19.5		252	12.5		284	10.7
	100b			134	12.7		164	10.0		196	16.0		217	10.5		249	10.7
	110			155	11.0		183	9.3		217	17.0		238	10.5		271	11.0
ED	65		June 27	305	4.0'	June 30	--	--	July 3	--	--	July 5	--	--	July 8	--	--
	70			307	8.0		317	3.3		350	11.0		367	18.5		420	11.0
	75			324	8.7		337	4.3		376	13.0		415	19.5		449	11.3
	80			312	8.3		326	4.7		359	11.0		394	17.5		427	11.0
	85			326	10.3		341	5.0		371	10.0		406	17.3		442	12.0
	90			306	7.7		317	3.7		345	9.3		379	17.0		412	11.0
	95			290	8.7		302	3.7		331	10.0		365	17.0		396	10.3
	100a			308	8.0		321	4.3		358	12.3		396	19.0		426	10.0
	100b			273	8.0		294	7.0		332	12.7		359	13.5		368	3.0'
	110			295	8.0		305	3.3		337	10.7		367	15.0		397	10.0
ED	70		July 10	444	12.0	July 12	468	12.0	July 18	--	--	July 25	--	--			
	75			481	16.0		511	15.0		521	1.7		--	--			
	80			460	16.5		492	16.0		529	6.2		--	--			
	85			479	18.5		515	18.0		567	8.7		--	--			
	90			444	16.0		473	14.5		575	17.0		612	5.3			
	95			428	16.0		458	15.0		535	12.8		--	--			
	100			461	17.5		491	15.0		547	9.3		--	--			
	110			426	14.5		451	12.5		471	3.3		--	--			

APPENDIX 4 (continued)

Location	Point (m)	Year	Date	ASH.	DSM.	Date	ASH.	DSM.	Date	ASH.	DSM.	Date	ASH.	DSM.	Date	ASH.	DSM.
ED	0	1973	May 23	28	5.6	May 25	—	—	May 29	—	—	May 30	—	—	June 2	—	—
	5			23	4.6		36	6.3		—	—		—	—		—	—
	10			23	4.6		33	5.0		40	1.8		—	—		—	—
	15			23	4.6		33	5.0		54	5.3		—	—		—	—
	20			23	4.6		33	5.0		80	11.8		—	—		—	—
	25			23	4.6		33	5.0		101	17.0		—	—		—	—
	30			23	4.6		33	5.0		100	16.8		—	—		—	—
	35			23	4.6		33	5.0		—	—		105	14.4		116	3.6
	40			23	4.6		33	5.0		102	17.3		—	—		—	—
	45			23	4.6		33	5.0		73	10.0		83	10.0		99	5.3
	50			21	4.1		33	6.3		99	16.4		114	7.3		120	3.0
	55			21	4.1		40	9.8		86	11.5		90	11.4		107	2.0
	60			21	—		33	—		—	—		85	10.4		—	—
	65			21	—		33	—		—	—		90	—		—	—
	70			21	—		33	—		—	—		85	10.4		—	—
	75			21	—		—	—		—	—		85	—		—	—
	80			21	—		—	—		85	12.9		90	5.3		98	2.7
	85			21	—		—	—		85	—		90	—		—	—
	90			21	—		—	—		—	—		—	—		—	—
	100			20	—		13.3	—		—	—		—	—		—	—
	105			19	3.8		40	7.0		77	12.3		85	4.0		92	3.5
ED	50		June 5	123	3.0	June 8	—	—	June 12	—	—	June 15	—	—	June 21	—	—
	55			124	5.7		178	18.0		182	1.0		—	—		—	—
	60			119	5.7		155	12.0		195	10.0		—	—		—	—
	65			117	4.5		148	10.3		210	15.5		262	17.3		—	—
	70			115	6.0		150	11.7		210	15.0		235	14.0		342	17.8
	75			116	6.2		136	6.7		192	14.0		234	14.0		324	15.0
	80			113	5.6		135	7.3		183	12.0		226	14.3		313	14.5
	85			113	5.0		140	9.0		190	12.5		233	14.3		313	13.3
	90			110	4.0		136	8.7		191	13.8		227	12.0		307	13.3
	105			118	8.7		—	—		—	—		—	—		—	—
ED	70		June 25	359	4.3	June 28	384	—	July 1	427	14.3	July 3	—	—	July 4	—	—
	75			330	1.5		360	—		403	—		423	—		436	3.5
	80			327	3.7		357	9.8		400	—		418	—		431	5.5
	85			323	2.3		348	8.3		393	14.3		411	9.0		424	13.0
	90			322	4.0		352	9.8		394	14.0		416	11.0		430	14.0
ED	75	1973	July 8	450	7.0	July 10	—	—		—	—		—	—		—	—
	80			477	11.5		—	—		—	—		—	—		—	—
	85			448	5.9		455	3.5		—	—		—	—		—	—
	90			449	6.3		—	—		—	—		—	—		—	—
CD	0	1973	May 22	6	1.8	May 26	—	0.6	May 29	33	8.3	May 30	—	—	June 2	—	—
	5			5	1.1		—	1.1		24	5.0		—	—		—	—
	10			4	1.0		—	1.3		31	7.0		—	—		—	—
	15			2	0.5		—	5.9		31	1.2		—	—		—	—
	20			6	1.4		—	0.6		24	6.7		—	—		—	—
	25			5	1.1		—	4.3		32	3.3		—	—		—	—
	30			6	1.4		8	0.6		—	—		—	—		—	—
	35			4	1.0		—	5.1		30	1.7		—	—		—	—
	40			4	0.9		—	5.0		62	12.7		77	15.0		84	2.3
	45			6	1.2		—	5.5		67	13.0		71	3.9		94	7.6
	50			5	1.0		—	5.3		64	12.7		69	5.0		84	5.0
	55			5	0.9		—	5.0		62	12.3		68	6.3		85	5.8
	60			5	1.0		—	5.4		62	11.8		68	6.0		83	5.0
	65			6	1.1		—	5.6		62	11.7		68	5.5		81	4.5
	70			6	1.1		—	5.5		61	11.0		67	6.5		84	5.5
	75			6	1.1		—	5.5		60	10.8		68	8.0		81	4.2
	80			6	1.2		—	5.8		61	10.7		75	14.0		86	3.7
	85			7	1.4		—	6.0		62	10.3		75	13.0		85	3.3
	90			7	1.4		—	5.8		62	10.7		76	14.3		87	3.5
	95			8	1.5		—	5.5		63	11.2		79	15.5		90	3.7
	100			6	1.2		—	5.3		62	11.7		73	10.5		88	5.0
	105			5	0.9		—	4.4		61	12.3		67	5.5		85	6.2
	110			5	1.0		—	5.0		62	12.3		67	5.0		77	3.3
	115			5	1.0		—	5.0		62	12.3		71	9.0		82	3.7
CD	45		June 5	112	6.0	June 8	148	12.0	June 12	175	6.8	June 15	—	—	June 21	—	—
	50			100	5.3		136	12.0		177	10.3		215	12.7		315	16.7
	55			100	5.0		138	12.7		195	14.3		234	13.0		334	16.7
	60			97	4.7		131	11.3		185	13.5		223	12.7		320	16.2
	65			93	4.0		122	9.7		173	12.8		215	14.0		298	13.8
	70			96	4.0		127	10.3		177	12.5		211	11.3		297	14.3
	75			92	3.8		125	11.0		173	12.0		213	13.3		299	14.3
	80			98	4.0		129	10.3		177	12.0		218	12.7		301	13.8

APPENDIX V (continued)

Loca- tion	Point (m)	Year	Date	ASH.	DSM.	Date	ASH.	DSM.	Date	ASH.	DSM.	Date	ASH.	DSM.
CD	85	1973	June 5 (cont'd)	97	4.0	June 8 (cont'd)	126	9.7	June 12 (cont'd)	174	12.0	June 15 (cont'd)	216	14.0
	90			100	4.3		130	10.2		179	12.3		221	12.8
	95			104	4.7		136	10.7		186	12.5		227	13.7
	100			104	5.3		137	11.0		190	13.3		--	--
	105			105	6.5		139	11.3		195	14.0		--	--
	110			93	5.3		126	11.0		186	15.0		--	--
CD	115		June 22	95	4.3	June 25	127	10.7	June 28	190	15.8	July 1	251	20.3
	60			321	1.0		331	3.3		359	9.3		393 ⁺	11.3
	65			298	0.0		305	2.3		332	9.0		375	14.3
	70			299	2.0		306	2.3		333	9.0		372	13.0
	75			303	4.0		311	2.7		339	9.3		380	13.7
	80			306	5.0		314	2.7		341	9.0		381	13.3
CD	85		July 4	302	6.0	July 5	309	2.3	July 8	335	8.7	July 9	373	12.7
	90			307	6.0		314	2.3		--	--		--	--
	65			407	11.0		430	22.5		--	--		--	--
	70			404	11.0		425	21.5		462	12.3		481	8.0 ⁺
	75			414	12.0		436	22.5		473	12.2		--	--
	80			417	15.0		438	21.0		445	2.3 ⁺		--	--
CD	85			405	10.0 ^g		--	--		--	--		--	--
	85			405	10.0 ^g		--	--		--	--		--	--

KEY: ASH = accumulative snow melt (in cm).

DSM = daily average snow melt (cm/day) between this date and previously listed date.

+ = snow gone by July 23 at all points, Snowbed #1.

a = from June 28.

b = melted out before this date; value low.

c = from June 20.

d = June 20 - June 22.

e = from May 17.

f = from May 18.

g = snow melted from site.

