

THE UNIVERSITY OF MANITOBA

THE WINTER ECOLOGY OF CAPE CHURCHILL CARIBOU

(Rangifer tarandus ssp.)

by

Mitch William Campbell

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(Rangifer tarandus ssp.)

BY

MITCH WILLIAM CAMPBELL

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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ABSTRACT

THE WINTER ECOLOGY OF CAPE CHURCHILL CARIBOU (RANGIFER TARANDUS ssp.)

by

Mitch W. Campbell

Aspects of snow conditions, plant community use, and feeding habits were examined for caribou occupying the Cape Churchill Wildlife Management Area. Studies were carried out over each of the 1989-90 and 1990-91 snow seasons. Attempts were made to interrelate feeding habits and plant community use with changing snow conditions based on 7 snow stations set up within four taiga and three tundra plant communities. Fundamental differences between taiga and tundra snow conditions are also discussed.

Plant communities were described based on quadrat and point quarter methods, prior to snowfall, within each of four taiga and three tundra plant community snow stations. Snow conditions at snow stations and caribou feeding sites were quantified through the excavation and examination of snow profiles. Aspects of thickness, hardness, and a mathematical index incorporating eight snow variables (Varrio Snow Index (VSI)) were examined for each profile.

Aspects of plant community use were quantified through tracking and the examination of feeding sites. Feeding habits were quantified through the analysis of feeding crater contents, pellet groups, and rumen samples.

Taiga and tundra snow conditions are fundamentally different. This was primarily due to the effects of wind on the more exposed tundra and the relative lack of wind in the taiga. The occurrence of rain, freezing rain, wet snow, and a thick snow cover had the net effect of elevating taiga VSI's while wind and periods of rain and freezing rain largely controlled tundra VSI's. Cape Churchill caribou reacted to elevated VSI's in part by shifting to communities with lower VSI's. A shift to communities with harder and/or thinner snow was also apparent and primarily related to feeding site access. Despite shifts in plant community use related to changing snow conditions, preferred forage species changed little either within or between snow seasons. Lichens were the most prominent plant group selected by Cape Churchill caribou as forage.

Cape Churchill caribou displayed a wide use of plant communities that varied both throughout the snow seasons and between them. Snow conditions within taiga plant communities differed both between themselves over both snow seasons, and differed between the two snow seasons. Tundra

plant communities also displayed variability over the same periods though not as severe as taiga sites. Cape Churchill caribou did however remain in feeding sites beyond threshold levels if suitable alternate plant communities were not available. These data imply that conventional wildlife management techniques used to determine caribou range tend dramatically to underestimate actual requirements. Through the long term field monitoring of representative plant community snow conditions and winter habitat use by caribou, a more realistic estimate of caribou range can be achieved.

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4.0 KEY TO ABBREVIATIONS

BR	=	Beach Ridge
BSP	=	Black Spruce Palsa
CCC	=	Cape Churchill Caribou
CCH	=	Cape Churchill Caribou Herd
CCWMA	=	Cape Churchill Wildlife Management Area
CR	=	Feeding crater
E/EW	=	Early Winter
HLT	=	Hummocky or Lichen Heath Tundra
L/LW	=	Late winter
M/MW	=	Mid-winter
RU	=	Rumen contents
SC	=	Scat/Fecal material
ST	=	Sedge or Graminoid Tundra
TF	=	Tamarack Fen - Shrub Thicket - Meadow Marsh
TWS	=	Tamarack - White Spruce Forest
WSF	=	White Spruce Forest

1.0 LITERATURE REVIEW

1.1 Introduction

Within the taiga, forest-tundra, and tundra regions, winter is the most critical period for wild ruminants (Ferguson and Mahoney 1991, Klein 1969, Miller 1976, Pruitt 1959, Russell and Martell 1984, Stardom 1975, Swift et al. 1980, Vernadski 1933).

Formozov (1946) was one of the first boreal ecologists to recognize the selective forces manipulating boreal species of plants and animals during the snow season. Formozov suggested that animals could be divided into species that do not inhabit snowy regions and as a result avoid them (Chionophobes), species that can withstand winters with considerable snow (Chioneuphores), and species whose ranges lie completely, or almost completely, in regions of hard continuous winters (Chionophiles). Caribou (Rangifer tarandus ssp.) are highly adapted to snow covered environments and as a result are termed chionophiles (Formozov 1946, Pruitt 1959, Russell and Martell 1984).

Early man's intrusion into the North American arctic interior was directly connected to caribou, more specifically barren-ground caribou (Rangifer tarandus

groenlandicus) and their ability to bridge the gap between the primary producers and the tertiary consumers within the arctic food chain. In times as recent as 1986 over 8000 people in the Keewatin district alone depended on caribou as their main source of food and winter clothing (Tennenhouse 1986).

Caribou numbers and movements in northern Canada rival those of ungulates living on present-day African savannas. This is surprising when one considers that the Canadian tundra produces an average standing crop of only 0.17-2.5 kg/km² compared to 170-200 kg/km² typically found on African savannas (Bliss et al. 1973, Klein 1969) . Despite the low productivity, diversity and rate of nutrient cycling, the tundra range makes up the most wide spread grazing system in the world. These findings suggest that caribou and their habitats deserve a great deal more attention and concern than they are currently being given (Chapin 1980).

1.2 Snow Study

Vernadski (1933) was the first to recognize the importance of snow to northern animals; "The presence of an ice and snow cover in the biosphere is, in its direct and

indirect results, one of the most important factors in nature". Another pioneer in snow ecology, Formozov (1946), concluded that reindeer, of all Scandinavian deer, are best adapted to snow, where representatives of the species are distributed in tundra and taiga regions with snow thickness varying from a maximum of 20 cm to greater than 100 cm. Increasingly, ecologists are finding that the collection and analysis of snow morphological data provides critical information concerning caribou movement and forage selection within boreal and arctic communities. In fact, studies have shown a convincing link between the characteristics of a snow cover and caribou population fluctuations (Bergerud 1974a, Bergerud 1980a, Gaare and Skogland 1975, Lent 1986, Loughrey and Kellsall 1970, Miller 1976, Pruitt 1979, 1985, Russell and Martell 1986, Stardom 1975, Telfer and Kellsall 1979). Both Pruitt (1959) and Bergerud (1974c) did, however, suggest that in the absence of extreme nival conditions (extremely hard and/or thick snow) caribou select communities primarily for suitable forages and secondarily for suitable nival conditions.

1.2.1 The Collection And Modification Of Snow

Barren-ground and, in some cases, woodland caribou encounter snow as an integral part of their environment for

at least 8 months of the year (Pruitt, 1959). Pruitt (1979) recognized 7 important periods during the snow season, each containing specific snow morphological characters to which caribou have adapted; 1. Fall critical period; 2. Pre-threshold period; 3. Threshold period; 4. Self-induced movement period; 5. Sub-marginal period; 6. Api-maturation period; 7. Spring critical period. As these periods are often difficult to identify, a more general division of a snow season into 3 ecologically important periods has been made by, among others, Russell and Martell (1984) and include; 1. Early winter (November through December); 2. Mid-winter (January through February); 3. Late winter (March through April).

The onset of snow cover is governed by the precise succession of meteorological events that bring the correct mass of moist air in contact with cold air making the arrival of a snow cover highly variable from year to year (Pruitt 1970). These same events are in part responsible for the differences between taiga and tundra snow. Pruitt (1984) described two different forms of tundra snow; 1. Upsik-Siqoq, where wind worked snow becomes consolidated into a mass (upsik), and Siqoq is the moving snow or windborne snow; 2. Zaboi-Vyduv, where a zaboi forms when a concave topographic surface fills with siqoq resulting in a large mass which persists well into the summer, and vyduv

represents a convex surface blown clear to reveal the substrate. Taiga snow also occurs in two forms (Pruitt 1984); 1. Api, or snow on the ground; 2. Qali, or the snow collected on trees. Both forms remain relatively unworked by wind due to the sheltered nature of most taiga communities (Pruitt 1984). These features of taiga and tundra communities often account for their variation in plant community structure. Plant communities are highly correlated with mean duration and thickness of the snow cover (Lent 1986). Gaare (1986) found that lichen communities are determined by the duration of the snow cover while their growth rates depend on the moisture regime during the snow free period. Communities with dense shrubs often trap wind-blown snow and as a result can become snow collection areas (Bergerud 1974a). Lent (1986) found the best lichen growths on reindeer ranges to be associated with moderately thick snow cover because of the protection and moisture offered. These conditions are most apparent within the taiga and forest ecotone and within concave surfaces (snow collection areas or zaboi) on tundra sites.

Only Soprovich (1989) has conducted community-based snow work within the Cape Churchill Wildlife Management Area. These studies were conducted on beach ridge (BR) (elevated marine gravel deposits isolated inland through

isostatic rebound), fen and modified (transition between beach ridge and fen) community types. Within the beach ridge community snow was relatively thin near the apex (the flattened top of the deposited marine gravel) and thick near the periphery (sloping sides of the marine deposit), values which averaged between 11.8 cm in January and 20.3 cm in March. The fen community averaged 27.3 cm in January and 40.0 cm in March, while the modified community averaged 27.3 cm in January and 41.6 cm in March. Hardness values were lower towards the apex and higher towards the periphery of beach ridge communities. Hardness values within the fen and modified communities varied considerably but remained greater than the beach ridge apex (Soprovich 1989).

1.2.2 Snow (Api) Thresholds

The two most ecologically important properties of a snow cover, when considering mammals, are hardness and thickness (Pruitt 1959). Although snow density has been used by many authors as a gauge to caribou range quality, it is currently considered too variable and misleading as it bears no statistical correlation to hardness (Pruitt 1990). Snow hardness and thickness generally increase from early to late winter on Caribou range (Adamczewski et al. 1988, Pruitt 1979, Schaefer 1988, Skogland 1978).

According to Carruthers et al. (1986) and Pruitt (1979) caribou have the ability to react to these changes by progressing down a gradient to regions with thinner and softer snow. This can cause extensive winter movements. The ability of caribou to detect differences in snow hardness and thickness is based on thresholds (values of snow hardness and thickness above which any given community becomes largely unavailable to caribou) to these characters that they will not transgress (Carruthers et al. 1986, Pruitt 1981).

The earliest recorded thresholds for snow thickness were presented by Formozov (1946) and Nasimovich (1955) who found that beyond 50-60 cm reindeer would move out of an area seeking thinner snow cover. These data could, however, be based on the smaller domestic reindeer and thus a lower tolerance for snow thickness. Today generally accepted thickness thresholds range between 60 and 70 cm (Henshaw 1968, Pruitt 1959, 1965, Russell and Martell 1984, Thomas 1990). Russell and Martell (1984) and Stardom (1975) found woodland caribou to have a higher threshold to snow thickness (65-74 cm) compared to barren-ground caribou (50 to 60 cm) a finding likely related to their larger size. Bergerud and Nolan (1970) found exceptions to the above values as they documented a reduction in number of feeding crater excavations when snow thicknesses exceeded

25 cm. Another extreme was observed by Brown and Theberge (1990) who found mean crater depth in Labrador between 58.3 and 118.2 cm.

Hardness thresholds for both barren-ground and woodland caribou are very complex and change with time of year, snow thickness and modification, exposure to wind, solar energy, and plant community. As a result, hardness thresholds (hardness values above which create conditions less desirable to caribou activity) recorded in the literature show a wide range from 6.5 g/cm² in the taiga to 9000 g/cm² in the tundra and above (Adamczewski et al. 1988, Pruitt 1981, 1965, Stardom 1975). Caribou will, however, increase their threshold of tolerance to hardness and thickness if softer and thinner snow is not available within suitable habitats (Pruitt 1979). Nonetheless, caribou avoid habitats with thick and hard snow if similar or adequate forage is available within habitats of thinner and softer snow (Bergerud and Nolan 1970, Fancy and White 1985, LaPerrier and Lent 1977, Miller et al. 1982, Pruitt 1959, 1979, 1981, Russell and Martell 1984, Skogland 1978, Stardom 1975).

Snow hardness may also have a dramatic effect on caribou movement. Collins and Smith (1991) noted that time spent walking generally increased with increased snow hardness. However, where the hardened snow is restricted

to a thin surface layer or crust, the energy costs of locomotion are higher than on uncrusted or softer snow with similar sinking depths (Fancy and White 1987). Hard snow can also increase the energetic cost of foraging while excavating feeding craters. The mean cost per digging stroke in light uncrusted snow by caribou was 118 J/stroke, while in dense snow with a thin hard crust the mean cost was 219 J/stroke (Fancy and White 1985). In addition Skogland (1978) found stroke rate to decrease with increasing hardness. These findings suggest that changing snow conditions can have a dramatic effect on energy expenditure by caribou and likely their use of plant communities. The fact that these parameters vary temporally, suggest a more cautious interpretation when used as an index to the energetic cost of foraging (Pruitt 1959, Soprovich 1989).

It was, in part, for these reasons that Pruitt (1979) developed the Varrio Snow Index (VSI) which incorporated snow morphological values, including thickness and hardness, with caribou activity. When modified to address local conditions, the VSI has the ability to simplify the complex nature of snow cover. In formulating log VSI Pruitt (1979, 1981) successfully related the characteristics of the snow cover with caribou use of their winter range. The mathematical relationship as described

by Pruitt (1979, 1981) is as follows:

$$VSI = (H > 1/2 (Hb * Tb) + (VTs) + (Hh * Th)) * Ta / 1000$$

WHERE: $H > 1/2$ = hardness of hardest layer more than half way up in the profile.

$Hb * Tb$ = hardness times thickness of basal layer.

$V * Ts$ = vertical hardness times thickness of surface layer.

$Hh * Th$ = hardness times thickness of hardest layer (if not $Hb * Tb$). If basal layer is the hardest then term $Hb * Tb$ drops out.

Ta = total thickness of api.

When using VSI the log of the index value (VSIL) is inversely proportional to nival quality of caribou range including both forage availability and ease of movement. There are, however, conditions that can defy the VSI if not understood. Within communities of hard-packed snow (VSIL = 5.00-8.00) and a layer of pukak (basal layer of loosely packed crystalline snow with hardness values between 10 and 500 g/cm²) caribou can expose underlying vegetation with a lower expenditure of energy than hardness values alone would predict (LaPerriere and Lent 1977). Snow in this

state is easily fractured into slab-like pieces with a series of sharp blows. Despite this exception the VSI has the potential of becoming a very powerful tool to predict caribou's use of their winter range.

1.2.3 Feeding Site Selection

Sight and smell are likely the main senses used by caribou to locate food beneath the snow (Bergerud 1974a, Bergerud 1974b, Bergerud and Nolan 1970, Brown and Theberge 1990, Helle 1984). Caribou cratering activity (the excavation of snow to access forage) is generally preceded by walking with their nose near the snow surface then stopping and moving their muzzle closer to or against the snow (Collins and Smith 1991). The purpose of this behaviour is thought to be an attempt to detect forage beneath the snow through smell. Pruitt (1959) also suggested that this behaviour also served a second purpose, to test the vertical hardness of the snow as a prelude to cratering. In the absence of protruding plant stems creating holes through the snow, caribou are considered unable to detect the presence of lichens through a snow cover greater than 25 cm (Bergerud 1974b, Bergerud and Nolan 1970). Exceptional circumstances have been reported by Helle (1984) where caribou have detected lichens at a depth of 72 cm with no apparent air holes, and by Brown and

Theberge (1990) who found evidence of Labrador caribou visually distinguishing snow-covered terrain containing preferred forage items. Once located, the forage species are made available for consumption through excavation or cratering.