APPENDIX 5

Snow Ablation Rates - A - Snowed #2*

Location(m)	Year	Date	ASN.	DSM.	Date	ASN.	DSM.	Date	ASN.	DSM.	Date	ASN.	DSM.	Date	ASN.	DSM.
0ee	1971	June 21	—	—	June 24	—	—	June 28	—	—	June 29	—	—	July 3	—	—
0.8			30	15.0												
1.5			38	18.8												
3.0			34	16.8		52	18.0		102	12.5		111	9.0		122	3.7
4.6			32	16.0		49	17.0		93	10.9		98	6.5		124	6.5
6.1			31	15.5		49	18.0		93	10.9		99	6.5		125	6.4
7.6			26	13.0		42	16.0		79	9.3		86	7.0		107	5.2
9.1			23	11.5		42	19.0		82	10.0		90	7.5		123	11.0
10.7			34	17.0		70	26.0									
11.4			23	14.5		28	5.0									
4.6		July 6	162	12.5	July 9	168	1.7	July 12	—	—						
6.1			157	10.8		209	14.0		232	7.7						
7.6			144	12.5		153	3.0									
0	1972	June 12	—	—	June 14	—	—	June 16	—	—	June 19	—	—	June	—	—
10			131	10.0		164	16.5		194	15.0		242	16.0		—	—
20			146	12.1		173	13.5		203	15.0		270	17.3		325	9.2
30			146	8.6		181	17.5		204	11.5		271	20.0		326	6.7
40			146	8.6		—	—		—	—		—	—		—	—
HS5			121	8.6		161	20.0		181	10.0		248	22.3		318	11.7
HS10			121	5.8		156	17.5		179	11.5		217	12.7		257	6.7
SN5			121	6.4		171	25.0		191	10.0		234	14.3		254	10.0
SN10			121	7.1		166	22.5		187	10.5		238	17.0		245	7.6
SN15			121	8.6		156	17.5		179	11.5		219	13.3		—	—
ELA												246	20.7		312	11.0
ELA												253			303	8.7
20		July 2	342	5.3	July 5	408	15.3	July 7	468	30.0	July 9	498	15.0	July 12	533	11.7
30			370	5.4		418	16.0		478	21.0		506	14.0		541	11.7
HS10			301	6.3		349	6.7		369	20.0		—	—		—	—
ELA			344	7.4		420	18.7		470	25.0		494	12.0		539	15.0
ELA			353	7.4		388	11.7		438	25.0		462	12.0		507	15.0
30EA						357			419	31.0		444	12.5		491	15.7
30EB						357			408	25.5		436	15.0		—	—
20		July 19	566	16.5	July 26	—	—									
30			585	22.0		—	—									
ELA			575	5.1		—	—									
30EA			546	7.9		559	1.9									
18	1973	June 4	93	5.9	June 11	186	13.3	June 24	342	12.0	June 30	426	14.0	July 6	491	10.8
ELA			84	5.1		157	9.9		308	11.6		392	14.0		459	11.2
18		July 10	544	13.3	July 24	761	15.5	July 31	806	6.4	Aug. 5	881	15.0			
ELA			513	13.5		692	12.8		737	6.4		812	15.0			

KEY:

- a. See Figure 3.
- aa. June 21st snow border, west bank.
- a. Snow gone by July 12th, 1971 at all points.
- b. From June 21st.
- c. Snow gone by July 26th, 1972 at all points.
- d. Melt from June 5th; accumulative melt from May 26th.
- e. Melt from May 28th; accumulative melt from May 18th; dwellings moved to area of last snow is July.
- f. Snow gone by August 5th, 1973 from all points.
- g. Melted out before this date; value low.
- ASN. Accumulative snow melt (in cm).
- DSM. Daily average snow melt (cm/day) between this date and previously listed date.

APPENDIX 5 (continued)
Snow Ablation Rates - B - Snowbed #3

Location(m)	Year	Date	ASBL	DSBL	Date	ASBL	DSBL	Date	ASBL	DSBL	Date	ASBL	DSBL	Date	ASBL	DSBL
0	1972	June 23	2	1.0	June 24	—	—	June 29	—	—	July 2	—	—	July 3	—	—
1.5			26	13.0		—	—		—	—		—	—		—	—
3.0			34	17.0		—	—		—	—		—	—		—	—
4.6			30	15.0		51	21.0		62	2.2		—	—		—	—
6.1			27	13.5		49	22.0		89	8.0		103	4.5		127	24.0
7.6															131	28.0
9.1			27	13.5		49	21.5		94	9.0					118	6.0
10.7			30	15.0		50	20.0		92	8.3					113	6.3
12.2			30	15.0		49	19.0		96	9.4					120	6.0
13.7			31	15.5		51	20.0		53	0.4						
15.2			32	16.0		39	7.0		—	—						
16.0			11	5.5		—	—		—	—						
6.1		July 6	143	5.5	July 9	—	—	July 12	—	—						
7.6			170	13.0		217	15.7		221	1.3						
9.1			157	13.0		197	13.3		—	—						
10.7			146	11.0		172	8.7		—	—						
12.2			131	3.7		—	—		—	—						
ECD	1972	June 12	65	10.8	June 19	157	13.1	June 25	223	11.0	July 2	263	5.7	July 7	318	11.0
END									212	9.2		235	6.1		307	10.4
ESD									219	10.3		259	5.7		307	9.6
CD			65	10.8		155	12.9		215	10.0		250	5.0		299	9.8
WCD			65	10.8		163	14.0		224	10.1		264	5.7		331	13.4
WED												254	4.3		322	13.6
VED												277	7.6		346	13.8
ECD		July 9	341	11.5	July 12	374	11.0	July 19	—	—	July 26	—	—			
END			334	13.5		365	10.2		489	17.7		527	5.4			
ESD			339	16.0		365	8.7		448	11.9		464	2.3			
CD			326	13.5		366	13.3		485	17.0		528	6.1			
WCD			355	12.0		397	14.0		439	6.0		—	—			
WED			351	14.5		394	14.3		428	4.9		—	—			
VED			374	14.0		426	17.3		494	9.7		—	—			
UN	1973	May 28	50	7.1	June 4	105	6.6	June 11	174	9.9	June 24	312	10.6	June 30	371	9.8
UD			59	7.9		96	5.7		171	10.7		324	11.8		384	10.0
MD			56	7.4		111	7.7		186	10.7		332	11.2		392	10.0
LD			57	7.6												
UD		July 7	438	9.6	July 10	530	30.7									
MD			450	9.4		525	25.0									
LD			457	9.3		515	19.3									

KEY:

- a - 0 and 23 at June 21 snow borders; transect from east to west across snowbed.
- b - Snow melted at all points, July 12, 1971.
- c - From June 21.
- d - July 2 to 3.
- e - Snow gone by July 25, 1972.
- f - From June 6.
- g - Snow gone by July 15, 1973.
- h - From May 21.
- UN - Upper willows.
- UD - Upper dwelling.
- MD - Middle dwelling.
- LD - Lower dwelling.
- ECD - Central east dwelling.
- END - North east dwelling.
- ESD - South east dwelling.
- CD - Central dwelling.
- WCD - Central west dwelling.
- WED - North west dwelling.
- VED - South west dwelling.

Appendix 6

Shortwave Radiation Values (cal/cm²/day) at Canoe Lake, N.W.T.

Daily Totals (from 00:15 am to 00:00 pm)

Year	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31										
1972	May																																									
1973																																										
1972	June	25	34	22	25	26	22	29	26	43	42	34	24	73	44	64	35	78	43	14	24	44	24	49	25	42	54	12	21	90	58	33	92	33	48	27	44	22	62	76		
1973																																										
1972	July	27	44	74	49	34	23	21	50	39	43	99	38	15	53	34	88	43	58	42	33	85	19	41	11	54	11	82	51	78	74	89	17	32	64	33	13	96	82	63	20	54
1973																																										
1972	August	67	93	21	92	00	23	72	24	15	33	39	36	43	36	13	56	56	31	51	89	13	61	48	21	76	35	11	71	01	29	16	3	38	75	38	15	150				
1973																																										
1972	Sept.	44	70	18	65	65	65	56	24	45	40	18	93	44	21	24	33	44	43	41	34																					
1973																																										

Key: * to ** - daily average over time period

Appendix 7

Wind Speeds and Directions for Stations at Canoe Lake, N.W.T.

Daily Average (km/hr)

Station	Year	Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1972 May		Di																															
#1 Upper		Av																															
#2 Upper		Av																															
1972		Di																															
Ridge		Av																															
#1 Upper		Av																															
#1 Lower		Av																															
1972 June		Di																															
#1 Upper		Av																															
#2 Upper		Av																															
1972		Di																															
Ridge		Av																															
#1 Upper		Av																															
#1 Lower		Av																															
1972 July		Di																															
#1 Upper		Av																															
#1 Lower		Av																															
1972		Di																															
Ridge		Av																															
#1 Upper		Av																															
#1 Lower		Av																															
1972 Aug		Di																															
#1 Upper		Av																															
#1 Lower		Av																															
1972		Di																															
Ridge		Av																															
#1 Upper		Av																															
#1 Lower		Av																															
1972 Sep		Di																															
#1 Upper		Av																															
#1 Lower		Av																															
1972 Oct		Di																															
#1 Upper		Av																															
#1 Lower		Av																															

Dir - direction
 Key: 1 - wind
 2 - after June 25, #1 Lower
 3 - blown over e - estimate

APPENDIX B (continued)

Month	Station	Year	Temp	Date																															
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
August	#1	1971	Av.	8.9	7.2	1.7	0.3	2.4	7.5	3.3	4.3	3.7	2.5	-0.9	3.3	-0.9	0.2	3.5	7.0	9.1	11.3	12.3	4.7	-0.1	-2.7	-0.8	-2.3	-2.6							
			Max.	10.0	13.9	6.1	2.2	6.7	17.2	5.6	4.4	9.4	6.7	1.1	11.1	3.7	2.2	12.8	17.2	16.7	18.3	10.0	1.1	-2.2	4.4	1.7	3.3								
			Min.	7.2	0.6	-1.1	-2.2	-1.7	-3.3	-0.6	-2.2	-1.1	-1.1	-3.9	-3.9	-3.9	-1.7	-2.8	1.7	2.2	6.7	5.6	0.6	-2.8	-3.3	-6.7	-7.8	-4.4							
			Av.	7.9	5.7	8.1	11.0	16.2	12.5	12.5	6.0	10.9	12.9	10.1	4.8	5.7	10.7	13.8	9.7	9.0	12.1	17.1	14.4	13.7	13.4	14.6	13.7	10.9	5.8	4.9	6.4	6.9	5.8	10.1	
		1972	Max.	10.6	7.8	10.0	16.1	23.3	15.0	15.0	8.9	16.7	16.7	15.0	5.6	7.2	15.6	17.2	11.7	10.6	20.0	21.7	17.8	18.9	17.8	20.6	18.9	6.1	8.9	5.6	11.1	10.0	8.3	17.2	
			Min.	5.6	3.3	2.8	3.3	7.2	3.0	5.0	3.3	2.2	7.8	5.0	4.4	4.4	4.4	11.7	7.8	-6.7	7.8	11.1	7.8	11.1	7.2	10.0	10.0	14.4	2.8	2.2	2.8	5.6	2.2	2.2	
			Av.	15.1	15.2	16.7	12.9	13.2	15.9	13.5	8.1	12.2	12.3	9.7	7.1	4.8	3.2	3.6	6.9	10.6	11.1														
			Min.	10.0	8.9	12.2	12.2	7.2	13.3	8.9	7.2	7.8	11.1	7.2	6.1	3.9	1.1	1.1	0.0	5.6	10.0														
	#2	1972	Av.	8.7	5.6	7.2	9.3	14.8	15.8	12.7	5.3	10.2	11.5	10.8	4.7	3.1	9.8	13.0	9.2	8.0	11.2	15.8	13.6	13.0	12.2	14.2	13.8	11.2	5.7	4.3	6.3	6.5	5.0	9.6	
			Max.	13.3	7.8	11.7	13.9	21.7	19.4	16.4	8.3	15.0	15.0	13.9	6.1	6.1	15.0	15.0	12.2	8.9	17.8	19.4	16.1	18.3	18.9	21.7	20.6	16.7	10.6	5.6	11.1	7.8	6.7	14.8	
			Min.	6.7	3.3	1.1	1.7	8.3	11.7	7.3	2.3	2.3	6.7	6.1	3.9	3.9	3.9	4.4	10.6	6.1	6.1	11.7	7.2	7.2	4.4	7.8	9.4	4.4	1.1	2.2	1.7	3.3	1.1	1.1	
			Av.	14.2	14.8	13.7	10.3	13.4	15.3	11.6	5.1	10.5	10.7	6.9	3.6	1.2	-0.9	1.0																	
	#3	1972	Max.	19.4	20.6	19.4	12.8	20.6	18.3	15.6	6.7	15.0	13.9	8.9	4.4	3.9	1.7	5.6																	
			Min.	7.2	8.3	6.7	4.4	3.3	12.2	5.6	3.9	4.4	8.9	3.9	1.7	-0.6	-3.9	-4.4																	
			Av.	8.7	5.1	7.3	9.4	16.3	16.1	11.8	4.6	9.0	12.1	10.9	4.1	5.1	10.5	13.3	9.8	8.2	11.4	17.0	14.2	12.8	12.2	14.2	13.8	11.2	5.7	4.3	6.3	7.0	5.2	10.2	
			Min.	12.2	7.8	12.2	15.6	26.7	23.9	13.6	8.9	16.7	16.7	13.6	5.0	6.7	16.7	17.8	11.1	10.0	13.4	24.4	18.3	20.0	18.9	21.7	20.6	16.7	10.6	5.6	11.1	10.0	8.9	18.9	
	Ridge	1973	Av.	13.2	13.8	12.9	9.4	11.1	13.6	10.9	4.8	9.7	9.7	6.5	3.1	1.1	-0.2	1.0																	
			Max.	17.8	18.9	18.3	12.2	19.4	17.2	15.0	6.1	14.4	12.8	10.0	3.9	3.9	3.9	2.8	5.6																
			Min.	7.2	7.2	6.7	5.6	3.2	10.0	5.0	3.9	3.3	7.8	7.8	1.7	-0.6	-3.9	-4.4																	
			Av.	14.1	14.3	14.2	11.3	12.7	14.1	12.1	7.7	11.2	10.7	8.8	6.7	5.3	4.3	4.8	7.2	9.7	9.6														
	NE Slope	1973	Max.	17.2	17.8	17.2	13.9	17.2	16.1	15.6	8.9	14.4	12.8	11.1	7.2	7.2	5.6	7.2	11.7	13.9	10.0														
			Min.	10.0	10.6	10.0	7.8	12.2	8.3	7.2	7.2	7.2	8.9	6.7	6.1	4.4	2.8	2.8	2.8	6.1	8.9														
			Av.	14.8	14.8	15.4	12.7	13.1	15.1	13.2	7.6	11.6	10.8	9.1	6.8	5.1	3.3	3.9	5.9	9.2	9.6														
			Min.	11.1	10.0	12.2	11.7	7.8	12.8	8.3	7.2	7.8	9.4	7.2	6.1	3.9	2.2	1.7	0.6	4.4	10.0														

APPENDIX 8 (continued)

Month	Station	Year	Temp	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Sept.	#1	1972	Av. Max. Min.	0.8 7.2 -3.9	0.3 6.1 -6.7	7.6 11.1 2.2	7.9 11.1 4.4	5.3 9.4 0	1.1 5.0 -4.4	1.3 3.3 0	0 1.7 -1.1	-1.0 1.7 -3.9	-1.7 0 -4.4	-0.8 3.9 -5.0	-0.9 3.3 -5.0	-2.0 -1.1 -2.8	0 3.9 -2.8	0.3 2.2 -0.6	-1.4 -0.6 -2.8
	#2	1972	Av. Max. Min.	1.0 6.1 -2.8	0.4 5.6 -4.4	6.8 10.6 2.8	7.3 10.6 2.8	4.7 8.9 -1.7	0.6 4.4 -5.0	1.4 2.8 0.6	-0.2 0.6 -0.6	-1.6 0.6 -3.9	-2.4 -1.1 -4.4	-1.3 2.8 -4.4	-2.1 1.7 -5.6	-1.7 -1.1 -2.2	0.1 3.3 -2.8	0.3 2.2 -1.1	-1.7 -0.6 -3.3
	#3	1972	Av. Max. Min.	1.4 6.7 -3.9	-0.1 6.7 -6.7	6.9 12.2 -1.1	7.6 13.3 2.2	4.1 10.0 -3.3	-0.2 4.4 -7.8	0.2 1.7 -0.6	-0.9 1.1 -1.7	-2.0 2.2 -4.4	-3.6 -1.1 -7.2	-1.5 5.6 -6.1	-4.1 1.7 -9.4	-3.4 -2.2 -3.9	-1.1 3.9 -4.4	-0.4 1.7 -1.7	-2.2 -1.7 -4.4
Sept. (cont)	#1	1972	Av. Max. Min.	-4.7 -2.8 -6.1	-5.1 -3.3 -6.7	-4.4 -0.6 -1.0	-3.2 -1.1 -4.4												
	#2	1972	Av. Max. Min.	-5.2 -3.3 -7.2	-5.4 -2.8 -5.6														
	#3	1972	Av. Max. Min.	-6.3 -2.2 -10.6	-6.1 -3.3 -9.4														

APPENDIX 9 (cont'd)

Month	Station	Year	Temp	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
July	#1	1971	Av.	82	86	81	86	85	87	82	80	79	84	85	73	67	64	65	87	67	64	65	87	94	91	79	79	87							
			Max.	94	93	91	94	94	94	92	90	87	78	78	84	98	97	94	94	92	92														
			Min.	69	61	67	74	63	64	71	70	80	87	73	71	60	49	41	34	44	71	90	89	40	66	74									
	1972	Av.	87	88	69	57	61	60	77	83	70	76	76	82	84	76	93	82	82	66	78	71	70	87	91	87	81	90	68						
		Max.	93	93	76	85	72	97	94	96	94	96	94	94	93	84	96	94	93	84	95	88	91	88	92	85	94	96	96						
		Min.	72	75	86	64	55	52	58	62	67	82	87	80	88	85	93	64	67	55	56	56	60	72	63	75	47								
	1973	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1974	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1975	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1976	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1977	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1978	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1979	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1980	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1981	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1982	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1983	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1984	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1985	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1986	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1987	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	
	1988	Av.	80	82	79	60	58	64	69	64	62	72	82	82	78	69	60	44	55																
		Max.	90	92	90	80	82	85	88	85	88	85	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	92	
		Min.	68	75	66	49	45	47	53	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54	54							