Caribou cratering sites are found in areas of less snow thickness and hardness than found generally within the feeding site (Feeding site = an area delineated by the outer most craters of a group of craters) (Collins and Smith 1991, LaPerrier and Lent 1977). Number of craters and total area cratered increase with decreasing site hardness while cratering time per active period increases linearly with hardness (Collins and Smith 1991, Skogland 1978). This increase in cratering time is usually at the expense of bedding time (Collins and Smith 1991). Mean bottom area of craters (area of ground exposed through cratering activity), however, was not found to be a function of thickness or hardness for reindeer (Collins and Smith 1991). In extreme cases reindeer can continue to expand craters, in soft deep snow, over periods of several days or even weeks (Helle 1984). Russell and Martell (1984), however, disagreed with the above suggesting that in fact time spent within craters increases with increased site hardness and thickness resulting in the excavation of larger craters as these values climbed.

1.2.4 Crater Form

Snow hardness and thickness also affects crater form. Pruitt (1991) found forest reindeer (Rangifer tarandus fennicus) to use three main forms of craters throughout the winter: 1. Suovdnji or individual feeding excavations; 2. Fieski or cooperative excavations of the perimeter of a crater; 3. Ciegat or linear extensions of a suovdnji excavated by a sequence of individuals. In mid-December R.t. fennicus were found to shift from suovdnji to fieski types of feeding craters with a corresponding shift in logVSI values of control sites from 1.64 to 2.07 and of feeding sites from 0.84 to 1.42. In early March wild forest reindeer began to use ciegat while mean log VSI of control sites increased from early winter values to 2.60-3.07 and mean log VSI of feeding sites increased to 1.74-2.13 (Pruitt 1991).

1.2.5 Snow Study Conclusions

Variation in snow cover from year to year may have the overall effect of causing caribou population fluctuations as well as large scale movements throughout their range, factors which would control the amount of grazing pressure over large areas locked out by adverse snow conditions (Collins and Smith 1991, Inglis 1975). The effects of fire

and large scale resource exploitation within arctic and subarctic regions is now a concern not solely with respect to initial habitat destruction, but habitat modification in part due to the modification of water tables, drainage, microclimates, plant communities, all of which play a role in changing the snow regime. The effects of habitat modification commonly occur long after the initial disturbance and are for this reason frequently overlooked by resource users and wildlife managers alike. More often than not these effects lead to unforeseen environmental changes many times greater than initial disturbance.

1.3 Status And Distribution

There is no definitive taxonomic status for the over 2000 caribou whose year-round range is within the Cape Churchill Wildlife Management Area. Bordering the Cape Churchill Wildlife Management Area to the south is the Penn Island herd of R.t.caribou (Darby et al. 1989), while to the north is the Kaminuriak herd of R.t.groenlandicus. Banfield (1961) noted that the annual winter migration of R.t.groenlandicus into the forested regions of northern Manitoba often included the Cape Churchill Region and thus complicated the identity of the Cape Churchill herd.

Banfield (1961) also noted that intergradation has taken place between the two subspecies along the Ontario-Manitoba border. In order to better understand where the Cape Churchill caribou sit demographically and taxonomically, a brief discussion on each of the Kaminuriak herd of barren-ground caribou and the Penn Island herd of woodland caribou is made.

1.3.1 The Kaminuriak Caribou Herd

The Kaminuriak caribou population declined as early as the mid-1800's and range-wide after 1900 (Klein 1969, Miller 1976). The Kaminuriak herd had reached a low of between 24000 and 53000 animals by 1968. The population suddenly increased to between 150000 and 210000 by 1982, while a photographic survey in 1985 revealed 260000 to 380000 animals. Tennenhouse (1986) suggested that natural birth rates alone would not explain this increase. Factors linked with earlier declines include below-normal annual mean temperatures, over-hunting, destruction of winter habitat through fire, delayed melting of snow on calving grounds, and a warming climate characterized by greater snowfall and a thicker snow cover (Crete and Payette 1990).

Although Kaminuriak caribou are isolated from the Cape Churchill Wildlife Management Area during the fall rut and spring calving periods, they still undergo periodic winter

migrations into the region (Banfield 1961, Gates 1989). Both calving and rutting grounds are located within the North West Territories in the general vicinity of Kaminuriak Lake (Gates 1989).

1.3.2 The Penn Island Caribou Herd

A current population estimate of 15000 Ontario Woodland Caribou, over 5000 of which make up the Penn Island caribou herd, has been made by Darby et al. (1989) and Resources Report (1990). According to Darby et al. (1989), 4800 of the Penn Island animals likely winter within the southern reaches of the Cape Churchill caribou range. Current counts within the southern tip of the Cape Churchill region suggest their use by over 3000 Penn Island caribou (Bergerud 1980b). The Penn Island herd choose rutting grounds outside of the Cape Churchill Wildlife Management Area and as a result are isolated from the Cape Churchill animals.

1.3.3 Cape Churchill Caribou

The resident Cape Churchill Caribou population has been increasing from a low of 58 animals in 1965, to 1237 in 1985 (Kearney and Thorleifson 1987). The fact that aerial surveys did not begin until 1976 likely had an effect on the accuracy of these figures. Current field

estimates from the present study are in excess of 2000 animals. Initial observations of relatively low numbers could have been the result of a general caribou decline recorded in the early 1900's (Bergerud 1974a, Crete and Payette 1990, Klein 1969, Miller 1976, Roby et al. 1984).

The Cape Churchill caribou herd occupies some 17000 km² bordered to the north and east by Hudson Bay, to the west by the CN rail line, and to the south by the Nelson River. Research to date has yielded little information concerning movement across these artificial boundaries. The Cape Churchill herd generally occupies the taiga during fall and early winter and the coastal tundra during the remainder of the year (Kearney and Thorleifson 1987, Teillet 1983). The Cape Churchill Wildlife Management Area is also periodically occupied, during winter, by both woodland caribou to the south (Penn Island herd), and barren-ground caribou to the north (Kaminuriak herd).

Observations made by Graham (1969) between 1700 and 1750 in the York Factory region included: "They (caribou) go along the coast past York Fort and Severn settlements in large herds in the months of May and September; but contrary to the birds of passage and other migratory animals they go to the southward in the beginning of summer and to the northward at the approach of winter". Graham also noted that caribou sign was rarely seen between

November and April within 100 km of the coast where tundra communities dominate. Another entry by Graham during the early 1700's described the fall migration of almost "countless" animals crossing the Nelson and Hayes rivers in a northward migration. These early explorers were likely referring to what is now known as the Penn Island herd of R.t. caribou as their calving and rutting grounds are located south and south east of the Hayes River.

1.4 Life History

Knowledge of the life history of Cape Churchill caribou is limited (Banfield 1961). The information available suggests that Cape Churchill caribou use tundra and associated beach ridge complexes during the spring, summer and early fall, and the taiga during late fall and early winter (Kearney and Thorleifson 1987). Terrestrial lichens represent the most important forage items during the snow season (Kearney and Thorleifson 1987). Cape Churchill caribou are moderately gregarious forming the largest herds in the spring and summer along the Hudson Bay coast. They are polygamous with adult bulls tending an aggregation of oestrous females. The rut usually commences in late October while parturition occurs in June (Kearney

and Thorleifson 1987). Pelage is chocolate brown in summer, grey brown in October and whitish beige in spring. The adults shed their winter coat in June and July. Bulls begin antler growth in April or May; it is usually complete by September. The largest bulls begin dropping their antlers in late November or early December. Cows begin growing antlers in late June and July and have stripped velvet by October. Pregnant cows carry their antlers until late June or early July (Kearney and Thorleifson 1987).

1.5 Plant Community Use

Caribou are extensive rather than intensive feeders. Feeding locations are constantly changing throughout the snow season and largely depend on snow conditions and how they affect access to, and procurement of winter forage (Baskin 1990, Bliss et al. 1973, Pruitt 1959). On rare occasions (perhaps when nival conditions are stable) smaller herds can stay in a good area for several weeks until extensive trampling and feeding excavations drive hardness beyond threshold values (Loughrey and Kelsall 1970).

1.5.1 Woodland Caribou

Woodland caribou spend the winter months completely within the taiga, shifting from open bogs to more exposed uplands and lakes as snow thickness increases and creates unfavorable conditions within the lower lying communities (Bergerud 1974b, Darby and Pruitt 1984, Schaefer 1988, Stardom 1975, Tucker et al. 1991). The Penn Island herd of woodland caribou use the coastal forest-tundra zone between mid-April and mid-December and traditionally aggregate on portions of the Hudson Bay lowlands and in adjacent taiga from early December to early April (Cumming and Beange 1987, Darby et al. 1989, Resources Report 1990). Penn Island caribou winter range is characterized by ombrotrophic raised bogs on which terrestrial lichens are abundant (Darby et al. 1989). Lichen woodlands, lichen heaths, palsa bogs and sinuously patterned peat lands are not selected by the herd (Darby et al. 1989). The Penn Island caribou move inland to their winter range during late fall (although specific routes or winter grounds have yet to be identified) while some animals remain on islands until ice formation (Darby et al. 1989, Cumming and Beange 1987). As yet little information exists describing late winter habitat use. In spring aggregations of females and young from the Penn Island Herd move towards their calving grounds on the coastal tundra. During calving they use tundra-covered ridges and islands isolated from inland

treed ridges by sedge meadows and coastal fen (Resources Report 1990). Males generally arrive by late May and remain in small groups around the periphery of the calving grounds (Resources Report 1990).

1.5.2 Barren-ground Caribou

Barren-ground caribou generally spend the winter months within the taiga. Following the October rut, R.t. groenlandicus aggregate into large groups of cows and calves (occupying forward positions) and adult males (on the periphery) and undertake an extensive migration into their taiga winter range (Baskin 1990, Loughrey and Kelsall 1970, Ouellet et al. 1993, Telfer and Kelsall 1979). This mass movement is usually complete by early December (Kelsall 1968). At least one exception can be found, on Coats Island N.W.T., where barren-ground caribou remain on the tundra year-round (Adamczewski et al. 1988). In Alaska, barren-ground caribou occupy winter range high in both lichen biomass and plant diversity commonly found in association with high center polygons (White and Trudell 1980a). Carruthers et al. (1986) found barren-ground caribou to inhabit 54.4 % lakes, 37.4 % open coniferous forest, 5.9 % herbaceous communities, 1.6 % closed coniferous forest, 0.6 % burned forest and, 0.1 % shrub communities on their winter range. Sexual differences were

also apparent as males used coniferous forest with greater snow thicknesses than did female-calf groups which preferred more exposed habitats (Carruthers et al. 1986, Loughrey and Kelsall 1970). On the wintering grounds of the central arctic herd Thomas (1990) found caribou to prefer forest stands greater than 70 years of age. The Kaminuriak herd of barren-ground caribou are closely associated with the Cape Churchill caribou herd by way of their geographical location and their occasional movements into the Cape Churchill Wildlife Management Area during winter. Little information concerning Kaminuriak caribou community use is available. Thompson and Klassen (1980) did find the highest winter densities of Kaminuriak animals on lichen-heath tundra in association with the forest ecotone, communities that extend well into the Cape Churchill Wildlife Management Area.

1.5.3 Cape Churchill Caribou

The Cape Churchill Caribou Herd is believed to spend the entire year within the Cape Churchill Wildlife Management Area. Movements within this area are generally from the coastal tundra to the taiga in early winter and from the taiga to the coastal tundra in late winter (Kearney and Thorleifson 1987). Little information is available on community use throughout the winter.

According to Soprovich (1989) the Cape Churchill Wildlife Management Area cover map (produced by the province of Manitoba) indicates that 5 % of the area is dry fen, 70 % saturated fen, 20 % beach ridge complex, <5 % willow, and 5 % black spruce. There is however some question as to the accuracy of the existing cover map (Soprovich 1989).

1.6 Feeding Habits

During winter, arctic plants are characteristically lower in protein than during the summer (Klein 1969, Swift et al. 1980). Nonetheless, energy is the most important single requirement for caribou, and lichens, both terrestrial and arboreal, are extremely high in digestible energy when compared with other winter forages (Russell and Martell 1984). Rencz and Auclair (1978) and Sveinbjornsson (1990) found 20 % of the biomass, 25 % of the nitrogen, and 12 % of the phosphorus of an open woodland is in the lichen mat which can cover up to 97 % of the forest floor.

Lichens are consumed by caribou extensively throughout the winter and early spring with other vegetation being consumed to a lesser extent (Andreev 1954, Barrette and Vandal 1986, Bergerud 1972, Bergerud and Nolan 1970, Gaare 1986, Holleman et al. 1979, Holleman and Luick 1977, Inglis

1975, Jacobsen et al. 1981, Miller 1976, Reimers 1980, Rominger and Oldemeyer 1990, Russell and Martell 1984, Scotter 1964, 1967, Shank et al. 1978, Stardom 1975, Thing 1980, Thomas and Hervieux 1986, Van Daele and Johnson 1983, White and Trudell 1980a). Evergreen forage can become an important part of the diet of pregnant females in late winter because of its greater nitrogen content, but seldom exceed lichen ingestion rates (Jacobsen et al. 1981, Russell and Martell 1984). There are, however, exceptions to the above findings. For Peary caribou (R.t. pearyi) of the Canadian Arctic Archipelago, grasses and sedges are the most important dietary component with mosses and lichens making up only small fractions of the total diet. Mosses, however, can at times reach percentages as high as 58 % (Miller et al. 1982, Shank et al. 1978, Thomas and Edmonds 1983). Adamezewski et al. (1988) also found lichens to be scarce in the winter diets of Coats Island barren-ground caribou (R.t.groenlandicus).

1.6.1 Woodland Caribou

Woodland caribou depend on both ground and arboreal lichens in general, and arboreal lichens in particular, during the snow season (Barrette and Vandal 1986, Bergerud 1972, Bergerud and Nolan 1970, Edwards and Ritcey 1960, Stardom 1975). Based on rumen contents Newfoundland

woodland caribou preferred, in order of importance, Cladonia alpestris, C. rangiferina, C. mitis, C. sylvatica, and Cetraria islandica (Bergerud 1972). A seasonal breakdown of preferred forage species was also provided by Bergerud (1972) where terrestrial lichens made up 38 %, arboreal lichens 2 %, sedges 10 %, fungi 12 %, deciduous shrubs 9 %, evergreen shrubs 12 %, and mosses 5 % of the fall diet, while in winter they choose arboreal lichens 54 % of the time, sedges 7 %, deciduous shrubs 3 %, evergreen shrubs 23 %, balsam fir 4 %, mosses 6 %, and terrestrial lichens 2 % of the time. These findings were similar to those reported by Gaare (1986) in his work on Alberta woodland caribou while Rominger and Oldemeyer (1990) found British Columbia woodland caribou to prefer an arboreal lichen-conifer diet during late winter. Darby and Pruitt (1984) and Stardom (1975) found Manitoba woodland caribou to prefer arboreal lichens at the beginning and middle of winter, turning to ground lichens by late winter when snow conditions within communities rich in arboreal lichens made access difficult.

1.6.2 Barren-ground Caribou

Ground lichens are the preferred forage of barren-ground caribou often composing 40% to 60% of winter diets (Reimers 1980, Scotter 1967, Shank et al. 1980). Of these

lichens; Cladonia alpestris, C. rangiferina, C. mitis, C. uncialis, Thamnolia spp., Dactylina arctica, Cetraria nivalis, Stereocaulon tomentosum, and Peltigera spp. make up the preferred species (Scotter 1964, 1967, Thomas and Hervieux 1986, White and Trudell 1980a). Non-lichen forages also considered important during the snow season include grasses, sedges, Equisetum spp., evergreen shrubs, and bryophytes (Reimers 1980, Scotter 1967, Shank et al. 1980, White and Trudell 1980a). More specific dietary needs have been reported by Boertje (1984) who found the winter diets of Alaskan barren-ground caribou (Rangifer tarandus granti) to include 62 % lichens, 6 % Vaccinium vitis-idea, 7 % forbs, 11 % graminoids, and 10 % mosses. North Central barren-ground caribou winter diets were composed of lichens 68.5 %, conifer needles 11.9 %, green leaves of Vaccinium spp., Ledum spp., other shrubs and forbs 5.6 %, twigs and bark 5.5 %, Bryophytes 4.9 %, and unidentified at 3.6 %. Of the lichen component 8.4 % was Stereocaulon spp., 46.9 % Cladina, Cladonia, and Cetraria, and 13.2 % foliose lichens (largely Peltigera) (Thomas and Hervieux 1986). In addition to the dietary needs supplied by plants, barren-ground caribou often derive additional minerals from ice and soil licks (Heard and Williams 1990). The specific diets of the Kaminuriak caribou herd are yet to be fully understood but are thought to be composed of

terrestrial lichens and grass-like plants in early winter which then change to arboreal lichens and woody browse in late winter (Miller 1976).

1.6.3 Forage Intake

In general the forage intake of caribou increases linearly with increasing plant biomass while the fraction of the day spent grazing decreases (White and Trudell 1980b). Although lichen intake rates change throughout the winter it is generally accepted that lichen dry matter intake rates range between 3.0 and 7.0 kg/day for an 80 kg animal, the mean of which would correspond to a metabolizable energy intake of approximately 38 MJ/day (Hanson et al. 1975, Holleman et al. 1979, 1980).

1.6.4 Feeding Habits Conclusions

Lichens, both terrestrial and arboreal, are quite obviously important to caribou and can generally be found in large quantities across the tundra and taiga regions. The resource is, however, limited by virtue of its slow recovery following grazing, its relative sensitivity to environmental pollutants and subsequent destruction, fire, and by adverse weather conditions that can lock it under a biologically impenetrable layer of snow. As a result we must be extremely cautious when estimating the range

requirements of caribou as they are most certainly much greater than they initially appear.

1.7 Weather

Weather has an impact on range use and migration patterns of caribou (Gavin 1975). High pressure systems can apparently trigger steady movements (Gavin 1975). Temperatures as low as -50°C have little effect on caribou activity, although colder winter temperatures have been associated with fewer calves the next fall (Ferguson and Mahoney 1991, Henshaw 1968, Russell and Martell 1984). With the addition of winds greater than 30 to 40 km/hr, coupled with low temperatures, activity can be disrupted. Caribou may aggregate and eventually lie down to conserve heat (Henshaw 1968, Russell and Martell 1984). Gavin (1975) observed that entire migrations may be turned around in the presence of strong winds and drifting snow. Gavin (1975) also noted the ability of caribou to detect storms and as a result trigger movements of up to 100 to 120 km one and a half to two days prior to their onset.

It has been long established that "severe winters" or "hard winters" cause fluctuations in ungulate populations (Edwards 1956). A temperature increase was observed in the

northern hemisphere during the first half of this century (Harrington 1987). This warmer period was also characterized by greater snowfall and a thicker snow cover (Harrington 1987). Thicker snow cover has, in turn, been found to be inversely correlated with pregnancy rates and yearlings/100 females (Ferguson and Mahoney 1991).

Weather conditions within the Cape Churchill Wildlife Management Area are derived from large scale cold air masses originating over Hudson Bay. Onshore winds moving across a strong temperature and pressure gradient up to 65 km inland combine to impose cold air temperatures on the adjacent terrestrial environment (Rouse 1991). Even with abundant solar radiation and saturated surfaces, evaporation is vigorously suppressed by these cold temperatures (Rouse 1991). The strong southward thrust of the arctic front in summer is a response to cold air masses spawned over Hudson Bay (Rouse 1991). It is of concern to know that any warming or cooling during climate change will have a double impact on the terrestrial environment through these strong linkages with Hudson Bay (Rouse 1991).

2.0 OBJECTIVES AND HYPOTHESES

The objectives of this project are to determine the relationship between Cape Churchill caribou and winter conditions from the beginning to the end of the snow season within the Cape Churchill Wildlife Management Area.

Research was conducted over a two year period 1989-90 and 1990-91. The fact that the study area possesses a rich mixture of taiga, forest-ecotone, tundra, and marine environments, makes both snow conditions, and the way in which caribou respond to these conditions, unique to North American caribou biology. A series of 4 null hypotheses have been advanced:

1. Cape Churchill caribou do not display a preference for one plant community type over another from December through April, and that this lack of preference is also apparent on a year-to-year basis. This null-hypothesis was tested using tracking data, caribou observations, and crater content analysis.

2. Forage groups chosen by Cape Churchill caribou do not change throughout the 1989-90 and 1990-91 snow seasons, or between the two snow seasons. Fecal analysis, rumen

analysis, and crater content analysis were used to test this null hypothesis.

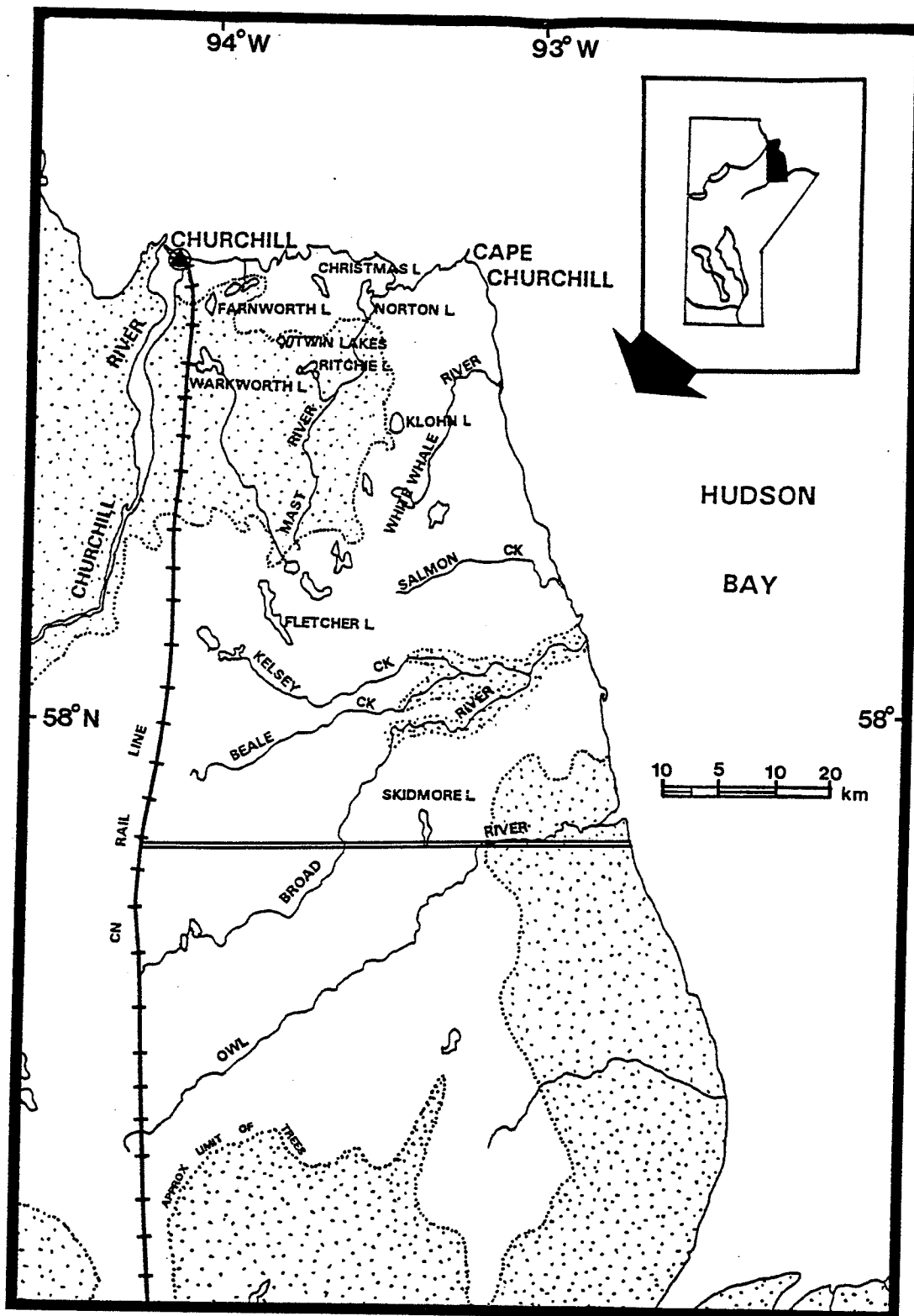
3. Snow conditions within the Cape Churchill Wildlife Management Area do not vary between December and April or between the two snow seasons (1989-90, 1990-91). This hypothesis was tested using a series of snow profiles analysed at each of seven vegetatively defined community types throughout the winter.

4. Cape Churchill caribou do not change their movements, plant community use or forage selection to agree with changes in snow cover conditions within the 1989-90 or 1990-91 snow seasons or between them. Snow work conducted on feeding craters and controls, placed within feeding sites, was used to test this hypothesis.

3.0 STUDY AREA

3.1 General Description

The Cape Churchill Wildlife Management Area (CCWMA) is approximately 17000 km² and has a respective eastern and western boundary of 93° 45' and 95° 00' W longitude while its northern and southern boundaries are respectively 58° 48' and 57° 00' N latitude. For logistical reasons the study area encompassed only the northern half of the CCWMA (approximately 8000 km²) terminating at the point at which the Owl River enters Hudson Bay west to the Canadian National Railway line, 57° 50' N latitude (Figure 1). The geology of the study area was summarized by Dredge (1992) and Sjors (1959). During the Precambrian era the Hudson Bay lowlands (in which the CCWMA is located) were part of an extensive region of granite and gneiss. Since that time erosion has produced a gently undulating peneplain extending west of both Hudson and James bays. Palaeozoic seas covered the peneplain on several occasions. Layers of sand, clay and coral were deposited during the Ordovician and Silurian periods, the accumulations of which were transformed into sedimentary rocks. These rocks (often



containing fossil material) vary from dark grey calcareous sandstone to yellow dolomitic limestone. They are often exposed where rivers and creeks cut through these materials. The sandstones, quartzites, and limestone, both carved and deposited by pre-Pleistocene glacial periods, remained relatively unchanged until the Pleistocene epoch when the Wisconsin glacier, between 1500 m and 3000 m thick, covered the study area. The sheer mass of the ice sheet depressed the region of the Hudson Bay lowlands approximately 600 m. As the glacier receded it deposited a layer of boulders and clay varying in thickness from 10 m to 30 m. The sea covered the lowland as the ice sheet melted and as a result deposited a layer of marine clay, 3 m to 10 m thick on top of glacial till. Following the disappearance of the ice, crustal recoil or isostatic rebound began, up to 5 m per 100 years at first, but has slowed to about 1 m per 100 years. Actual rates are, however, largely dependant on location.

Continuous permafrost occurs throughout the region. The exception to this rule occurs under water courses, lakes, and to a certain extent in elevated gravel deposits of both glacial and marine origin. According to Sjors (1959) permafrost has been found as deep as 44.5 meters and is closest to the surface under areas of organic soils because of their insulating qualities. As permafrost is

impervious to water, the Hudson Bay lowlands are characterized by extensive areas of wet peatlands, small ponds, shallow lakes and braided streams. The lowlands are also characterized by well-drained communities such as beach ridges, peat plateaus, ice pushes of various origins, and palsas (evident in the taiga). The vegetation of the region is diverse and includes representative plant species from each of four complex ecosystems, the taiga, forest-ecotone, tundra and marine. According to Rouse (1991) Hudson Bay (a mid continental southern extrusion of the arctic ocean) both dominates and determines the climate, soils and vegetation of the Churchill region by creating a cold climate not typical of the latitude. These conditions cause arctic and subarctic conditions to extend much farther south, most predominantly along the Hudson Bay coast. Mean daily temperatures range from -27°C in January to 12°C in July. Precipitation (in water equivalent values) falling as snow, rain, sleet, hail and fog, averages 410 mm/year (Environment Canada Weather Records 1965-1980). Most of this falls as snow which averages 175 cm over a mean period of 210 days. Prevailing winds blow from the north-west and average 24 km/hr throughout the year. Peak wind speeds generally occur during the fall season.

3.2 Plant Communities

The geology and climate of the study area provide conditions for a latitudinally complex array of plants, which by association, form equally complex communities compared to other regions of similar latitude. Communities were initially outlined according to Brokx (1965), Johnson (1987) and Scott (pers. comm., 1989). The 7 communities and nomenclature for characteristic plants and lichens follow:

1) Hummocky lichen tundra (HLT): These ecosystems, characteristically ombrotrophic and well drained, typically take the form of high center polygons, ridge systems of low center polygons, peat ice pushes, and string bogs along the base of gravel ridges. The ditch systems of high center polygons and central depressions of low center polygons add a hydric mineraltrophic component to these otherwise xeric sites. Dominant lichen species include Cladina rangiferina, Cetraria nivalis, and Cladina mitis, while the dominant flowering plants include Vaccinium vitis-idaea, Andromeda polifolia, Carex vaginata, and Vaccinium uliginosum.

2) Sedge tundra (ST): ST, the most hydric of the

tundra ecosystems, is typically a low lying minerotrophic community composed primarily of graminoid species. Lichen cover generally represents less than one percent while flowering plants, specifically Eriophorum spp., Carex aquatilis, Scirpus caespitosus, Andromeda polifolia, and Salix arctophila represent the common species.

3) Beach ridge complex (BR): The most xeric of the tundra ecosystems, these sites are typically composed of marine gravels protruding above surrounding tundra ecosystems. Lichen species, including Alectoria ochroleuca, Cetraria islandica, and Thamnolia subuliformis, are typical within the plant communities, while common flowering plants include Dryas integrifolia, Carex glacialis, and Arctostaphylos rubra.