APPENDIX 11

Summer Ground Temperatures (°C)*

Plant Type	D	Aug 13-31 Daily Max.	Sep 1-14 Daily Max.	Sep 15-19 Daily Max.	Nov 24 Max.	1st Max.	May 18-31 Daily Max.	June Daily	1-17 Daily Max.	June 21-30 Daily Max.	July Daily	Aug Daily	1-17 Daily Max.	Exp. Daily						
Shrub - 1) Top	5	6.4	7.7	1.6	2.6	-0.2	0.0	-7.1	7.7	8.5	10.4	9.6	13.2	10.6	14.0	19.0	22.7	12.5	14.4	11.0
a - M18	10	5.1	5.9	1.3	1.0	0.2	0.3	-6.3	-0.1	1.0	1.5	2.9	4.2	3.5	4.2	6.9	8.0	5.7	6.8	4.0
b - na	30	3.0	3.4	0.7	1.0	0.1	0.2	-5.2	-1.7	-1.2	-1.0	0.2	0.3	0.9	1.0	2.8	3.0	3.4	3.5	1.2
c - na	50	2.6	2.8	0.6	0.8	-0.3	0.1	-4.4	-2.8	-2.0	-1.9	-0.8	-0.2	-0.4	0.0	0.8	0.9	1.8	1.9	-0.1
- 2) Mallow	10	3.3	3.9	0.9	1.3	0.1	0.2	-5.0	-0.9	-0.4	-0.1	1.0	1.6	2.0	2.5	5.2	6.3	4.8	5.9	2.6
a - M18	30	2.0	2.0	0.6	0.7	-0.1	0.0	-4.7	-2.6	-2.3	-2.2	-0.6	-0.5	-0.2	-0.2	1.2	1.3	2.1	2.1	0.2
b - M27; c - M15	50	2.4	2.8	0.4	0.5	0.0	0.0	---	---	---	---	---	-0.8	-0.4	-0.4	0.4	0.4	1.3	1.4	-0.1
Spruce - Birch	5	6.4	7.2	1.2	1.9	-0.1	0.0	---	-1.5	-0.4	-0.1	4.4	5.3	4.5	5.2	8.8	10.7	9.0	10.4	5.8
a - M18	10	4.4	4.6	1.4	1.6	0.5	0.6	---	-0.6	-0.2	-0.2	1.0	1.7	2.3	2.7	5.7	6.4	5.8	6.5	3.5
b - M23	30	2.7	3.0	0.9	1.0	0.1	0.2	---	-2.2	-1.6	-1.6	-0.7	-0.5	-0.2	-0.2	0.8	0.9	2.5	2.6	0.5
c - M18	50	-2.2	2.6	0.5	0.7	-0.2	0.0	---	-2.7	-2.8	-2.8	-1.3	-1.3	-0.1	0.0	0.2	0.3	1.6	1.7	-0.2
Upper Willow - 1) Dense	5	5.7	6.1	2.6	3.5	0.3	0.5	---	-0.1	-0.1	-0.1	6.7	9.3	6.1	7.1	12.0	13.5	11.7	15.1	10.0
a - M19	10	5.1	5.4	1.8	2.4	0.4	0.5	---	-0.3	-0.3	-0.2	1.3	2.1	2.5	3.0	6.5	10.2	6.5	7.3	4.7
b - J14	30	4.0	4.0	1.5	1.6	0.6	0.6	---	-1.1	-0.8	-0.7	-0.3	-0.2	0.1	0.2	3.4	3.5	4.7	4.8	2.3
c - J5	50	2.6	2.9	0.8	0.9	-0.1	-0.1	---	-1.9	-1.8	-1.7	-1.1	-1.0	-0.9	-0.8	1.3	1.4	3.2	3.3	0.9
- 2) Open	10	4.0	4.8	0.1	0.5	-1.7	-1.5	-1.1	-2.0	---	---	2.8	4.0	4.3	5.2	7.9	9.2	5.3	5.6	6.2
a - J1, M24, J5	30	4.1	4.4	1.1	1.3	-0.6	-0.5	-1.1	-1.8	-1.6	-1.6	-0.5	0.0	3.1	3.8	7.8	8.7	5.4	5.7	4.5
b - J16; c - J10	50	2.5	2.7	0.2	0.4	-1.0	-1.0	-1.1	-1.8	---	---	-1.0	-1.0	0.0	0.0	2.9	3.2	4.3	4.4	2.2
Upper Meadow - 1) Laric	5	3.3	3.2	2.6	3.7	0.8	1.0	---	-1.2	-0.5	-0.5	3.6	5.0	6.3	7.3	11.6	13.7	9.5	10.7	9.2
a - M19	10	6.3	7.5	2.6	3.5	0.8	0.9	---	-1.2	-0.7	-0.6	1.8	3.0	4.6	5.4	9.2	10.9	8.1	9.8	7.1
b - J16; c - J9	30	4.2	4.3	2.0	2.3	0.8	0.8	---	-2.2	-1.7	-1.7	-0.9	-0.9	1.4	1.5	4.6	4.8	5.7	5.8	3.6
- 2) Masic: A) S. chan	0	11.2	13.2	3.3	5.6	-0.2	0.0	---	-0.2	---	---	-0.3	-0.2	12.3	16.8	15.9	18.9	9.3	11.4	12.6
a - J13	5	6.4	7.2	1.8	2.9	0.1	0.3	---	-0.2	---	---	-0.3	-0.2	5.9	7.0	9.5	10.5	7.2	8.0	7.7
b - Jy5	15	4.7	5.1	1.4	1.9	0.1	0.1	---	-0.1	-0.1	0.0	0.0	0.0	4.7	7.0	7.7	6.3	6.7	6.1	
c - J21	30	4.6	4.8	1.7	1.9	0.5	0.6	---	-0.1	-0.1	2.6	2.6	6.1	6.4	6.4	6.5	5.4	5.4	5.4	
	50	2.7	2.8	1.3	1.4	0.2	0.2	---	-0.2	---	-0.5	-0.4	0.3	0.3	4.1	4.2	4.9	4.9	3.5	
- 2) Tall: B) Tall	5	5.6	6.4	1.1	2.1	-0.4	-0.3	---	-1.3	---	-0.8	0.0	4.9	5.9	9.2	10.5	7.0	7.9	7.4	
a - J13	10	3.8	4.2	1.5	2.1	0.2	0.3	---	-0.1	---	-0.0	0.0	3.3	4.1	7.6	8.4	6.9	7.4	6.4	
b - J27; c - J19	30	3.8	4.2	1.2	1.7	-0.1	-0.1	---	-0.6	---	-0.6	-0.6	2.7	3.5	7.0	7.8	6.6	6.9	5.6	
Upper Late Malt	0	10.9	12.6	3.6	5.4	0.3	0.6	---	0.0	---	---	---	---	---	---	10.9	13.4	12.8	13.9	16.2
a - Jy1	5	8.0	9.4	4.5	6.6	0.6	1.1	---	0.0	---	---	---	---	---	---	9.8	12.3	12.3	13.9	12.9
b - J13	15	8.6	9.6	3.1	3.7	0.9	1.2	---	0.0	---	---	---	---	---	---	7.4	8.6	9.6	10.7	10.2
c - J13	30	7.7	8.1	3.1	3.6	0.9	1.0	---	0.0	---	---	---	---	---	---	5.3	6.1	9.1	9.6	8.6
	50	6.3	6.6	2.8	2.8	0.7	0.7	---	0.1	---	---	---	---	---	---	3.4	3.9	7.8	7.9	7.2
Hydric Late Malt - 1) SD	5	7.6	9.4	1.8	3.0	0.0	0.0	-1.4	0.0	---	---	-0.1	0.0	4.1	6.0	12.6	14.6	8.3	9.1	9.1
a - J15	10	5.5	6.7	1.5	2.1	0.0	0.1	-1.1	0.0	---	---	-0.1	0.0	1.7	2.4	8.8	10.0	6.3	7.6	6.3
b - A2; c - J19																				
- 2) Hydric	0	11.1	13.3	3.9	6.1	-0.1	0.0	-0.9	0.1	---	---	---	---	-0.1	0.0	10.2	10.4	9.4	10.9	11.1
a - J25	5	5.8	6.9	1.9	2.9	0.1	0.3	-0.4	-0.2	---	---	---	---	0.1	0.1	5.0	5.7	6.8	8.0	6.9
b - Jy31	10	3.4	4.1	0.8	1.6	-0.7	-0.4	-1.3	-1.0	---	---	---	---	-1.1	-1.1	1.2	3.8	5.2	6.0	5.0
c - Jy5	30	3.8	4.0	1.3	1.5	0.0	0.1	-0.9	0.9	---	---	---	---	-0.7	-0.6	3.1	3.4	5.4	5.6	4.3
	50	3.4	3.6	1.6	1.7	0.1	0.1	0.0	0.0	---	---	---	---	-0.3	-0.2	2.6	2.9	5.2	5.3	4.0
Lower Meadow - 1) Hydric	0	9.2	12.5	2.8	4.0	-0.3	-0.1	-1.3	-0.5	-0.7	-0.6	5.8	7.3	7.8	10.3	13.2	16.1	7.2	8.7	9.7
a - M29	5	6.1	6.8	1.2	1.7	-0.6	-0.5	-1.5	-0.9	-0.9	-0.9	0.1	0.6	2.9	4.1	8.9	10.5	6.5	7.4	5.3
b - Jy9	10	6.6	7.1	1.9	2.2	0.3	0.4	-0.6	-0.3	-0.3	-0.3	0.0	0.2	2.7	3.6	8.2	9.3	6.9	7.2	5.2
c - J7	30	3.4	3.6	0.6	0.8	-0.9	-0.8	-1.1	-1.4	-1.4	-1.4	-1.4	-1.3	-0.9	-0.8	4.2	4.7	4.8	4.9	2.4
	50	2.2	2.4	0.8	0.9	-0.7	-0.6	-0.8	-1.3	-1.5	-1.5	-1.4	-1.3	-1.1	-1.1	2.0	2.1	4.3	4.5	1.6
- 2) Masic	0	9.9	12.0	2.0	4.3	-0.6	-0.3	-1.8	-0.9	---	---	1.6	2.3	10.1	13.4	14.8	17.4	7.5	8.9	10.8
a - J1	-5	5.1	5.8	1.2	1.6	-0.2	-0.2	-0.6	-0.5	---	---	0.6	0.9	4.3	5.8	9.1	10.3	6.3	6.9	6.5
b - J24	10	4.6	5.2	1.0	1.3	-0.3	-0.2	-0.8	-0.8	---	---	-0.3	0.3	3.6	4.9	8.8	10.2	6.1	6.6	5.9
c - J16	30	3.1	3.3	0.9	1.0	-0.3	-0.2	-0.6	-0.8	---	---	-0.5	-0.3	0.5	0.7	5.3	5.6	5.0	5.0	3.6
Lower Willow	0	8.5	10.0	0.7	2.0	-0.9	-0.7	---	-0.7	---	---	3.4	4.2	9.4	12.9	14.2	17.1	8.1	9.8	
a - J3	5	5.0	5.6	0.9	1.3	-0.5	-0.5	---	-0.6	---	---	0.6	1.3	3.9	7.6	9.1	10.2	5.7	6.1	6.6
b - Jy3	10	4.5	4.8	1.6	1.8	0.3	0.4	---	-0.2	---	---	-0.2	-0.1	4.7	5.6	8.3	8.9	6.1	6.3	6.0
c - J13	30	3.2	3.4	1.4	1.5	0.1	0.2	---	-0.3	---	---	-0.2	-0.2	1.3	1.4	4.0	4.4	5.4	5.5	4.2
	50	2.0	2.2	0.9	1.0	0.0	0.0	---	-0.9	---	---	-0.8	-0.8	-0.1	0.0	4.3	4.6	4.4	4.5	2.9

Key:

- a - August 13 to November 24 - 1972
- b - May 18 to August 17 - 1973
- 1st - Value on first day of readings
- Exp - Average over length of exposure, 1973
- Daily - Daily average of recorded temperatures
- Max - Average of maximum daily recorded temperatures
- D - Depth of thermometer (cm)
- SD - Snow debris to 5 cm deep over site
- Open - Ground cover = 40-60% herbaceous plants and bare soil
- Tall - Herbaceous growth 10-30 cm high

(*Salicetum chmisonis equisetorum arvensis*
plant association)

- a - Date of first recording in 1973
- b - Date of exposure from snow, 1972
- c - Date of exposure from snow, 1973
- M - May
- J - June
- Jy - July 1-11; 22-24; 28-31
- A - August
- Dense - Ground cover = leaf litter
- S. chan - 40-60% cover of *Salix chmisonis*
- na - no snow cover

APPENDIX 12

Vegetation Analysis for Selected Plant Species - Snowbed #1
At Chionophilus Communities^a

Species**	UPPER WILLOWS			In Lea (5 m) of Willows			UPPER MEADOW			Leric			LATE MEAT			Hydric		
	Mesic						Mesic						Upper Slopes					
	RF (%)	Biomass Av (gm)	Height (cm)	RF (%)	Biomass Av (gm)	Height (cm)	RF (%)	Biomass Av (gm)	Height (cm)	RF (%)	Biomass Av (gm)	Height (cm)	RF (%)	Biomass Av (gm)	Height (cm)	RF (%)	Biomass Av (gm)	Height (cm)
	6	2	Av Max	12	7	Av Max	16	11	Av Max	7	Av Max		18	10	Av Max	4	3	Av Max
1. Salix																		
Chamaeneris	17	-	2 5	58	48.7	2	100	60.3	5	43	2		10	0.1	2 5	0	0	0
2. S. polaris																		
ab. pseudo-	0	0	0	0	0	0	13	0.2	2	57	1 2		72	8.2	1 3	50	0.1	2 3
polaris	100	1683.6	79 150	17	32.0	80	0	0	0	14	10 13		0	0	0	0	0	0
3. S. pulchra	0	0	0	17	0.3	2 4	0	0	0	0	0		0	0	0	0	0	0
4. S. reticulata																		
5. Spiraea																		
laevigata	50	9.5	20 35	33	0.2	10 20	13	0.2	10 17	57	13 23		0	0	0	0	0	0
6. Rosa acicularis	33	-	20 25	0	0	0	0	0	0	0	0		0	0	0	0	0	0
7. Rubus chamaemorus	50	1.9	10 17	0	0	0	0	0	0	0	0		0	0	0	0	0	0
8. Sibbaldia																		
procumbens	0	0	0	0	0	0	13	2.0	5 7	43	5 8		17	0.2	2 4	0	0	0
9. Betula																		
glandulosa	33	-	30 50	8	-	5 10	6	-	5 20	29	5 10		0	0	0	0	0	0
10. Linnaea																		
borealis	33	-	2 3	8	-	2 3	0	0	0	57	3 5		0	0	0	0	0	0
11. Cassiope																		
tetragona	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
12. Empetrum																		
nigrum	50	0.2	5 10	0	0	0	0	0	0	29	4 7		0	0	0	0	0	0
13. Vaccinium																		
uliginosum	83	37.3	10 13	33	2.7	6 15	6	-	5 10	29	5 10		0	0	0	0	0	0
14. V. vitis-idaea	67	3.4	5 8	0	0	0	0	0	0	29	2 5		0	0	0	0	0	0
15. Equisetum																		
arvense	33	0.6	20 27	67	1.5	13 20	88	1.5	10 13	29	10 13		67	0.6	8 13	50	0.1	8 18
16. Carex																		
lachenalis	0	0	0	0	0	0	19	-	15 18	86	10 13		89	1.5	15 20	0	0	0
17. C. podocarpa	50	9.5	25 50	75	11.5	35 51	94	28.7	28 51	71	23 31		89	-	22 31	0	0	0
18. C. aquatilis	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
19. Eriophorum																		
Schumacheri	0	0	0	0	0	0	0	0	0	0	0		0	0	0	25	-	5 20
20. Arctostaphylos																		
latifolia	67	0.5	40 55	50	1.6	35 61	75	5.2	28 46	86	25 30		33	0.6	17 36	25	0.2	5 10
21. Calluna vulgaris																		
canadensis	0	0	0	8	147.0	55 70	6	-	30 42	0	0		0	0	0	0	0	0
22. Festuca																		
altica	33	1.4	30 50	25	2.5	41 46	6	0.1	30 40	43	42 61		0	0	0	0	0	0
23. Phlebotia alga	0	0	0	0	0	0	0	0	0	0	0		10	0.5	4 5	50	1.4	2 3
24. Poa arctica	67	0.1	10 20	50	0.8	13 20	81	3.4	15 20	86	18 25		78	1.9	15 25	50	3.1	8 13
25. Trisetum																		
spicatum	0	0	0	0	0	0	31	0.3	13 20	43	11 18		33	0.1	13 20	0	0	0
26. Aconitum																		
delphinifolium	0	0	0	42	0.6	10 18	63	1.8	11 15	0	0		0	0	0	0	0	0
27. Anemone																		
narcissiflora	33	1.9	5 10	58	0.4	17 25	31	0.6	23 36	37	15 20		0	0	0	0	0	0
28. A. Richardsonii	33	0.1	3 5	50	0.1	3 5	38	0.4	7 8	0	0		0	0	0	0	0	0
29. Ranunculus																		
acris	0	0	0	8	-	5 10	31	0.1	4 5	0	0		22	0.1	9 20	25	-	3 5
30. R. pygmaeus	0	0	0	0	0	0	13	-	2 3	14	3 5		72	0.7	9 13	75	0.1	10 13
31. Oxyria digyna	0	0	0	0	0	0	25	0.2	8 20	0	0		94	2.1	15 20	100	0.2	10 18
32. Ranunculus arcticus	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
33. Polygnum																		
bisorta	0	0	0	58	6.3	20 30	81	3.7	17 30	37	17 25		6	-	8 10	0	0	0
34. P. viviparum	0	0	0	25	-	10 15	25	0.2	10 15	57	13 20		11	-	5 8	0	0	0
35. Epilobium																		
angustifolium	17	-	20 25	17	4.0	15 20	0	0	0	0	0		0	0	0	0	0	0
36. E. angustifolium	0	0	0	0	0	0	0	0	0	0	0		11	0.1	2 4	0	0	0
37. Polemonium																		
acutifolium	0	0	0	8	-	10 18	6	-	13 15	0	0		0	0	0	0	0	0

APPENDIX 10. (continued)

Species**	UPPER WILLOWS			UPPER MEADOW			LATE MELT		
	Mesic			In Lee (5 m) of Willows			Mesic		
	RF Biomass Height (X) Av (gm) (cm)	6	2 Av Max	RF Biomass Height (X) Av (gm) (cm)	12	7 Av Max	RF Biomass Height (X) Av (gm) (cm)	16	11 Av Max
36. <i>Viola epipactis</i>	33	-	2 5	42	1.2	2 3	31	0.4	3 8
39. <i>Saxifraga punctata</i>	17	-	3 25	8	0.7	2 5	19	0.1	8 15
40. <i>S. rivularis</i>	0	0	0	0	0	0	0	0	0
41. <i>Dodecatheon frigidum</i>	0	0	0	17	-	15 20	31	0.7	15 25
42. <i>Myosotis alpestris</i>	0	0	0	25	-	15 18	19	0.1	13 15
43. <i>Castilleja leucophaea</i>	0	0	0	25	0.1	15 20	25	1.2	12 18
44. <i>Pedicularis anodonta</i>	17	-	5	-	15 20	6	-	13 20	0
45. <i>Mimulus biflorus</i>	0	0	0	0	0	0	31	0.1	2 5
46. <i>Stellaria longipes</i>	17	-	2 3	67	0.3	3 5	44	0.1	1 2
47. <i>Antennaria monophylla</i>	0	0	0	33	3.1	10 13	25	0.5	2 5
48. <i>Arnica alpina</i>	0	0	0	8	-	25 31	6	-	20 25
49. <i>A. lanceolata</i>	0	0	0	58	1.4	18 20	56	1.4	18 25
50. <i>Artemisia arctica</i>	67	13.4	15 36	83	10.8	25 41	100	36.5	25 46
51. <i>A. filifolia</i>	33	1.9	13 25	25	1.0	8 13	13	0.3	8 13
52. <i>Potentilla fruticosa</i>	17	2.6	5 10	67	1.3	14 20	69	1.7	11 20
53. <i>Senecio lugens</i>	0	0	0	33	0.2	23 31	6	0.2	20 25
54. <i>Achillea borealis</i>	17	-	15 21	8	-	13 18	19	1.1	15 20
Dead surface organic	100	617.8	2 1	100	415.8	8 1	100	174.8	14 1
Moss (live)	67	3.5	2	100	91.8	7	100	20.4	11
Lichen (live)	33	0.2	2	17	0.4	7	56	0.5	11
Bare ground and rock	0			0			0		

	Laric (see above)		
	RF Biomass Height (X) Av (gm) (cm)	16	11 Av Max
Dead surface organic	100	79.2	6 1
Moss (live)	100		7
Lichen (live)	71		7
Bare ground and rock	71	17	7

APPENDIX 1A (continued)

Species **	LOWER MEADOW						LOWER WILLOWS						CREEK MEADOW						Chlorophyllous Communities [†]
	Hydric			Mesic			Mesic			Mesic			Mesic						
	(Σ) Av	Biomass	Height	(Σ) Av	Biomass	Height	(Σ) Av	Biomass	Height	(Σ) Av	Biomass	Height	(Σ) Av	Biomass	Height				
	(g)	(g/m ²)	(cm)	(g)	(g/m ²)	(cm)	(g)	(g/m ²)	(cm)	(g)	(g/m ²)	(cm)	(g)	(g/m ²)	(cm)				
1. <i>Salix Chamissoana</i>	50	4.3	2	5	91	305.2	2	5	20	-	2	5	0	0	0	sp			
2. <i>S. polaris</i> ssp. <i>pseudopolaris</i>	67	5.9	2	4	27	-	1	2	0	0	0	0	0	0	0	sp			
3. <i>S. pulchra</i>	0	0	0	0	0	0	0	0	100	828.7	100	250	0	0	0	r, sp. b			
4. <i>S. reticulata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	b			
5. <i>Spiraea Beauverdiana</i>	0	0	0	0	9	-	5	10	0	0	0	0	0	0	0	b			
6. <i>Rosa acicularis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	b			
7. <i>Rubus chamaemorus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	sp-a			
8. <i>Sibbaldia procumbens</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	sp			
9. <i>Betula glandulosa</i>	0	0	0	0	55	0.4	10	20	0	0	0	0	0	0	0	r, sp. b			
10. <i>Limonium boreale</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	b			
11. <i>Cassiope tetragyna</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	r-a, sp. la			
12. <i>Empetrum nigrum</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	r, sp. b			
13. <i>Vaccinium uliginosum</i>	0	0	0	0	18	0.2	5	8	0	0	0	0	0	0	0	r, sp. b			
14. <i>V. vitis-idaea</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	r, sp. b			
15. <i>Epilobium arvense</i>	83	2.0	13	15	73	0.6	13	23	100	38.6	10	20	80	9.7	13	20	r-a, sp-a		
16. <i>Carex Lachmannii</i>	100	19.2	10	13	82	4.5	18	23	20	0.1	5	10	0	0	0	sp			
17. <i>C. pedocarpa</i>	0	0	0	0	27	-	17	36	20	0.4	13	30	50	125.8	23	46	b		
18. <i>C. aquatilis</i>	0	0	0	0	27	-	30	35	20	-	18	37	0	0	0	sp			
19. <i>Eriophorum Schuchneri</i>	50	1.0	10	15	0	0	0	0	20	-	13	17	0	0	0	sp			
20. <i>Arctagrostis latifolia</i>	67	11.0	15	23	82	1.9	19	41	80	0.5	23	48	20	-	40	80	r, sp. b		
21. <i>Calamagrostis canadensis</i>	0	0	0	0	0	0	0	0	0	0	0	0	60	103.1	33	44	sp		
22. <i>Festuca altaica</i>	0	0	0	0	0	0	0	0	0	0	0	0	20	-	30	45	b		
23. <i>Phlepra algida</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	sp			
24. <i>Poa arctica</i>	83	18.0	15	20	73	5.6	22	36	20	1.5	15	20	60	2.0	23	38	r, sp. b		
25. <i>Trisetum spicatum</i>	0	0	0	0	27	-	18	20	0	0	0	0	0	0	0	sp			
26. <i>Aconitum delphinifolium</i>	0	0	0	0	9	-	10	15	0	0	0	0	20	-	10	13	sp		
27. <i>Anemone narcissiflora</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	r, sp. b			
28. <i>A. Richardsonii</i>	0	0	0	0	0	0	0	0	60	3.1	3	5	20	-	6	10	sp		
29. <i>Ranunculus alpestris</i>	50	0.1	5	10	45	0.1	18	30	40	0.1	3	5	0	0	0	sp			
30. <i>R. pygmaeus</i>	100	1.1	5	8	45	0.1	8	15	20	-	2	3	0	0	0	sp			
31. <i>Oxyria digyna</i>	0	0	0	0	36	0.1	2	4	0	0	0	0	80	0.5	15	20	sp		
32. <i>Rumex arcticus</i>	0	0	0	0	18	-	36	41	0	0	0	0	30	1.4	53	76	sp		
33. <i>Polygonum bistorta</i>	0	0	0	0	9	-	10	12	0	0	0	0	0	0	0	r, sp. b			
34. <i>Polygonum viviparum</i>	17	0.1	3	5	55	0.4	8	23	0	0	0	0	0	0	0	sp			
35. <i>Epilobium angustifolium</i>	0	0	0	0	0	0	0	0	20	-	15	23	0	0	0	r-a			
36. <i>E. angustifolium</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	sp			
37. <i>Polemonium acutifolium</i>	17	-	5	8	27	-	22	30	40	-	20	28	80	6.9	30	43	sp		
38. <i>Viola epipactis</i>	0	0	0	0	36	-	2	4	40	0.6	3	5	60	0.4	5	7	sp		
39. <i>Saxifraga punctata</i>	50	0.8	2	4	82	0.2	20	25	40	0.1	5	8	0	0	0	sp-a, sp-a			
40. <i>S. rivularis</i>	17	0.1	2	3	0	0	0	0	0	0	0	0	0	0	0	sp			
41. <i>Dodecatheon frigidum</i>	0	0	0	0	0	0	0	0	0	0	0	0	20	-	10	12	sp		
42. <i>Hyssopus alpestris</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	sp			
43. <i>Castilleja Menziesii</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	sp			
44. <i>Pedicularis nudica</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	sp			
45. <i>Mimulus biflorus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	sp			
46. <i>Stellaria longipes</i>	17	0.1	1	2	0	0	0	0	0	0	0	0	30	0.1	2	3	r, sp. b		
47. <i>Antennaria monocephala</i>	0	0	0	0	9	-	1	3	0	0	0	0	20	-	6	7	sp-a		
48. <i>Arnica alpina</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	sp-a			
49. <i>A. Lessingii</i>	0	0	0	0	0	0	0	0	0	0	0	0	60	0.1	13	25	sp-a		
50. <i>Artemisia arctica</i>	0	0	0	0	27	-	28	25	0	0	0	0	20	-	10	15	r-a		
51. <i>A. Tilioides</i>	0	0	0	0	45	-	17	23	40	-	23	38	80	4.8	32	54	sp		
52. <i>Petasites frigidus</i>	33	0.2	10	15	91	19.5	16	25	80	5.8	20	25	60	2.1	18	25	r, sp. b		
53. <i>Sonchis lugens</i>	0	0	0	0	0	0	0	0	0	0	0	0	30	0.3	37	60	sp		
54. <i>Achillea borealis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	sp			
Dead surface organic	100	111.0	5	17	100	174.5	12	8	100	337.5	2	2	100	370.1	4	1			
Moss (live)	100	37.3	4		100	65.3	3		100	46.5	2		80	0.2	4				
Lichen (live)	33	0.1	4		64	4.8	3		40	2.0	2		0	0.0	4				
Bare ground and rock	0		6		0		11		0				0						