4) Tamarack-white spruce forest (TWS): This ecosystem is common along the transition between tundra and taiga (Forest-ecotone). These sites are primarily minerotrophic, occupying a relatively broad range of moisture conditions. Dominant tree species include tamarack (Larix laricina) and white spruce (Picea glauca), with minor intrusions of black spruce (Picea mariana). The more common lichen species include Cladina rangiferina, Cetraria islandica, and Cladina stellaris, while the common flowering plants include Carex vaginata, Empetrum nigrum, Vaccinium uliginosum, and Vaccinium vitis-idaea.

5) White spruce forest (WSF): This well-drained taiga ecosystem is generally associated with gravel ridges and/or gravel deposits. Plant communities on these sites commonly include a thick lichen mat. The dominant canopy is composed primarily of Picea glauca, with minor intrusions of Picea mariana within the more mesic microsites. Common lichen species include Cladina stellaris, Cladina rangiferina, and Cladina mitis. Common flowering plants include Vaccinium vitis-idaea, and Empetrum nigrum. Non-flowering plants including Equisetum spp. and feather mosses, are also common.

6) Black spruce palsa (BSP): These are relatively well-drained ecosystems elevated above surrounding taiga due to a frozen peat core. Common tree species included Picea mariana, with minor intrusions of Larix laricina. Thick lichen mats, especially along elevated north-easterly edges, are characteristic of the plant community. Common lichen species include Cladina stellaris and Cladina rangiferina. Common flowering plants include Ledum groenlandicum, Empetrum nigrum, and Vaccinium vitis-idaea. Equisetum spp. and mosses, especially Sphagnum spp. are also common especially towards the center of these communities.

7) Tamarack fen - shrub thicket - meadow marsh (TF):
A plant community composed of three distinct sub-

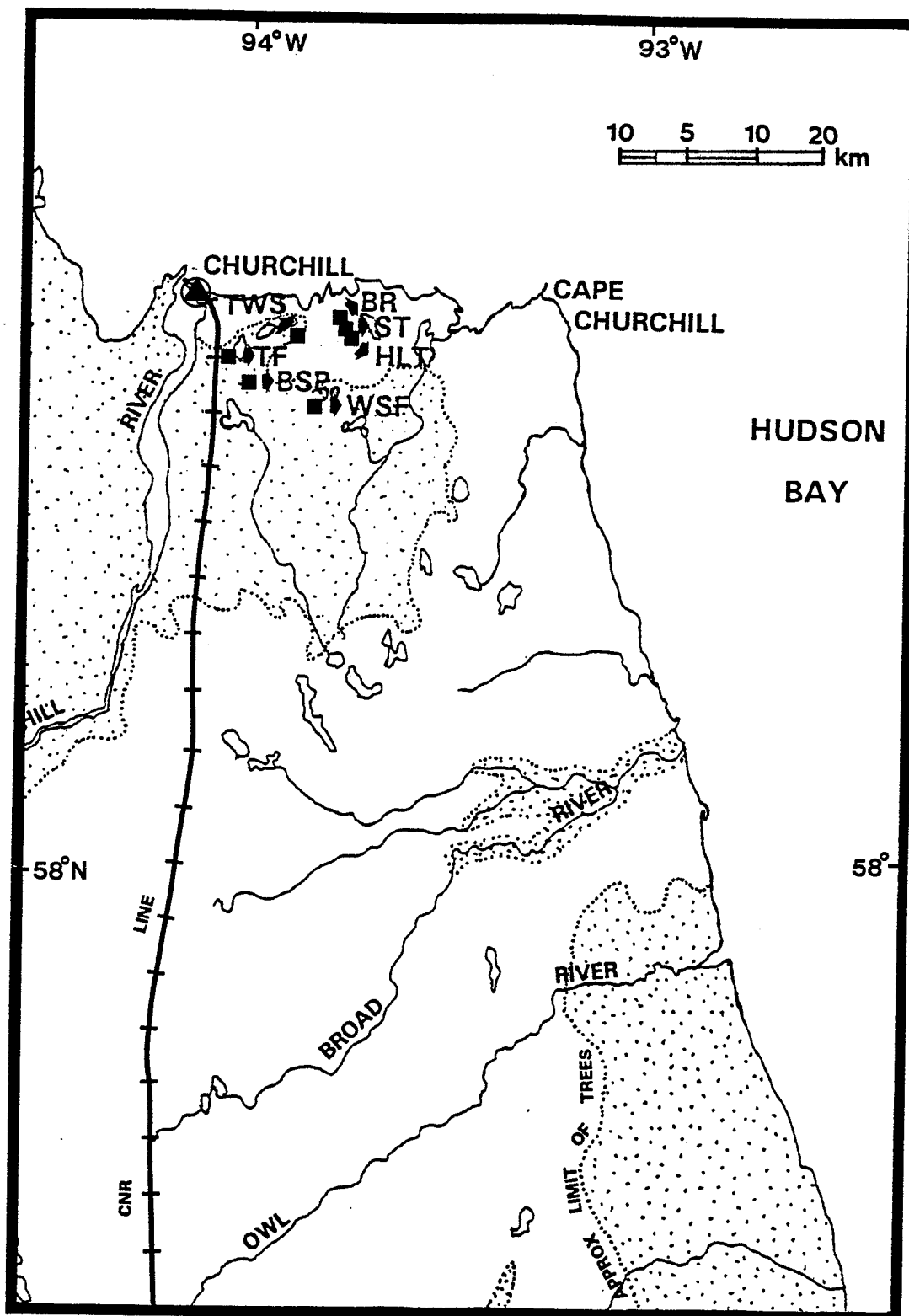
communities whose moisture conditions range from open ponds (hydric) to moderately well drained Carex hummocks. They are typically minerotrophic, and generally occupy depressions rich in organic matter. The tree species is exclusively Larix laricina. Graminoids and shrub species dominate these communities. Common flowering plants include Carex aquatilis, and Salix spp.. Both Equisetum spp. and mosses were also common, particularly amongst the bases of Carex aquatilis. Lichens are poorly represented within these communities, generally making up less than one percent.

4.0 METHODS

4.1 Snow Study

4.1.1 Snow stations

Snow stations were established over the summer of 1989 within the four taiga and three tundra plant communities found in the study area (Figure 2). The location of these sites was based on a number of criteria; 1. plant community composition based in part on community descriptions by Johnson (1987), Brokx (1965), and Scott (Pers. comm. 1989). 2. The use of plant communities by Cape Churchill caribou was based on conversations with local hunters, and unpublished reports by Teillet (1983) and Kearney and Thorleifson (1987). 3. Topographical features based on the work of Sjors (1959) and personal observations. Site designation and acceptance was based upon its ability to accept a 50 m transect, the minimum distance necessary to complete 8 undisturbed series of api profiles. This procedure also served to reduce the number of sites to a practical number. The taiga stations included WSF, TWS, BSP, and TF while the tundra communities included BR, ST, and HLT. Each of the plant communities, in which



snow stations would be located, were within a day's travel of the Institute Of Arctic Ecophysiology (IAEP) located 10 km east of the townsite of Churchill. All seven sites could be sampled within a three day period. The approximate center of each community was located and a 50 m tape extended along a random compass bearing. Because of the north-south orientation of the BR community, randomly chosen compass bearings were restricted to those falling within $\pm 45^\circ$ of 360° N or $\pm 45^\circ$ of 180° S. To mark each site permanently, metal poles were secured at 0 m and 50 m.

In total a series of eight snow variables and one index were compared within each community over both snow seasons. The eight variables included: 1. Total thickness (TTH), 2. Basal thickness (BTH), 3. Thickness of the hardest layer (THHL), 4. Thickness of the uppermost layer (STH), 5. Hardness of the hardest layer more than half way up the profile (HHH), 6. Hardness of the hardest layer (HHL), 7. Basal hardness (BHD), and 8. Vertical hardness (VH). The Varrio Snow Index (VSI), developed by Pruitt (1979), was also examined. This index used each of the eight snow variables, in a mathematical equation, to predict their cumulative effect on caribou (Rangifer tarandus) winter activities. The values generated by the VSI are inversely related to caribou

activity. Of the 8 variables examined, two, snow thickness and hardness of the hardest layer, dominate the trends observed for plotted VSI values. For this reason the analysis concentrated on these variables. Data collected for the remaining six variables are listed in Appendix A.

4.1.2 Api Profiles:

Snow cover (Api) conditions were monitored over both the 1989-90 and 1990-91 snow seasons at each of the seven plant community types (snow stations) a minimum of once a month with a bi-weekly limit. Snow stations were usually inaccessible until early to late December when creek and lake crossings were more predictable. Initial site examination included an estimate of the degree of use and/or disturbance. Temperature, wind speed and direction, cloud cover, and precipitation (a qualitative account) were also recorded. Profiles were excavated approximately one meter from the station marker leeward to the prevailing winds (north west).

A single profile consisted of a snow trench approximately one meter long and one half meter wide excavated to ground level. Each profile was cut perpendicular to the snow station orientation (perpendicular to a line connecting the two marker poles). Following excavation, the windward face of the profile was

"cleaned" with a soft brush to reveal any distinctive layering. Using a tape measure each of the visibly exposed layers were measured from ground to snow surface revealing layer thickness and location. At times when layers were difficult to identify (during conditions of poor light) a pencil would be used to probe through the profile from the ground up. As the pencil encountered greater or lesser resistance a line would be etched in the profile and would represent the boundary between two layers. This method relied on visual confirmation.

Once identified, each layer was tested for hardness using a modified NRC (National Research Council Of Canada) type snow kit capable of measuring a range of hardness values between 1.0 and 100000 g/cm² (Klein et al. 1950). This process was completed three times for each layer in the profile, and an average taken. Once horizontal hardnesses were completed, the gauge was turned 90° and compressed into the api surface three times to reveal vertical hardness. Vertical hardness was measured in undisturbed api anywhere along the one meter edge of the api profile. While still on site, the series of steps described above were repeated two additional times in the same location, using fresh api. This was achieved by removing just enough snow parallel to the face of the first profile to reveal fresh undisturbed snow. This was usually

no greater than 10 cm. Immediately following the completion of the three transect profiles, an additional three were excavated five meters to the left and right. The aforementioned processes of profile preparation and measurement would be repeated until a total of nine profiles was completed. This would constitute one visit to one community. The remaining six stations would be completed in as rapid succession as possible.

As snow conditions vary greatly diurnally, sampling was restricted to between 1000 hours and 1600 hours. Under these restrictions a complete sampling session would take an average of three days to complete, depending on weather and field assistance. During each consecutive visit api profiles were excavated five meters windward of the previous session's excavation to avoid sampling previously disturbed api. Once the sampling procedure for one community type was completed, the excavations were filled to avoid modification to the site through heat loss from exposed ground, as well as from modifications caused by drifting. Environment Canada Climatological Monthly Weather Summaries generated in Churchill over the 1989-90 and 1990-91 snow seasons were also used along side the snow morphological data in an attempt to determine, at least partly, the reasons for temporal change in community snow conditions.

Following each sampling session log VSI's (Pruitt 1979, 1981) were calculated for each snow station and plotted. The non-parametric Mann-Whitney test was used to determine significant differences in snow morphology, both within and between snow seasons, as the data did not conform to a normal distribution. The first of these involved the comparison of taiga ($n = 36$ (ie; $4 * 9$) profiles per visit) and tundra ($n = 27$ (ie; $3 * 9$) profiles per visit) communities for hardness, thickness, and VSI, where the median values generated from each visit were tested for significant differences during the same sampling period and between the two snow seasons. The second involved the comparison of individual communities ($n = 9$ profiles per visit summed into early, mid-, and late winter components) the median values of which were compared both over early, mid-, and late winter and between snow seasons using the same snow parameters discussed in the taiga and tundra comparison.

4.2 Plant Community Analysis

Percent cover was measured for herbs, lichens, shrubs, pteridophytes, and canopy cover during the month of August 1990. In addition tree densities were also calculated

within taiga sites. A tape measure was paid out, within a sample of each of the seven plant communities (snow stations), between previously marked poles to superimpose a calibrated 50 m transect. Percent species composition was estimated using a 1.0 m by 0.5 m rectangular quadrat divided into 50 - 10 cm by 10 cm smaller plots, analysed alternately, each of which was further divided into 4 - 5 cm by 5 cm sub-plots yielding 100 sub-plots per 1.0 m by 0.5 m quadrats. Plant species sampled within each of the 10 cm by 10 cm smaller plots were given cover values of 1 - 4 (1 = 25 % cover, 2 = 50 % cover, 3 = 75 % cover, and 4 = 100 % cover) according to their presence or absence within each of the sub-plots. Once one 1.0 m by .5 meter quadrat was completed, the quadrat would be moved between the 1 m and 2 m increments on the transect. The above would be repeated until fifty 1.0 m by 0.5 m quadrats or a total of five thousand 5 cm by 5 cm subquadrats were completed.

Unidentifiable plants that were uncommon (three or less per transect) were recorded as "unknown". Sedges and grasses lacking flowering heads for identification were recorded under Carex spp. or grass spp.. Plant species requiring biochemical identification such as many of the ground lichens, and mosses, were identified to as low a taxon as possible.