APPENDIX 12 (continued)

B: Adjacent Chionochloa Communities*

SPECIES	RIDGE						SNOWPATCH						BIRCH						REMARKS
	S-Facing			N-Facing			S-Facing			N-Facing			S-Facing			N-Facing			
	RF	Biomass Height		RF	Biomass Height		RF	Biomass Height		RF	Biomass Height		RF	Biomass Height		RF	Biomass Height		
	(X)	Av (cm)		(X)	Av (cm)		(X)	Av (cm)		(X)	Av (cm)		(X)	Av (cm)		(X)	Av (cm)		
	10	6	Av Max	10	6	Av Max	10	6	Av Max	10	6	Av Max	10	6	Av Max	10	6	Av Max	
1. Salix reticulata	100	12.4	1 2	100	2 5		33	-	2 5	25	-	2 5	0	0	0	0	0	0	un
2. S. pulchra	20	-	30 40	100	10 20		67	5.7	10 30	100	6.5	5 15	57	0.4	40 75	57	0.4	40 75	un, um, lln, lv
3. S. reticulata	0	0	0	0	0		0	0	0	0	0	0	14	-	4 5				un
4. Spiraea nemoralis	0	0	0	0	0		0	0	0	0	0	0	29	-	15 25				un, um
5. Rosa acicularis	0	0	0	0	0		0	0	0	0	0	0	71	2.7	13 25				un
6. Rubus chamaemorus	10	-	5 8	0	0		33	-	5 10	0	0	0	0	0	0				un
7. Dryas octopetala	10	-	5 8	0	0		0	0	0	0	0	0	0	0	0				un
8. Betula glandulosa	60	23.8	15 30	100	5 15		83	6.4	10 20	75	13.3	10 20	100	1176.3	42 70				un, um, lln, lv
9. Linnaea borealis	0	0	0	0	0		0	0	0	0	0	0	29	-	2 5				un
10. Cassiope tetragona	40	30.5	2 5	50	2 5		67	111.2	8 10	25	-	2 5	43	0.1	5 13				un(P1), um(P2)
11. Empetrum nigrum	20	-	2 5	50	2 5		100	22.3	5 6	100	54.4	3 5	57	-	5 7				un, um
12. Ledum groenlandicum	50	30.6	5 15	100	5 10		67	3.8	5 8	75	159.5	5 10	43	-	10 23				un(19.6 gm/m ²)
13. Vaccinium uliginosum	100	84.3	5 5	50	5 10		100	86.3	8 13	75	40.8	10 15	100	45.4	10 15				un, um, lln
14. V. vitis-idaea	100	14.6	2 5	100	2 5		100	16.2	2 5	75	70.4	3 6	100	292.9	5 13				un, um, lln, lln, lv, um
15. Equisetum arvense	60	1.1	10 20	0	0		17	0.6	13 20	0	0	0	0	0	0				un
16. Carex lugens	90	3.7	10 15	100	15 23		67	11.0	15 20	50	4.1	13 19	0	0	0				un
17. Eriophorum vaginatum	0	0	0	0	0		17	-	5 15	0	0	0	0	0	0				un
18. Arctagrostis latifolia	50	-	25 36	100	34 41		50	-	15 25	25	0.7	15 31	29	-	8 15				un, um, lln, lln, lv
19. Festuca altaica	0	0	0	0	0		0	0	0	0	0	0	14	-	16 23				un, um
20. Poa arctica	20	-	10 48	100	13 18		33	-	13 20	25	-	10 18	71	3.9	10 13				un, um, lln, lln, lv
21. Anemone nemorosa	60	0.7	13 18	100	13 18		17	-	15 18	50	0.1	13 20	17	-	10 13				un, um
22. Polygnum bistorta	80	0.3	13 15	100	15 23		100	2.2	10 18	100	3.1	8 13	17	-	10 13				un, um, lln, lln
23. Epilobium angustifolium	10	-	41 60	0	0		0	0	0	0	0	0	0	0	0				un, um
24. Saxifraga punctata	0	0	0	0	0		17	-	15 18	25	-	15 20	0	0	0				un, um, lln, lln, lv
25. S. bronchialis	10	-	15 18	0	0		0	0	0	0	0	0	0	0	0				un
26. S. trinervia	10	-	6 15	50	15 15		0	0	0	0	0	0	0	0	0				un
27. Pedicularis capitata	30	-	15 18	100	12 15		17	-	5 11	25	-	10 13	0	0	0				un
28. P. labradorica	10	-	13 17	100	13 14		0	0	0	25	-	11 15	0	0	0				un
29. P. Kanai	40	0.2	16 18	100	14 16		0	0	0	25	-	8 13	0	0	0				un
30. Minuartia arctica	30	-	3 8	50	3 4		17	-	4 5	25	-	3 6	0	0	0				un
31. Stellaria media	50	0.1	2 4	100	2 3		50	0.1	2 3	0	0	0	57	0.8	2 3				un, um, lln, lln, lv
32. Arnica leucogaster	0	0	0	0	0		0	0	0	25	-	18 20	0	0	0				un, lln, um
33. Artemisia arctica	0	0	0	100	13 20		0	0	0	0	0	0	0	0	0				un, um, lln, lln, lv, um
34. Potamogeton frigidus	60	0.3	8 20	50	6 9		50	0.4	10 13	100	0.5	8 43	29	-	13 20				un, um, lln, lln, lv, um
35. Senecio fuscatus	20	-	10 15	100	8 13		0	0	0	0	0	0	0	0	0				un
36. Senecio angustifolius	20	-	10 18	100	13 20		17	-	10 15	50	0.7	15 20	43	-	10 13				un(0.1 g/m ²)
37. Parrya medialis	10	-	15 18	0	0		0	0	0	0	0	0	0	0	0				un
38. Douglasia ochroleuca	30	1.7	3 8	50	2 5		0	0	0	0	0	0	0	0	0				un
39. Loiseleuria procumbens	80	24.9	3 5	50	3 5		17	-	2 5	0	0	0	0	0	0				un
40. Silene acaulis	20	-	2 4	50	3 5		0	0	0	0	0	0	0	0	0				un
41. Lupinus arcticus	60	9.3	13 25	100	13 18		17	-	15 20	25	-	19 26	17	-	8 12				un
42. Arctostaphylos alpina	80	7.4	3 8	100	2 4		0	0	0	0	0	0	86	1.0	2 3				un
43. A. rubra	20	8.0	4 8	0	0		67	0.8	1 3	50	0.8	3 5	0	0	0				un
44. Pyrola grandiflora	20	0	0	0	0		67	0.1	3 6	25	-	4 8	43	-	6 13				un
Dead surface organic	100	226.7	6 0	100			100	432.5	4 1	100	352.8	2 0	100	442.0	2 1				
Moss (live)	100	63.1	6	100			100	293.5	4	100	225.4	2	100	67.7	2				
Lichen (live)	100	123.0	6	100			100	50.1	4	100	39.9	2	100	5.4	2				
Bare ground & rock	100	12x	10	100	30x		0	6		0	4		0	7					

Key:

- * see Figure
- RF for complete species lists, see Lambert (1968)
- RF relative frequency
- Av average
- Max maximum
- Biomass above-ground standing live and dead (average over all biomass quadrats)
- (-) did not occur in biomass quadrats
- a number of quadrats
- b includes scattered specimens of *Poa annua*
- c average for 2 quadrats in an area of ground squirrel burrows
- d survey over two sidehills: NW-facing slope (Shaded #1) and NE-facing slope (#1 Ridge); includes PQ North Slope
- e mainly *Poa arctica* with occasional plants of *Poa alpina*
- f mainly *Stellaria leucogaster* with scattered individuals of *S. leucogaster* and *S. borealis*
- g in area of ground squirrel burrows
- h *Pyrola* plants in upper willows
- i percentage of dead organic composed of blow-in debris accumulated in the snowpatch
- j percentage cover - average for quadrats with bare ground
- k presence of species noted only: willows (w), upper meadow (um), late meadow (lm), lower meadow (llm), creek meadow (cm), ridge (r), snowpatch (sp), birch (b), N-facing (n), S-facing (s), not recorded (np)

APPENDIX 13

Vegetation Analysis for Selected Plant Species, Snowed #2
A: Chionochloa Communities*