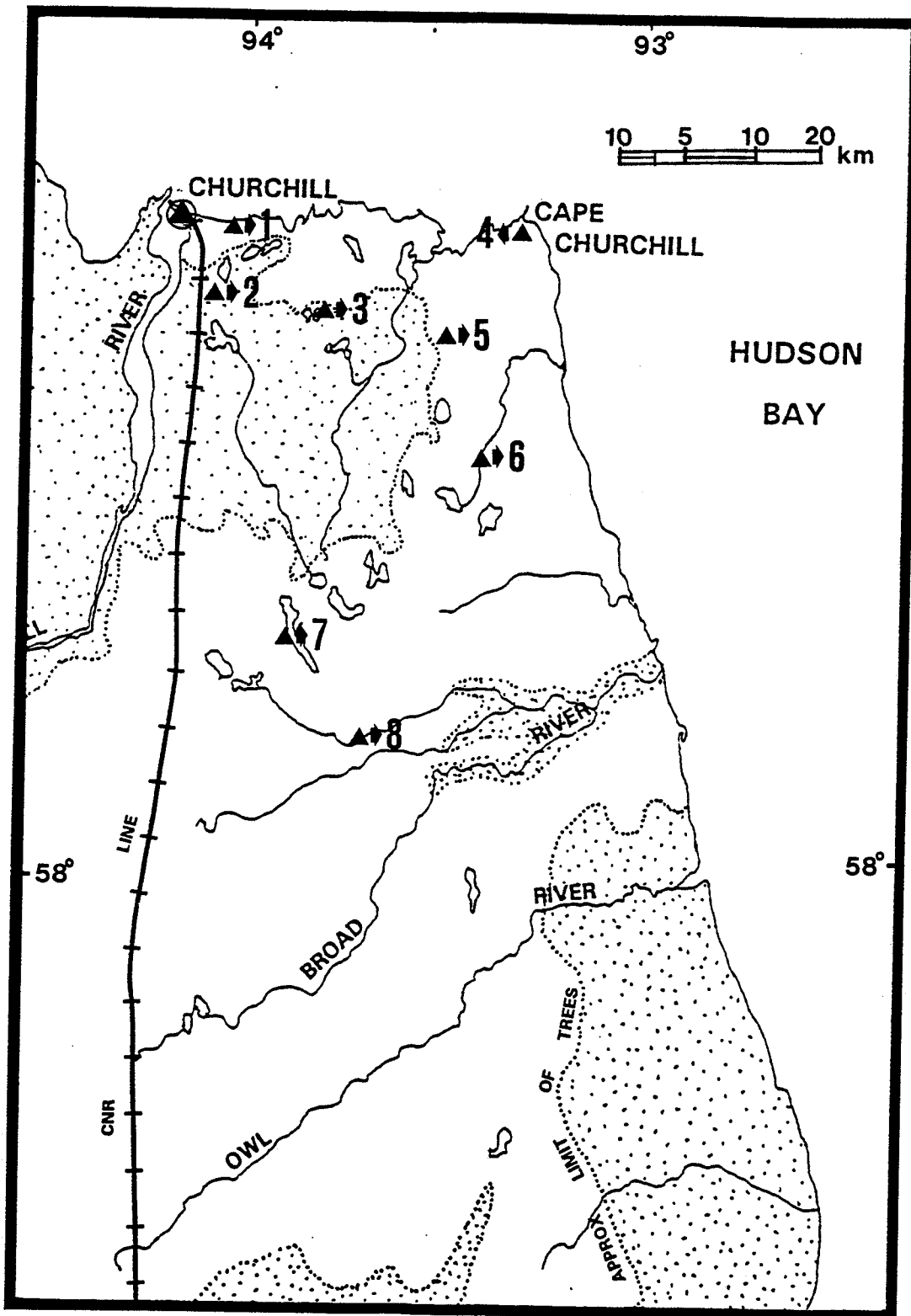
Immediatly following the analysis of ground vegetation

the point quarter method was used to determine tree densities (Brower and Zar 1977). For the purpose of this study a tree was defined as any woody species over 2 m in height and a minimum diameter at breast height (DBH) of 2 cm.. Using a compass an imaginary line was made to bisect the transect perpendicularly at the 0, 10, 20, 30, 40, and 50 m intervals. Within each of the four quarters established for the six transect points, the distance to the center of the nearest tree at breast height, its circumference at breast height (to be converted into diameter), and its identity were recorded. Data were later converted into stand composition, density, and area (through use of conversion tables). Percent canopy cover was recorded by lying down with the head centered at each of the six previously established points, and estimating the amount of sky visible through the canopy. The value obtained was then subtracted from 100 % yielding one of 9 cover classes from 10 % to 100 %. The data set obtained using the analysis of understory and overstory was then analysed using the CANOCO PCA (Principal Components Analysis) software package (Gittins 1985, Ter-Braak 1988) to determine the degree to which each of the 7 community types were related based on biotic variables.

4.3 Tracking

Cape Churchill caribou were tracked during the 1989-90 and 1990-91 snow seasons. Most of the tracking took place within six survey areas, three from within the taiga; the Twin Lakes, Warkworth Lake, and Ritchie Lake survey areas, and four from the tundra, the Cape Churchill, White Whale River, Fletcher Lake, and Kelsey Creek survey areas (Figure 3). During the 1989-90 snow season tracking began December 10th, and terminated May 1st while in 1990-91 tracking began January 10th, following the movement of Cape Churchill Caribou into the study area, and again terminated May 1st. A snowmobile equipped with an odometer precise to 50 m was used.

Tracking consisted of two primary activities, ground searches and the tracking procedure itself. Ground searches were conducted from a central base camp and five remote base camps set up within the study area. The goal of a ground survey was to locate both caribou and their sign, and to plot this information on 1:250000 scale National Topographic Series Transverse Mercator Projection map sheets. The ground survey generally required two to three days to complete depending on weather, caribou abundance, and dispersion. Within taiga communities, existing trails were travelled by snowmobile and on foot,



while in more open country, pre-set compass bearings were followed on snowmobile. Upon completion ground surveys took on the appearance of a spoked wheel the center of which was a base camp. Each survey covered an area of approximately 100 km². This figure did, however, vary depending on visibility, community type and topography. Searches surrounding the main base camp were conducted first, followed by remote surveys within the study area if local surveys were negative. Survey patterns would cycle through the local base camp and each of the remote base camps until sign or the animals themselves were encountered. Through conversations with trappers and hunters from surrounding communities, attempts were made to gather information on the herd outside the study area, especially when ground surveys produced negative results. In many cases this information proved valuable; however, locations of animals, their numbers and other useful information was often incomplete. Once a positive result was recorded, the ground survey would provide the information necessary to initiate the second activity.

Tracking was initiated in areas identified by ground surveys as having the highest caribou density. Tracking began when fresh (< 24hr) caribou sign (pellet groups, tracks, or the animals themselves) was encountered, and proceeded in the same direction as the animals. Track age

was estimated using knowledge of recent precipitation and rates of ground drifting. Odometer readings were recorded each time the tracks entered or exited a new plant community. The plant communities themselves were identified by vegetation protruding through the snow or through the excavation of snow to reveal plant species for positive community identification. Between odometer readings notes were made indicating number of caribou per group, direction of travel, approximate age of tracks, number of feeding craters encountered, the date, and location. Caribou sign was followed until either weather or darkness terminated the session, or until the group or individuals had been sighted. When caribou were sighted, number, behaviour, time, and community use were recorded for each of the individuals making up the group. If, while tracking a group of caribou, the group was sighted at the end of the day, tracking was terminated and recommenced the following morning. If observed early in the day the animals were backtracked to avoid disturbance. Tracking would resume the following morning at the site at which the caribou were last observed and in the direction in which they exited the site. Distances covered on foot were estimated by flagging vegetation along the tracks and later ground truthing on snowmobile. Following tracking, vegetation exposed in feeding craters, and the dimensions

and snow conditions of craters were sampled. Ground surveys and follow-up tracking were repeated a minimum of once every eight weeks. A full tracking session generally required three weeks to complete. Some months produced little or no tracking data due to persistent poor weather, and/or equipment failure.

Community use data were summed daily and divided by the total number of caribou/km to yield percent community use based on distance. Variables were then compared through the snow season to document changes in plant community use by CCC (Cape Churchill caribou). A Chi-squared test was performed using both tracking data and a tally of the communities in which feeding craters were found. The expected values of community use based on tracking alone were then compared to the observed (cratered communities) to determine any significant differences between communities used primarily for movement versus feeding. Although data used for observed and expected values were not completely independent, this test, I believe, still offers a more quantitative means of determining time spent within any one community then offered through a simple comparison. It should also be noted that an estimate of % availability introduces error reducing the dependability of the test result (Alldredge and Ratti 1986).

4.4 Feeding Site Analysis

Feeding crater snow conditions were measured periodically during tracking sessions. Observations of caribou groups during tracking provided the starting point for this series of api profiles. Previously observed animals were located the next morning, by snowmobile, and approached cautiously with the headlight disconnected to reduce stress on the animals.

Once on site, six fresh craters (< 15 min. old) would be chosen beginning with the first crater or nearest crater to an imaginary line drawn by extending the line of approach through the site. All approaches by snowmobile were made in a straight line aimed directly into the center of the group, and did not follow any specific magnetic bearing. Often the tracks being followed dictated the direction of approach. Once the initial crater was located, the remaining five craters were identified in sequence by moving to the nearest neighbor. Craters were defined as any area of ground physically exposed by caribou.

Snow work would begin immediately by first removing a thin layer of disturbed api at the region of the crater most recently excavated (the active edge). Two other

profiles were also sampled within the feeding crater. While facing the active edge, these two regions were located in the closest lower left and lower right hand corners. Again in both these regions profiles were prepared by removing only enough api to reveal undisturbed snow. Each of the three profiles were then analysed as described in the section "api profiles". Once again only the variables hardness, thickness, and the Varrio Snow Index (VSI) were examined. Values of the remaining six variables are listed in Appendix B. The aforementioned steps were repeated for each of the six selected feeding craters.

Following completion of feeding crater profiles, two control craters (areas in which the caribou did not crater) were excavated 5 m to the left and 5 m to the right of each of the six feeding craters. Attempts were made to mimic the size, shape and orientation of the craters. Once 54 profiles were examined (36 control and 18 feeding crater . profiles) vegetation samples would be taken from each crater. Exposed vegetation within each of the six feeding craters was removed to the substrate using a knife and placed into a paper bag. Only exposed vegetation within the crater (within the active edge) was sampled; disturbed snow from within the crater was not removed to access vegetation.

Calculation of VSI's, as described in the section "snow study", was the primary means of analysing the snow data. Comparisons between control log VSI's, hardness and thickness and experimental or feeding crater values were made using the Mann-Whitney U test statistic to determine significant differences. The median value of a series of sampling units ($n = 3$ profiles per crater and control) was calculated over early, mid-, and late winter. Both craters and controls were then tested for significant differences over early, mid-, and late winter, and between snow seasons. In addition comparisons were made between early, mid, and late winter feeding crater snow conditions to determine temporal thresholds to feeding. Snow station log VSI's were also compared with both feeding and control craters using the same non-parametric test. Log VSI's of both control and feeding craters along with an analysis of their vegetative content proved to be useful when analyzed with snow station data as they provided a means to compare snow parameters within similar but spatially segregated communities. Analysis of vegetation samples are explained in greater detail in the following section "feeding habits".

4.5 Feeding Habits

4.5.1 Crater Analysis

Exposed vegetation was collected from caribou feeding craters encountered during tracking sessions. All craters encountered were divided into the previously defined 3 segments within which only exposed vegetation was collected. The leading edge, or active edge, of the crater generally offered the greatest amount of exposed plant material varying from 0.1 m^2 to 0.25 m^2 . Craters from which vegetation was sampled were also measured dimensionally (L x W), to provide an index of time spent within the crater. Exposed hummocks showing signs of feeding (evident from scattered clumps of plant material) were also sampled for plant material. Generally 0.25 m^2 was sampled from the center of feeding activity on large hummocks, while only a few cm^2 were sampled from smaller hummocks. The actual size of sample was dictated by the snow border surrounding the plant material. Vegetation samples were placed in paper bags. Large continuous craters (fieski) excavated by several caribou were found during late winter and rarely during early and mid winter. These craters, at times 20 meters across, made up the only exception to the vegetation collection rule. When such a crater was encountered, vegetation would be sampled from each of the identifiable active edges. Dimensions were

measured from the most central active edge (as these large craters were generally longitudinal in orientation with the active edges always on the uphill side of the crater) across the crater perpendicularly bisecting a line joining the extreme left and right lowermost edges of the crater.

Bagged crater contents were kept frozen until their return to base camp, at which time they were set on drying racks above a fuel oil furnace for one week. This served to remove enough moisture for dry storage. Samples were then sorted (using a dissection scope when necessary) according to genus and species. In many cases plant fragments could not be identified and were classified as unknown. Following the sorting procedure, all remaining plant matter was termed litter. Each identified species was then given a labelled bag. The bags were then air dried at 26⁰ C for 48 hours and weighed to the nearest 0.01 g. The total weight of all species was tallied, and individual weights were converted into percent values. Crater content and dimension were compared and monitored throughout both the 1989-90 and 1990-91 snow seasons.

4.5.2 Rumen Analysis

Rumens were collected from hunter-kill sites during the 1989-90 and 1990-91 snow seasons. While ground searching and tracking, snowmobile tracks encountered were

followed on occasion. Frequently, these tracks led to kill sites (evident from gut piles, legs, head and skin). Word of a successful hunt from the community often led to a snowmobile trip specifically to recover rumens. Once at a kill site, rumens were collected whole and placed into doubled plastic garbage bags. Twenty-five rumens were collected over the 1990-91 snow season. Of the 25 rumens, five were from January and the remainder from April. During the spring of 1992, individual rumen samples were partially thawed, mixed and divided into three subsamples. Available funds restricted the maximum number of samples analysed to 12. Five of these samples were from January 1991, while the remaining seven were randomly selected from the 19 remaining April samples. One sample from each rumen was shipped to the Department of Natural Resource Sciences, Habitat Lab, at Washington State University, Pullman, Washington. At the lab, samples were thawed and placed in a blender to break the plant material down into cellular components. Eight samples were randomly removed from the blended sample and placed on glass slides. At the appropriate magnification, 25 different fields were examined per slide yielding a total of 200 fields. Plants within each field were identified by comparing their cellular composition with that of a series of reference slides. All identifiable plants were then assigned percent

abundance values. Further information regarding the microhistological determination of dietary components based on pellet group and rumen analysis can be obtained from several sources (Davitt 1979, Finders and Hansen 1972, Holecheck and Gross 1982, Korfhage 1974, Sparks and Malechek 1968).

4.5.3 Pellet Group Analysis

Caribou pellet groups were collected from feeding sites during crater examinations. Pellets were bagged on site and air dried with vegetation samples. Samples were then pooled according to month and year of collection. Of the 150 samples collected, 50 were from the 1989-90 snow season and the remainder from the 1990-91 snow season. In keeping with the rumen analysis only 12 samples were analysed. To complement the periods chosen for the rumen analysis, January and April scat samples from each year were selected. Three sub samples were randomly selected from the remaining samples for each of four collection dates; January 1990, April 1990, January 1991, and April 1991. The samples were then mailed to the habitat lab in Washington State University. At the lab they were hydrated and broken down in a blender. The remainder of the analysis followed that for the analysis of rumen samples.

4.5.4 Data Analysis

Species diversity and percent composition within craters, pellets, and rumens, were tallied throughout the winter. A Friedman two way analysis of variance (Scheffler 1980) was then used to compare; 1. All plant species (found within craters, scats, and rumens) between early, mid-, and late winter for both 1989-90 and 1990-91, 2. plant groups including lichens, graminoids, evergreen shrubs, and deciduous shrubs (found within craters, pellets, and rumens) between early, mid-, and late winter over both the 1989-90 and 1990-91 snow seasons, and 3. Crater, rumen, and scat species and plant group compositions between early, mid-, and late winter and over both the 1989-90 and 1990-91 snow seasons. The above applications of the Friedman AOV test were hoped to determine potential differences, or lack thereof, in plant species selection throughout the snow season, as well as determining any differences or similarities between the three choosen analyitical techniques. Using the crater and rumen analysis techniques one crater/rumen and its vegetative contents equalled 1 sampling unit while several pellets making up one pellet group represented 1 fecal (pellet group) sampling unit.

5.0 RESULTS

5.1 Plant Community Structure

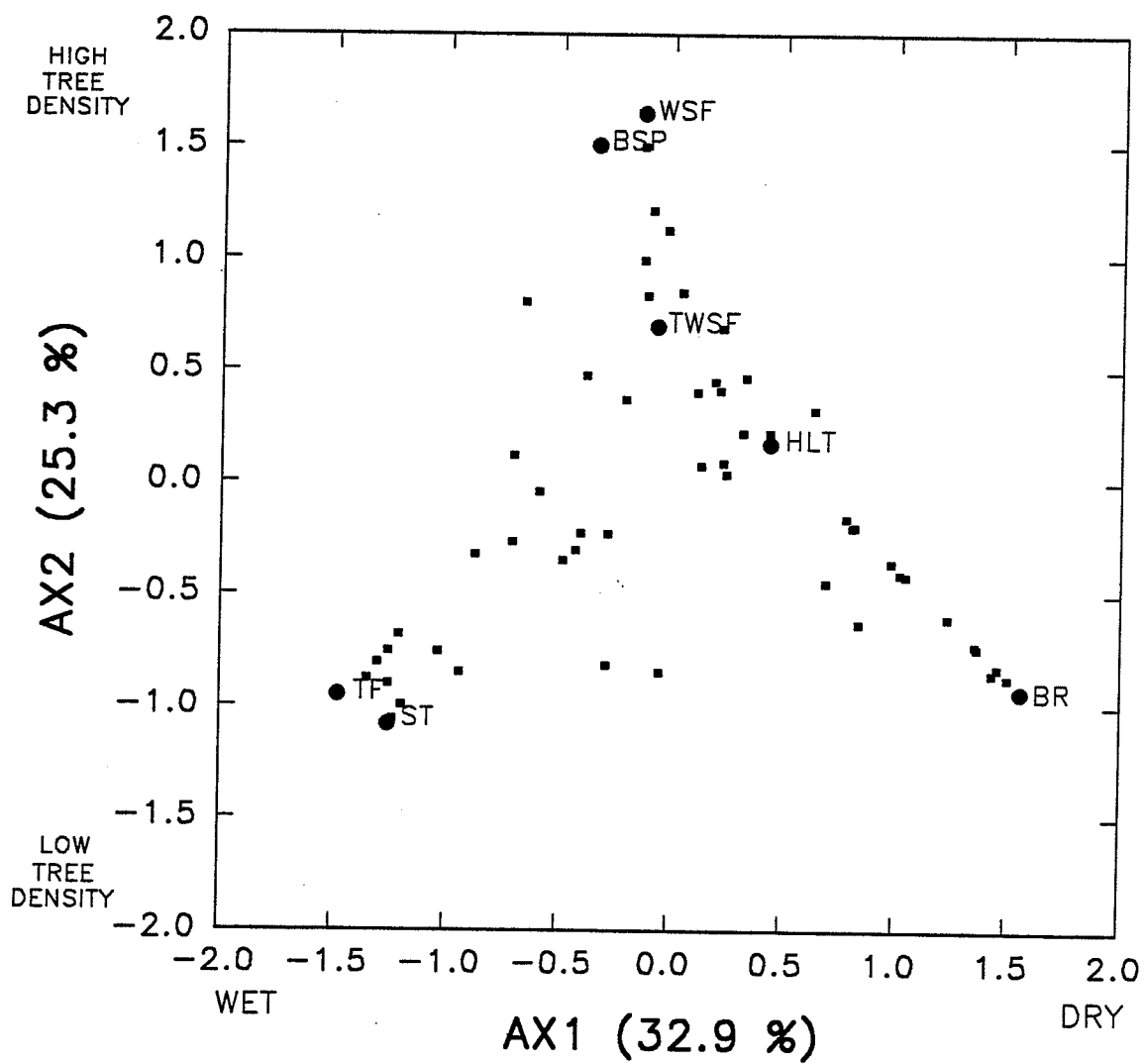
5.1.1 Ordination Of Plant Communities

Four of the seven plant communities were within the forested taiga and three were within the treeless tundra. To determine the degree to which these communities were related a Canonical Correspondence Analysis (CANOCO) was used (Gittins 1985, Ter-Braak 1988). Vegetation data from each community were entered into the ordination using the frequencies of individual plant genera, and when possible, species, and discussed as an index of percent ground cover.

The CANOCO PCA (principal components analysis), examines the variance between data points by assigning them negative or positive eigenvectors. This examination of variance is conducted along four axes of which the first accounts for the maximum variance within the data and the second third and fourth progressively smaller amounts of variance. Although ordination axes are not necessarily related to ecological variables they are seldom independent of them (Austin 1985).

The ordination of the seven snow station communities

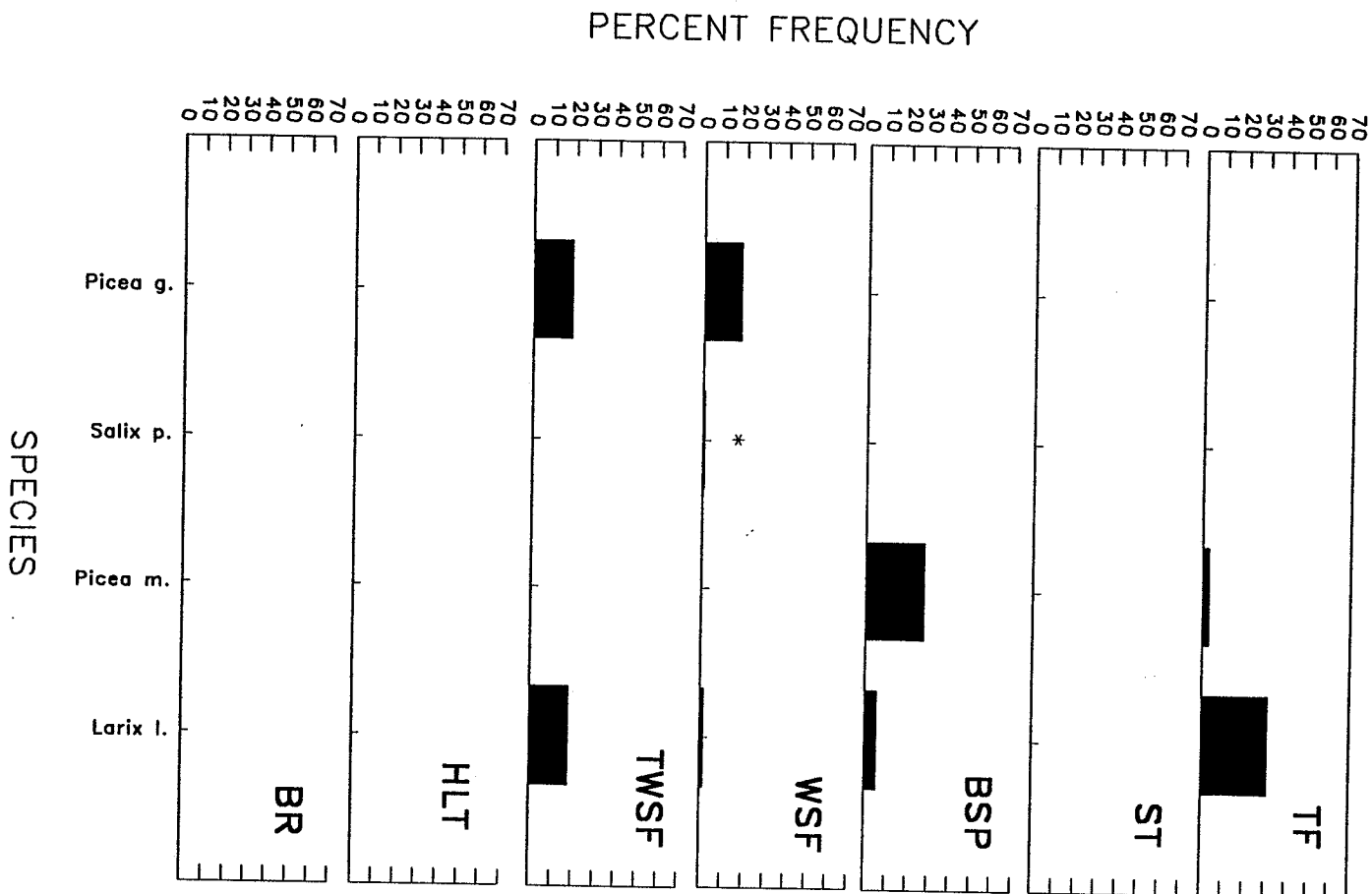
required only the first two axes as higher axes did not appear to improve community separation. Axis one accounted for 32.9 % of the variation while axis two covered 25.3 %, a total of 58.2 % of the variance accounted for in the first two axes (Figure 4). The spatial separation along axis one, within both taiga and tundra communities, appears to be related to moisture. Examples of species with very positive eigenvectors within axis 1 included; Shepherdia canadensis (+1.7), Dryas integrifolia (+1.6), Carex glacialis (+1.6), Thamnia subuliformis (+1.6), and Alectoria nigricans (+1.5), while examples of species with strongly negative values included Triglochin maritimum (-1.4), and Pyrola uniflora (-1.4), Epilobium palustre (-1.4), Betula glandulosa (-1.2), Carex aquatilis (-1.2), Eriophorum spp. (-1.2),. Generally moisture increases with decreasing eigenvector values. Axis two appears to be related to graminoid cover, more specifically Carex spp., and is consistent through all communities. Examples of species with highly positive loadings in axis two are Epilobium angustifolium (+1.6), Ledum groenlandicum (+1.5), Bryoria spp. (+1.5), and Peltigera spp. (+1.4), while examples of species with highly negative values include Eriophorum spp. (-1.3), Carex saxatilis (-1.3), Carex limnosa (-1.2), and Carex capitata (-1.1). In all cases total graminoid cover increases with decreasing eigenvector



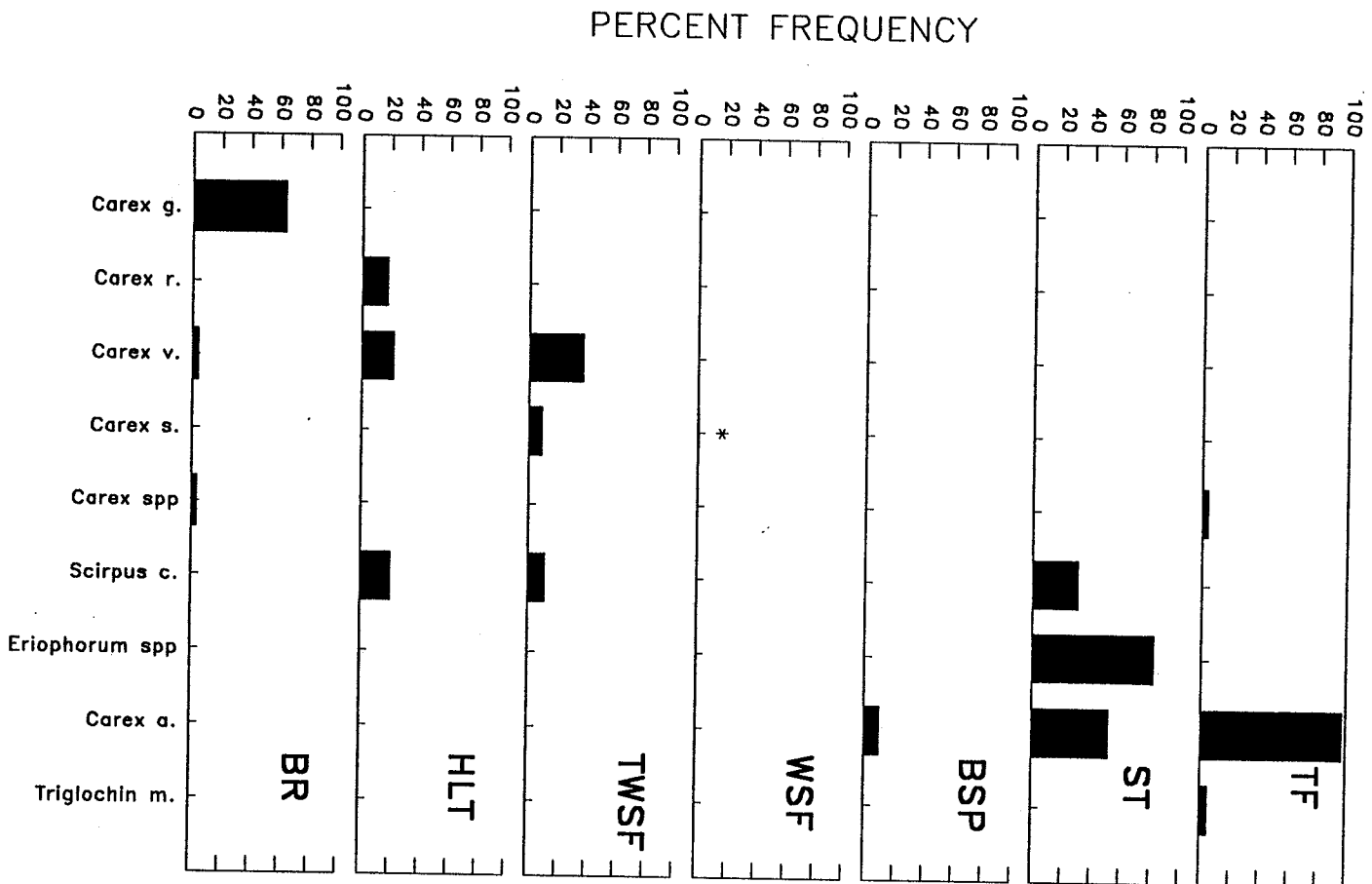
values. Another relation apparent in axis two concerns tree densities within taiga communities. Along axis two tree densities increase with increasing eigenvector values with the exception of the WSF community as BSP densities were over 500 trees/hectare greater. A combination of both axis one and axis two appears to be related to species richness. Those communities with the greatest number of documented species fall within the center of Figure 4, while those with the fewest species are located towards the extremes.