Species ^{***}	WE-Facing			UPPER MEADOW SW-Facing			Xeric	LATE MELT			Flat			
	RF	Biomass	Height	RF	Biomass	Height		RF	Biomass	Height		RF	Biomass	Height
	(%)	Av (gm)	(cm)	(%)	Av (gm)	(cm)		(%)	Av (gm)	(cm)		(%)	Av (gm)	(cm)
Q	12	6	Av Max	6	3	Av Max	1 (SN 10) Av Max	7	3	Av Max	6	3	Av Max	
1. Salix Chamissoensis	100	83.6	2 5	50	88.7	2 5	y	0	0	0	0	0	0	
2. S. polaris ssp. pseudopolaris	67	21.1	2 3	0	0	0	y	43	6.6	1 3	33	9.1	2 3	
3. S. pulchra	0	0	0	4	30	55	y	0	0	0	0	0	0	
4. Spiraea														
Bosquerioides	17	-	10 15	0	0	0	x	10 15	0	0	0	0	0	
5. Rubus chamaemorus	0	0	0	0	0	0	x	6 10	0	0	0	0	0	
6. Sibbaldia procumbens	0	0	0	0	0	0	y	0	0	0	0	0	0	
7. Betula glandulosa	0	0	0	0	0	0	y	0	0	0	0	0	0	
8. Limnosa borealis	17	-	2 5	0	0	0	x	1 3	0	0	0	0	0	
9. Cassiope tetragona	67	136.8	2 5	0	0	0	x	0	0	0	0	0	0	
10. Empetrum nigrum	17	0.1	2 3	0	0	0	x	2 4	0	0	0	0	0	
11. Ledum groenlandicum	8	-	2 5	0	0	0	y	0	0	0	0	0	0	
12. Vaccinium uliginosum	0	0	0	50	0.6	10 15	x	10 12	0	0	0	0	0	
13. V. vitis-idaea	42	1.4	2 4	0	0	0	x	3 5	0	0	0	0	0	
14. Equisetum arvense	50	0.3	11 15	83	2.3	17 30	x	8 13	86	2.3	11 20	83	5.0	11 23
15. Carex Lachenalii	50	1.1	13 15	17	-	13 18	x	15 20	86	2.4	11 13	50	1.9	13 18
16. C. peduncarpa	67	2.8	20 25	100	54.5	30 61	x	30 41	57	4.6	13 25	50	12.6	25 30
17. Lupula multiflora	17	0.1	25 34	0	0	0	x	40 51	0	0	0	0	0	
18. Arctagrostis latifolia	0	0	0	17	-	25 30	x	0	0	0	33	0.3	25 30	
19. Festuca altaica	8	0.1	25 40	0	0	0	y	0	0	0	0	0	0	
20. Poa arctica	83	1.8	17 20	83	2.0	25 30	x	10 15	86	6.6	13 20	100	11.5	8 15
21. Trisetum spicatum	42	0.1	14 20	17	-	15 20	y	29	0.1	15 18	33	0.2	15 20	
22. Aconitum delphinifolium	0	0	0	67	0.2	12 20	y	0	0	0	0	0	0	
23. Anemone narcissiflora	50	0.3	13 30	0	0	0	x	0	0	0	0	0	0	
24. A. Richardsonii	67	0.4	10 13	67	1.6	8 13	y	0	0	0	0	0	0	
25. Ranunculus nivalis	0	0	0	33	0.4	18 30	y	29	0.9	15 25	0	0	0	
26. R. pygmaeus	0	0	0	17	-	2 8	y	57	0.8	5 8	100	0.9	8 15	
27. Oxycis digyna	8	-	1 3	100	1.5	18 30	y	86	8.2	10 23	100	20.8	8 20	
28. Polygonum bistorta	42	0.4	18 30	0	0	0	x	15 20	0	0	0	33	0.1	8 15
29. P. viviparum	50	0.1	7 10	67	0.3	13 20	y	0	0	0	0	0	0	
30. Epilobium	0	0	0	0	0	0	y	29	0.1	2 5	67	0.7	1 3	
31. Polomonium acutifolium	0	0	0	83	0.8	30 76	y	0	0	0	0	0	0	
32. Viola epipactis	33	0.4	1 3	33	0.2	2 4	y	29	0.1	2 4	33	0.4	2 4	
33. Saxifraga punctata	42	0.1	15 20	83	0.2	20 25	y	29	0.1	13 25	33	0.5	3 8	
34. S. divaricata	8	-	3 6	0	0	0	y	71	0.1	1 3	17	-	1 3	
35. Dodecatheon frigidum	33	1.0	13 20	17	-	10 13	y	14	-	15	0	0	0	
36. Myosotis alpestris	0	0	0	33	-	20 25	y	0	0	0	0	0	0	
37. Castilleja leucophaea	0	0	0	0	0	0	x	0	0	0	0	0	0	
38. Pedicularis seductica	8	-	10 13	0	0	0	x	8 10	0	0	0	0	0	
39. Mimulus biflorus	0	0	0	0	0	0	y	14	-	2 3	0	0	0	
40. Stellaria longipes	0	0	0	100	8.7	2 5	x	0	0	0	4	-	2 8	
41. Anemone monocephala	50	0.1	9 15	0	0	0	x	0	0	0	0	0	0	
42. Arisaema Lesingii	50	0.5	12 20	0	0	0	y	29	0.3	15 20	0	0	0	
43. Artemisia arctica	92	5.5	17 30	67	8.1	20 30	x	25 30	29	0.9	10 13	0	0	0
44. A. Tillei	0	0	0	83	7.2	15 30	y	29	0.6	10 20	0	0	0	
45. Potentilla frigidus	58	0.1	8 10	50	0.1	5 8	x	10 13	43	0.1	9 13	0	0	0
46. Senecio lugens	0	0	0	33	-	30 41	x	15 18	0	0	0	0	0	
47. Phlippeia algida	0	0	0	0	0	0	y	14	-	2 3	0	0	0	
48. Gentiana glauca	0	0	0	0	0	0	x	3 6	0	0	0	0	0	
49. Loiseleuria procumbens	17	-	2 5	0	0	0	y	0	0	0	0	0	0	
50. Parosela Kotzebuei	17	0.1	1 3	33	0.1	5 6	y	14	0.1	1 3	0	0	0	
51. Ranunculus Turneri	0	0	0	17	-	20 30	y	0	0	0	0	0	0	

APPENDIX 13

Vegetation Analysis for Selected Plant Species, Snowed #2
A: Chionophilus Communities*

Species ^Q	NW-Facing			UPPER MEADOW SW-Facing			Xeric			LATE MELT NW-Facing			Flat		
	RF Biomass Height			RF Biomass Height			RF Biomass Height			RF Biomass Height			RF Biomass Height		
	(X) Av (gm) (cm)	12 6 Av Max		(X) Av (gm) (cm)	6 3 Av Max		(X) Av (gm) (cm)	1 (SW 10) Av Max		(X) Av (gm) (cm)	7 3 Av Max		(X) Av (gm) (cm)	6 3 Av Max	
1. Salix Chamissoana	100	83.6	2 5	50	88.7	2 5	y			0	0	0	0	0	0
2. S. polaris ab. pseudopolaris	67	21.1	2 3	0	0	0	y			43	6.6	1 3	33	9.1	2 3
3. S. pulchra	0	0	0	4	30	55	y			0	0	0	0	0	0
4. Spiraea				0	0	0									
5. Ranunculus	17	-	10 15	0	0	0	x	10 15		0	0	0	0	0	0
6. Sibbaldia procumbens	0	0	0	0	0	0	x	6 10		0	0	0	0	0	0
7. Betula glandulosa	0	0	0	0	0	0	y			0	0	0	0	0	0
8. Linnaea borealis	17	-	2 5	0	0	0	x	1 3		0	0	0	0	0	0
9. Cassiope tetragona	67	336.8	2 5	0	0	0	x			0	0	0	0	0	0
10. Saxifraga nigrum	17	0.1	2 3	0	0	0	x	2 4		0	0	0	0	0	0
11. Ledum groenlandicum	8	-	2 5	0	0	0	y			0	0	0	0	0	0
12. Vaccinium uliginosum	0	0	0	50	0.6	10 15	x	10 12		0	0	0	0	0	0
13. V. vitis-idaea	42	1.4	2 4	0	0	0	x	3 5		0	0	0	0	0	0
14. Equisetum arvense	50	0.3	11 15	83	2.3	17 30	x	8 13		86	2.3	11 20	83	5.0	11 23
15. Carex lasiocarpa	50	1.1	13 15	17	-	13 18	x	15 20		86	2.3	11 13	50	1.9	13 18
16. C. peduncarpa	67	2.8	20 25	100	54.5	30 61	x	30 41		57	4.6	13 25	50	12.6	25 30
17. Lycopodium multiflorum	17	0.1	25 36	0	0	0	x	40 51		0	0	0	0	0	0
18. Arctostaphylos latifolia	0	0	0	17	-	25 30	x			0	0	0	33	0.3	25 30
19. Festuca arctica	8	0.1	25 40	0	0	0	y			0	0	0	0	0	0
20. Poa arctica	83	1.8	17 20	83	2.0	25 30	x	10 15		86	6.6	13 20	100	11.5	8 15
21. Trietum spicatum	42	0.1	14 20	17	-	15 20	y			29	0.1	15 18	33	0.2	15 20
22. Aconitum delphinifolium	0	0	0	67	0.2	12 20	y			0	0	0	0	0	0
23. Anemone narcissiflora	50	0.3	13 30	0	0	0	x			0	0	0	0	0	0
24. A. Richardsonii	67	0.4	10 13	67	1.6	8 13	y			0	0	0	0	0	0
25. Ranunculus nivalis	0	0	0	33	0.4	18 30	y			29	0.9	15 25	0	0	0
26. R. pygmaeus	0	0	0	17	0.2	2 8	y			57	0.8	5 8	100	0.9	8 15
27. Oxyria digyna	8	-	1 3	100	1.5	18 30	y			86	8.2	10 23	100	20.8	8 20
28. Polygala bistorta	42	0.4	18 30	0	0	0	x	15 20		0	0	0	33	0.1	8 15
29. P. viviparum	50	0.1	7 10	67	0.3	13 20	x			0	0	0	0	0	0
30. Epilobium	0	0	0	0	0	0	y			29	0.1	2 5	67	0.7	1 3
31. Polemonium acutifolium	0	0	0	83	0.8	30 76	y			0	0	0	0	0	0
32. Viola epipactis	33	0.4	1 3	33	0.2	2 4	y			29	0.1	2 4	33	0.4	2 4
33. Saxifraga punctata	42	0.1	15 20	83	0.2	20 25	y			29	0.1	13 25	33	0.5	3 8
34. S. rivalaris	8	-	3 6	0	0	0	y			71	0.1	1 3	17	-	1 3
35. Dodecatheon frigidum	33	1.0	13 20	17	-	10 13	y			14	-	15	0	0	0
36. Myosotis alpestris	0	0	0	33	-	20 25	y			0	0	0	0	0	0
37. Castilleja Reupii	0	0	0	0	0	0	x			0	0	0	0	0	0
38. Pedicularis sudsotica	8	-	10 13	0	0	0	x	8 10		0	0	0	0	0	0
39. Mimulus biflorus	0	0	0	0	0	0	y			14	-	2 3	0	0	0
40. Stellaria longipes	0	0	0	100	8.7	2 5	x	2 3		0	0	0	4	-	2 8
41. Anemone monocephala	50	0.1	9 15	0	0	0	x			0	0	0	0	0	0
42. Arnica Lessingii	50	0.5	12 20	0	0	0	y			29	0.3	15 20	0	0	0
43. Artemisia arctica	92	5.5	17 30	67	8.1	20 30	x	25 30		29	0.9	10 13	0	0	0
44. A. Tillei	0	0	0	83	7.2	15 30	y			29	0.6	10 20	0	0	0
45. Petasites frigidus	58	0.1	8 10	50	0.1	5 8	x	10 13		43	0.1	9 13	0	0	0
46. Senecio lugens	0	0	0	33	-	30 41	x	15 18		0	0	0	0	0	0
47. Phlox alba	0	0	0	0	0	0	y			14	-	2 5	0	0	0
48. Gentiana glauca	0	0	0	0	0	0	x	3 6		0	0	0	0	0	0
49. Loiseleuria procumbens	17	-	2 5	0	0	0	y			0	0	0	0	0	0
50. Parnassia Kotzebuei	17	0.1	1 3	33	0.1	5 6	y			14	0.1	1 3	0	0	0
51. Ranunculus Turneri	0	0	0	17	-	20 30	y			0	0	0	0	0	0