Using percent frequency (as determined through plant presence or absence within 5000 - 5cm X 5cm subplots) along the y-axis and species plotted in order of decreasing eigenvector values along the x axis, a series of figures (5 - 11) have been generated to show dominant plant species within each of the seven communities. The seven vegetation classes and corresponding figures include: 1. tree canopy (Figure 5), 2. graminoids (Figure 6), 3. lichens (Figure 7), 4. mosses (Figure 8), 5. evergreen shrubs (Figure 9), 6. deciduous shrubs (Figure 10), 7. forbs (Figure 11). For each community, the three dominant species within the 7 general vegetation classifications are plotted. Cover values for all species, and communities including canopy composition are listed in Appendix C. Using cover values and the spatial separation provided by the ordination, a

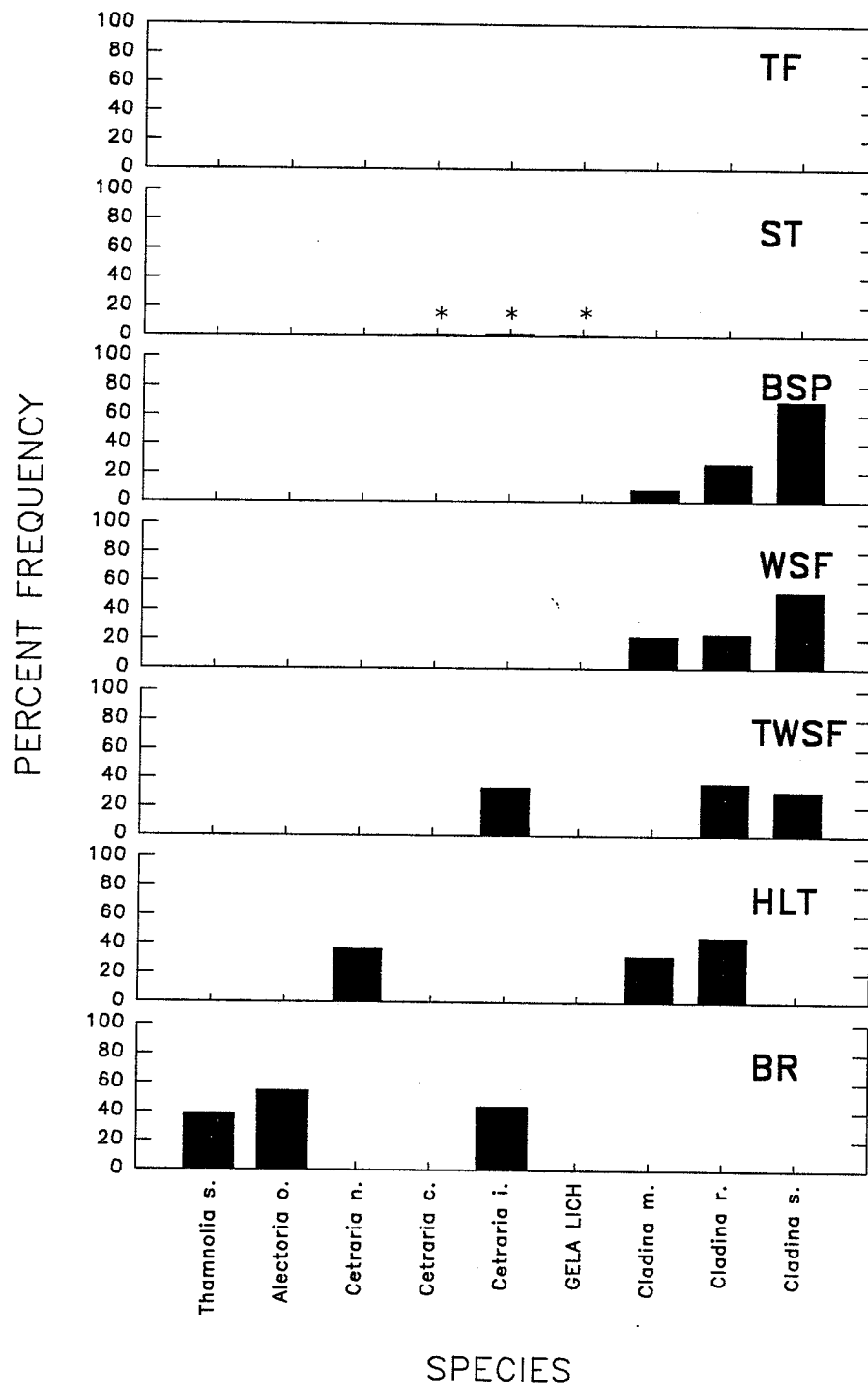
TREES



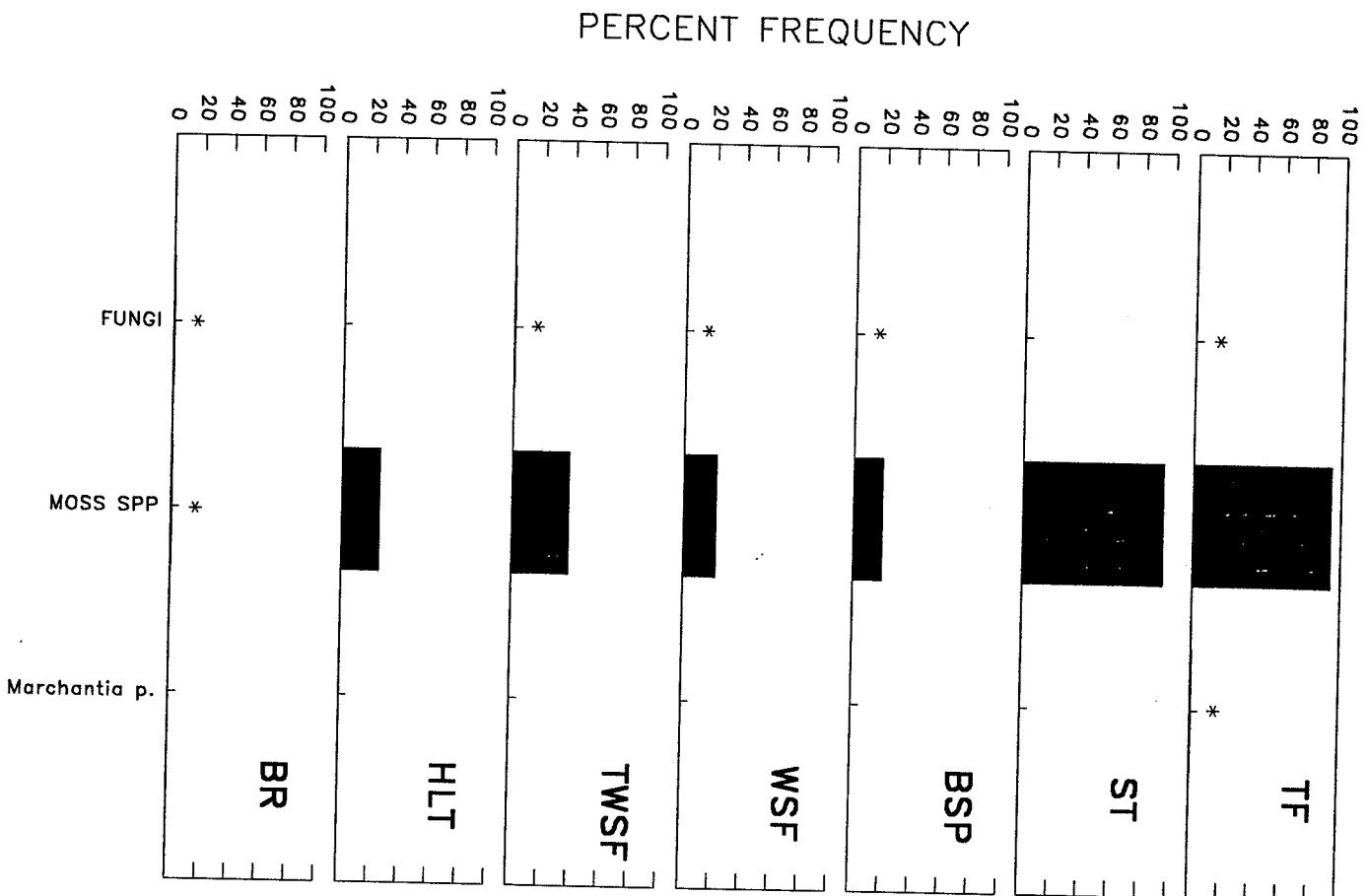
GRAMINOIDS



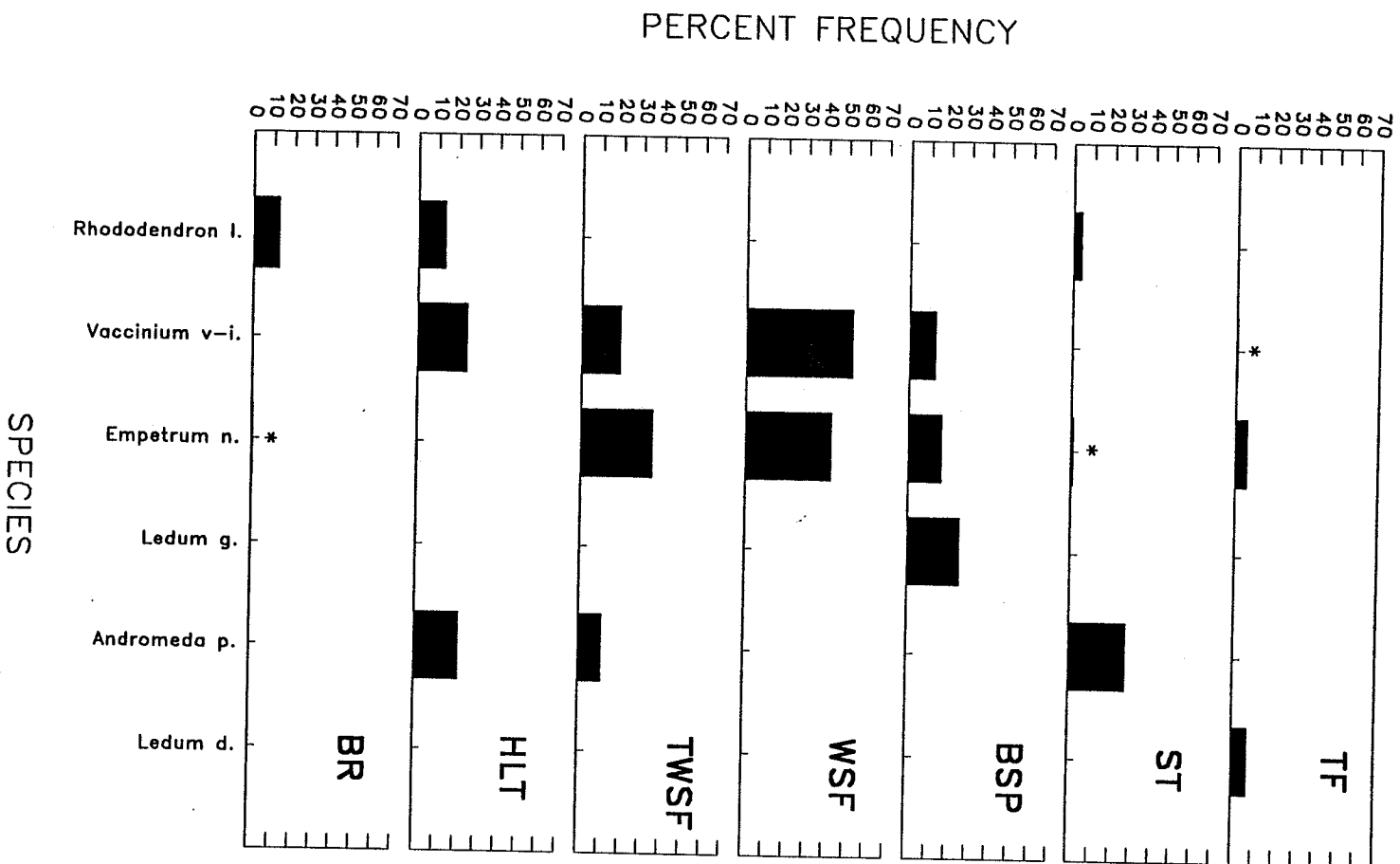
LICHENS



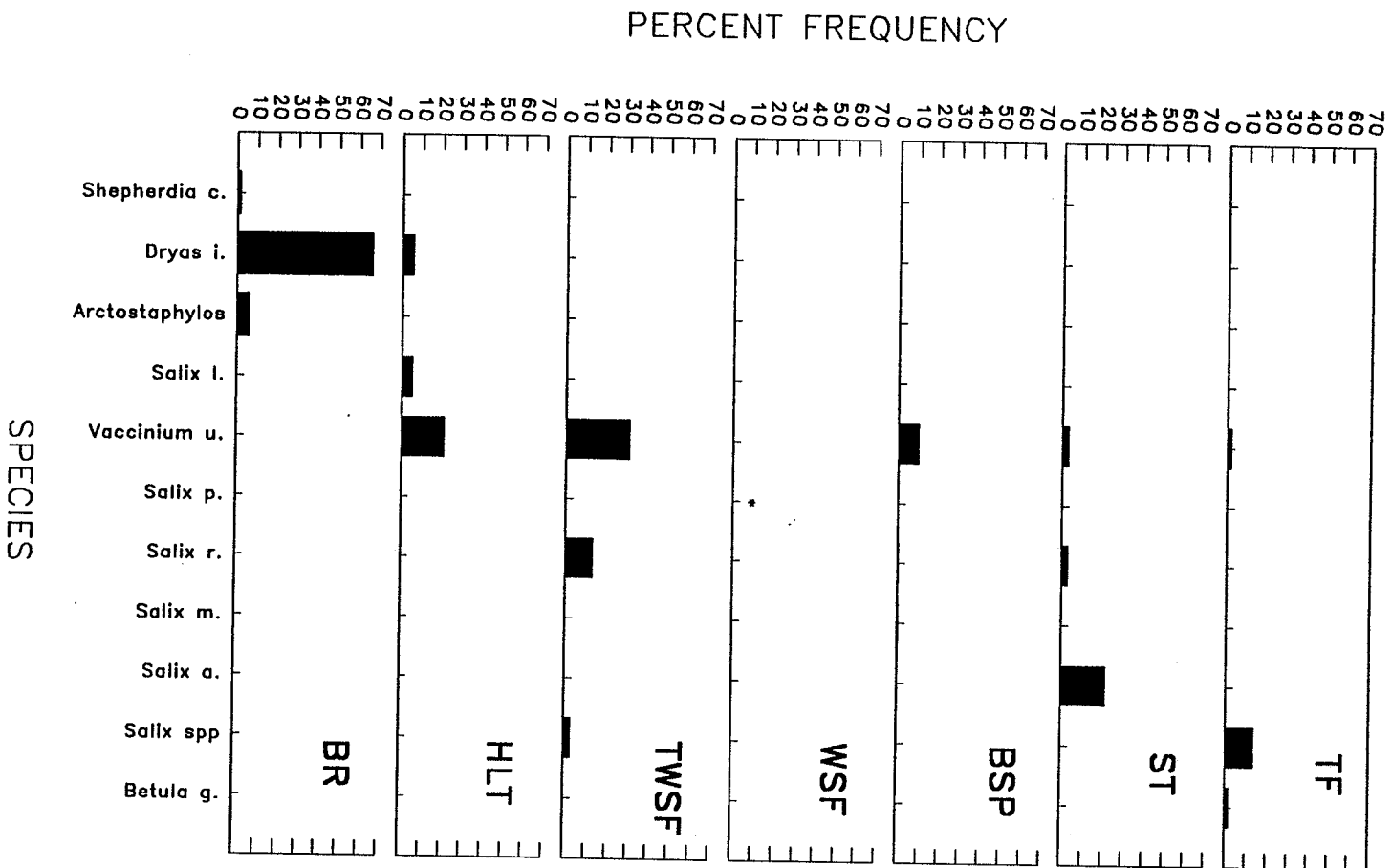
MISCELLANEOUS SPECIES



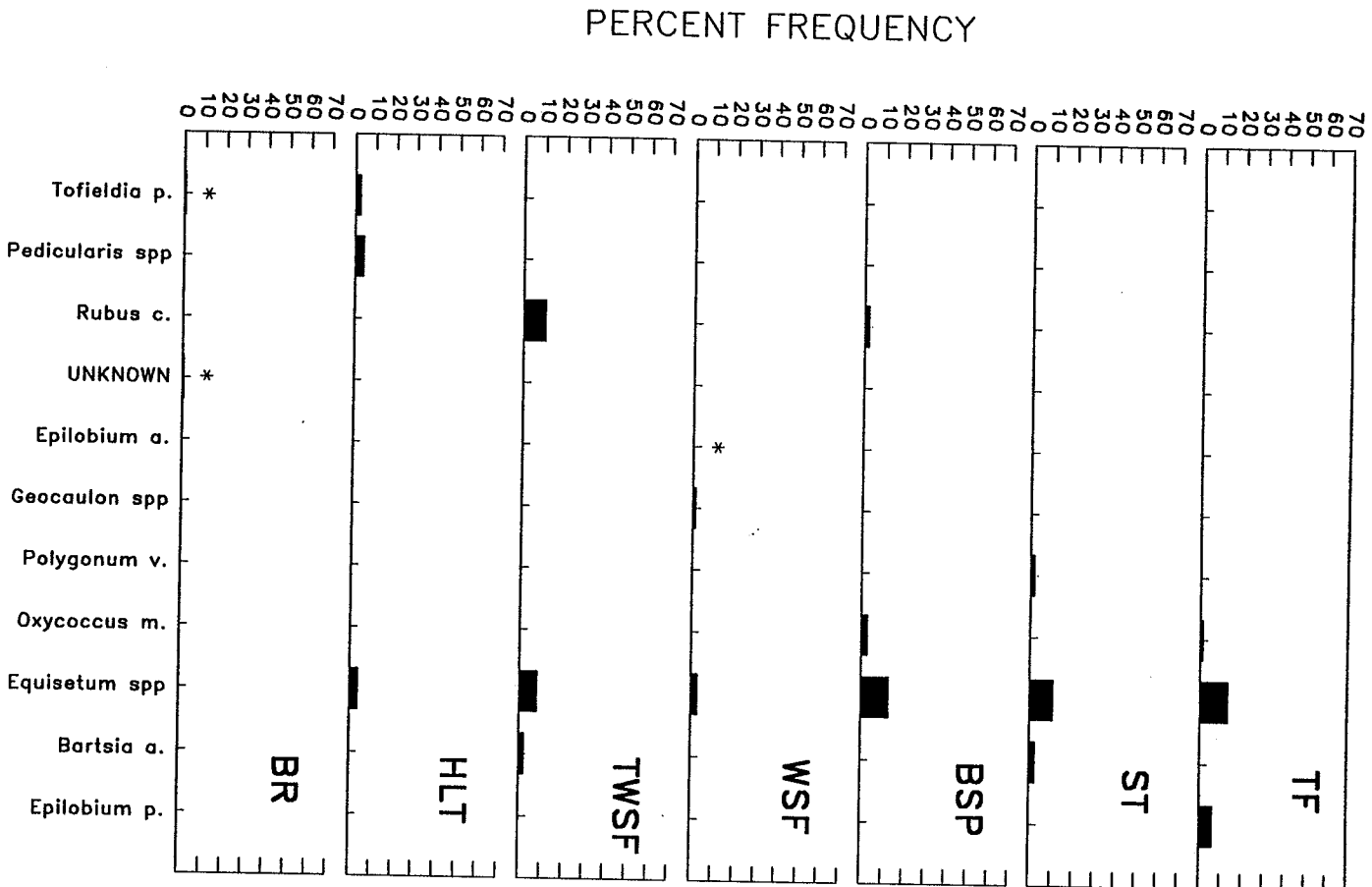
EVERGREEN SHRUBS



DECIDUOUS SHRUBS



FORBS



SPECIES

series of community descriptions have been generated.

5.1.2 Taiga Community Structure

The tamarack (Larix laricina) fen community, (TF), is made up of a mosaic of sedge meadow grading into shrub thicket and tamarack forest. It is predominantly a minerotrophic wetland environment and is the most hydric of the 7 communities. The microtopography of the site ranges from water-filled depressions to the tops of low tamarack tussocks generally less than 100 cm in height. The entire community can be likened to a lake with islands of each of the remaining taiga habitats scattered, to a greater or lesser degree, throughout. The dominant community found in association with TF is the BSP community. Tree densities are the lowest in the TF at 397 trees per hectare of which approximately 92 % are tamarack and the remaining 8 % black spruce. Approximately 31.3 % of the community has a canopy cover of tamarack while 2.9 % has a canopy of black spruce. A total of 23 species of ground vegetation were identified giving TF the second lowest species richness of all communities. Carex aquatilis was the most common graminoid followed by Triglochin maritimum and Carex spp.. Mosses also displayed high cover values particularly at the bases of sedges. The TF community was the only site having little to no representation from the lichen group. Common

evergreen shrubs included Ledum decumbens, Empetrum nigrum, and Vaccinium vitis-idaea. Salix spp., Betula glandulosa, and Vaccinium uliginosum were the most common deciduous shrubs. The common forb included Epilobium palustre while Equisetum spp. was the most common Pteridophyte.

The black spruce palsa (BSP) community was the second driest taiga site and third driest of both the taiga and tundra communities. It is commonly associated with, but elevated up to 3 meters above, the surrounding TF community. This elevation above the surrounding wetland is the result of an expanding frozen core that at one time likely began its evolution as a tamarack fen pond succumbing to the invasion of Sphagnum-like mosses. The community is ombrotrophic and relatively well drained except in areas of thermokarst and frost cracking where the frozen core is exposed. The BSP recorded the greatest tree densities of all the taiga communities at 1445 trees per hectare of which 83 % were black spruce and 17 % tamarack. Total canopy cover was 33 %, 28 % percent of which was black spruce and 6 % tamarack. A total of 24 species of ground vegetation were identified within the community making it third lowest in species richness. Graminoids were poorly represented with only one recorded species (Carex aquatilis). Mosses were a common ground cover and were primarily of the genus Sphagnum. Lichens were the

dominant plant group with Cladina stellaris, C. rangiferina, and C. mitis being the most common respectively. Evergreen shrubs included Ledum groenlandicum, Empetrum nigrum, and Vaccinium vitis-idaea. Common deciduous shrubs included Vaccinium uliginosum, Salix myrtillifolia, and S. reticulata. Rubus chamaemorus represented the most common forb while Equisetum spp. represented the most common Pteridophyte.

White spruce (Picea glauca) forest (WSF) was the second driest taiga community and the third driest of both the taiga and tundra. WSF is a well-drained site generally associated with inland gravel ridges such as eskers, kames, and beach ridges, and in some areas can penetrate to within a kilometer of the Hudson Bay coast. Tree densities are the second highest at 918 trees per hectare of which 88 % are white spruce, 1 % tamarack, and less than 1 % Salix planifolia. In total the canopy covered 20 % of the community of which white spruce represented 18 %, tamarack 2 %, and Salix planifolia 1 %. A total of 22 plant species were identified giving it the lowest species richness of all the communities studied. These low numbers were reflected in the graminoids where Carex scirpoidea was the most common graminoid at 1 % ground cover. Mosses were only slightly higher than BSP cover values. Lichens were common, specifically within clearings. The most common

lichens included Cladina stellaris, C. rangiferina, and C. mitis. Common evergreen shrubs included Vaccinium vitis-idaea, and Empetrum nigrum. Deciduous shrubs including Salix planifolia and Betula glandulosa were not common. Geocaulon lividum and Epilobium angustifolium made up the forbs.