APPENDIX 13 (continued)

Specieses	2													
	WE-FACING			UPPER MEADOW SH-FACING			Xeric			LATE MELT				
	RF Biomass Height			RF Biomass Height			RF Biomass Height			RF Biomass Height				
(X) Av (gm) (cm)	(X) Av (gm) (cm)	(X) Av (gm) (cm)	(X) Av (gm) (cm)	(X) Av (gm) (cm)	(X) Av (gm) (cm)	(X) Av (gm) (cm)	(X) Av (gm) (cm)	(X) Av (gm) (cm)	(X) Av (gm) (cm)	(X) Av (gm) (cm)	(X) Av (gm) (cm)	(X) Av (gm) (cm)		
Q	12	6	Av Max	6	3	Av Max	1 (SH 10)	Av Max	7	3	Av Max	6	3	Av Max
	Q *			Q *					Q *			Q *		
Dead surface organic	100	289.3	7 6	100	309.2	3 1	x		100	187.5	3 49	100	451.0	4 91
Moss (live)	100	89.3	6	100	40.3	3	x		100	236.8	3	100	8.8	3
Lichen (live)	71	12.2	6	67	0.4	3	x		0	0.0	3	0	0.0	3
Bare ground and rock	0		12	17	5 t	6	y		100	5 t	7	67	15 t	6

B: Birch-Willow Borders*

Specieses	PQ 050 BIRCH				PQ 000 BIRCH				PQ 005 BIRCH-WILLOW				PQ 045 BIRCH-WILLOW			
	Height				Height				Height				Height			
	F (cm)	F	SS	Av Max 72 73 72 73	F (cm)	F	SS	Av Max 72 73 72 73	F (cm)	F	SS	Av Max 72 73 72 73	F (cm)	F	SS	Av Max 72 73 72 73
1. Salix pulchra	x 30	40	x x x x	y	y				x 50	80	x x x x	y	x 80	99	x x x x	y
2. Spiraea Beauverdiana	y				x 20	30	x x x x		x 15	25	x x x x	y				
3. Betula glandulosa	x 30	38	x x x x	x	x 20	30	x x x x		x 10	15	x x x x	x	x 50	100	x x x x	x
4. Linnaea borealis	y				x 2	4	x x x x		x 2	5	x x x x	y				
5. Cassiope tetragona	y				x 5	8	x x x x		x 2	4	x x x x	y				
6. Empetrum nigrum	y				x 5	8	x x x x		x 2	3	x x x x	y				
7. Ledum groenlandicum	y				x 5	8	x x x x		x 5	8	x x x x	y	x 6	7	x x x x	y
8. Vaccinium uliginosum	x 10	15	x x x x	x	x 8	10	x x x x		x 10	13	x x x x	x	x 20	40	x x x x	x
9. V. vitis-idaea	x 3	6	x x x x	x	x 2	4	x x x x		x 3	6	x x x x	x	x 3	4	x x x x	x
10. Equisetum arvense	y				x 13	20	x x x x		x 13	20	x x x x	y	x 17	30	x x x x	y
11. Carex lugens	x 20	30	x x x x	y	y				y				y			
12. Arctagrostis latifolia	x 20	30	x x x x	y	y				y				x 30	76	x x x x	y
13. Festuca altaica	x 30	51	x x x x	y	y				y				y			
14. Poa arctica	x 25	30	x x x x	x	x 10	15	x x x x		y				y			
15. Anemone narcissiflora	x 15	28	x x x x	x	x 15	20	x x x x		y				y			
16. Polygonum bistorta	x 8	13	x x x x	x	x 13	18	x x x x		x 13	20	x x x x	x	x 8	10	x x x x	x
17. Epilobium angustifolium	y				x 20	28	x x x x		x 30	51	x x x x	y	x 3	5	x x x x	y
18. Saxifraga punctata	y				y				y				x 3	5	x x x x	y
19. S. tricuspidata	x 10	15	x x x x	y	y				y				y			
20. Pedicularis sp.	y				x 1	3	x x x x		x 2	4	x x x x	y	y			
21. Stellaria longipes	x 5	18	x x x x	y	y				x 18	20	x x x x	y	y			
22. Arnica lessingii	y				y				x 20	30	x x x x	y	y			
23. Artemisia arctica	y				y				y				x 45	61	x x x x	y
24. Artemisia Tiliacii	y				y				y				x 18	30	x x x x	y
25. Petasites frigidus	x 8	12	x x x x	x	x 6	10	x x x x		x 8	12	x x x x	y	x 10	15	x x x x	y
26. Saussurea angustifolia	x 20	30	x x x x	y	y				y				x 10	13	x x x x	y
27. Lupinus arcticus	x 15	18	x x x x	x	x 10	15	x x x x		y				y			
28. Arctostaphylos alpina	x 5	6	x x x x	y	x 4	7	x x x x		y				y			
29. Pyrola grandiflora	x 2	4	x x x x	y	x 5	12	x x x x		y				x 10	18	x x x x	x
30. Lycopodium selago	y				y				y				y			
Dead surface organic	x				x				x				x			
Moss (live)	x				x				x				x			
Lichen (live)	x				x				x				x			
Bare ground and rock	y	Ot			y	Ot			y	Ot			y	Ot		

APPENDIX 13 (continued)

(1) Key:

- * - see Figure 3
 * - for complete lists of snowbed plant species, see Lambert (1968)
 a - species from Appendix 1a not listed here did not occur at this snowbed
 b - *Epilobium anagallidifolium*
 c - *Pedicularis labradorica*
 d - *Stellaria calycantha*: 1 quadrat only
 e - mainly from PW EL3
 n - did not flower
 o - did not set seed
 um - upper meadow
 lm - late melt
 s - % of dead organic composed of blown-in debris accumulated in the snowpack
- t - % cover: average for quadrats with bare ground
 x - present in quadrat
 y - not present in quadrat
 z - occurring in same melt zone adjacent to quadrat
 Q - number of quadrats
 P - presence
 F - flowered
 SS - set seed
 Av - average
 Max - maximum
 RF - relative frequency
 Biomass - above-ground standing live + dead biomass quadrats
 (-) - did not occur in biomass quadrats

(2) List of Quadrats

Quadrat	Slope°	Aspect	Drainage	Melt Area		Vegetation Type
				1972	1973	
050	15	W	Good	May 20-31	May 20-28	edge birch and hummocky terrain
000	0	-	Good	May 31-Jn 5	May 28-Jn 4	birch - top of #2 creek gully
005	20	E	Good	Jn 5-12	Jn 9-11	edge birch-willow and snowbed meadow
045	20	W	Good	Jn 5-12	Jn 11-13	birch + willows
ca	40	NE	Good	Jy 2-5	Jn 30-Jy 6	um, Cassiope dominated, above crest of drift
A	20	NE	Good	Jn 25-Jy 2	Jy 6-10	um, Cassiope dominated, below PQa
B	30	NE	Good	Jn 12-19	Jy 10	um, Cassiope dominated, below PQa
C	35	NE	Good	Jn 12-19	Jy 6-10	um, Salix Chamissonis, below PQ8
018	40	ENE	Good	Jy 2-7	Jy 2-5	um, Salix Chamissonis, below PQ005
EL1	30	E	Good	Jn 25-Jy 2	Jn 24-30	um, S-end of snowbed, 3 m high bank
E	35	SW	Good	Jn 19-25	Jy 2-5	um, creek meadow
040	15	SW	Good	Jy 2-5	Jn 30-Jy 6	um, creek meadow
WL1	25	SW	Good	Jy 2-7	Jy 10-15	um, creek meadow
SW10	5	SE	Good	Jn 5-12	Jn 13-18	um, dry meadow
0	20	NE	Good	Jn 25-Jy 2	Jy 15-20	lm, 1 meter above creek
F	20	NE	Good	Jy 7-12	Jy 15-20	lm, 40% bare ground and rock
020	30	NE	Good	Jy 12-19	Jy 15-20	lm, 20% bare ground and rock
EL3	40	ENE	Good	Jy 12-19	Jn 30-Jy 6	lm, adjacent to flat, S-end of snowbed
EL2	0	-	Good	Jy 2-4	Jn 30-Jy 6	lm, S-end of snowbed
EL4	0	-	Good	Jy 12-19	Jy 20-24	lm, rocky area next to creek
EL5	0	-	Good	Jy 19-26	Jy 24-31	lm, rocky area next to creek

APPENDIX 14 (continued)

Key:

- RF = relative frequency
 Biomass = above-ground standing live and dead (grams per meter²)
 f = flowers (% of quadrats with species)
 ss = set seed (% of quadrats with species)
 72 = 1972
 73 = 1973
 Q = # of quadrats
 Av = average
 Max = maximum
 * = see Lambert (1968) for complete lists of snowbed species
 a = species from Appendix 1A not listed here did not occur at this snowbed
 b = W_{5A} only
 c = organic only, sorted from samples
 t = adjacent
 um = upper meadow
 lm = late melt

List of Major Quadrats

Quadrat#	Slope°	Aspect	Drainage	Melt Area	Vegetation Type
S1	20	S	Good	Jy 7 - 9 Jn 27 - 30	um, scattered 30 cm Salix pulchra bushes
E1	5	S	Good	Jy 7 - 9 Jn 20 - 24	um, Salix-Chamaedaphne
E2B3	2	S	Good	Jy 12 - 19 Jn 30 - Jy 7	um, edge with later melt zones
W1	2	E	Good	Jn 12 - 19 Jn 4 - 11	um, mesic grassy meadow
W2	20	E	Good	Jn 20 - 23 Jn 11 - 15	um, mesic
W3	30	E	Good	Jn 25 - Jy 2 Jn 15 - 18	um, mesic
W4	15	E	Good	Jy 2 - 7 Jn 20 - 24	um, mesic
W5A3	35	E	Good	Jy 7 - 12 Jn 24 - 30	lm, bare soil + rock = 10%
W6	15	E	Good	Jy 12 - 18 Jy 7 - 10	lm, bare soil + rock = 60%
W7	15	E	Good	Jy 19 - 26 Jy 10 - 15	lm, bare soil + rock = 90%, 2 meters from creek at base of gully.

*Quadrats W1 - W7 along transect along a steep, E-facing creek bank: transect perpendicular to length of snowbed.

Ranunculus Ranunculus Carex Carex Carex Arctagrostis Poa Trisetum Phippis
nivalis pygmaeus Lachenalii podocarpa lugens latifolia arctica spicatum aloides

KEY
 - flower buds
 - in flower
 - period of flowering to fruit ripening
 - period of ripened fruit
 - period of seed dispersal

Figure 15. Phenological Time-Tables of Selected Plant Species

END

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