The tamarack-white spruce forest (TWS) community commonly makes up the transition between taiga and tundra (forest-ecotone) on sites with moderate to good drainage. In addition this community type can be found within the taiga where white spruce communities on gravel ridges grade into tamarack fen. The microtopography can vary up to a meter between elevated well-drained hummocks of frost heaved marine sediments and gravel, to lower-lying depressions of finer sediments which in the spring collect water. The site studied was a forest ecotone community with a tree density of 751 trees per hectare, the second lowest of the four taiga sites. The total canopy cover of all tree species was 33 %, 54 % white spruce and 46 % tamarack. A total of 40 plant species were identified making this community the second highest in overall species richness. Graminoids showed moderate representation where the species Carex vaginata, Scirpus caespitosus, and Carex scirpoidea were the most common respectively. Mosses were the second highest of the taiga communities. Common

lichens included Cladina rangiferina, Cetraria islandica, and Cladina stellaris. Common evergreen shrubs included Empetrum nigrum, Vaccinium vitis-idaea, and Andromeda polifolia. The most common deciduous shrubs include Vaccinium uliginosum, Salix reticulata, and Salix spp.. Common forbs included Rubus chamaemorus, and Bartsia alpina while Equisetum spp. was again the most common Pteridophyte.

5.1.3 Tundra Community Structure

The most mesic of the tundra communities was sedge tundra (ST). The ST community is found on minerotrophic sites of low relief. During the spring melt these sites often form extensive ponds which can persist well into mid-summer depending on the year. By August 1st the sites are usually free of standing water and at times can become dry enough to create a fire hazard. ST communities are closely associated with hummocky lichen tundra communities which often grade into a complex mosaic making their separation, at times, extremely difficult. A total of 30 species were identified giving ST a species richness third highest of the seven communities studied. Graminoids were the most common plant group with Eriophorum spp., Carex aquatilis, and Scirpus caespitosus being the most common respectively. Moss cover values were the greatest of all

communities at 95 %. Lichens included Cetraria islandica, Gelatinous lichens, and Cetraria cucullata each with cover values of less than 1 %. Common evergreen shrubs included Andromeda polifolia, Rhododendron lapponicum, and Empetrum nigrum. Of the deciduous shrubs Salix arctophila, S. reticulata, and Vaccinium uliginosum were the most common. Bartsia alpina and Polygonum viviparum represented the most common forbs. Equisetum spp. represented the most common Pteridophyte.

The hummocky lichen tundra (HLT) community was found in association with patterned ground which can take the form of strings, palsas, ice pushes, low center polygons and high center polygons. The site selected was a complex of high center polygons and ice pushes with a microtopography between ditch bottom and hummock top of between 50 and 100 cm. The hummocks are formed of peat, largely composed of graminoid material, that was forced above what was once a sedge meadow by expanding ice formed within a concentric polygon of sublimation cracks on a level peat surface during the spring melt. These ice filled cracks or ditches around the perimeter of the raised hummocks are minerotrophic and poorly drained while the raised hummocks are ombrotrophic and well drained. A total of 47 plant species were found giving hummocky lichen tundra the greatest species richness of the 7 communities

examined. Lichens were the dominant plant group of the community with Cladina rangiferina, Cetraria nivalis, and Cladina mitis respectively, being the most common. Common graminoids included Carex vaginata, Scirpus caespitosus, and Carex rupestris. Mosses were common specifically in association with the more mesic ditch systems. Vaccinium vitis-idaea, Andromeda polifolia, and Rhododendron lapponicum were the most common evergreen shrubs. Common deciduous shrubs included Vaccinium uliginosum, Dryas integrifolia, and Salix lanata. Pedicularis spp., and Tofieldia pusilla represented the common forbs while Equisetum spp. once again represented the most common Pteridophytes.

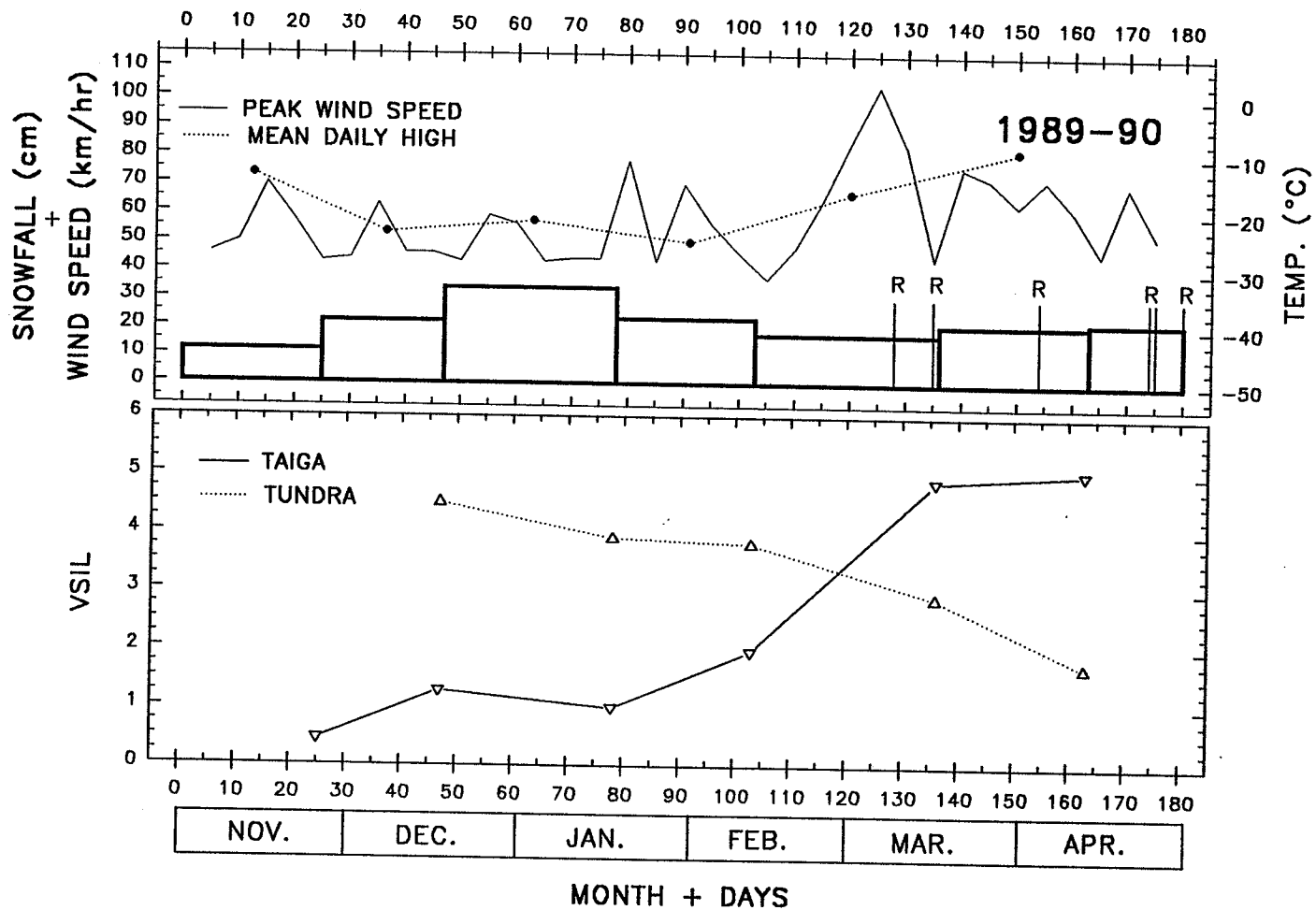
The beach ridge community (BR) was the most xeric of all communities. The BR site is made up of water-sorted gravels, and small stones built up by wave action from Hudson Bay, and isolated inland by isostatic rebound. The community is elevated up to five meters above the surrounding tundra and as a result is extremely well drained. The beach ridges within the study area generally run parallel to the existing Hudson Bay shore line giving them a resultant north-south orientation and an easterly and westerly exposure along their sloping sides. The tops of the BR communities are approximately 30 meters across and of low relief. The site studied was set up along the

flat top of the beach ridge. A total of 28 plant species were identified giving the beach ridge the fourth highest species richness. Lichens were the dominant plant group with Alectoria ochroleuca, Cetraria islandica, and Thamnolia subuliformis, respectively, being the most common. Common graminoids included Carex glacialis, C. vaginata, and Carex spp.. Dryas integrifolia had the single highest species ground cover value at 66 %, while the remaining deciduous shrubs, Arctostaphylos spp., and Shepherdia canadensis, had respective covers of 6 % and 1 %. All moss species were less than 1 %. The most common evergreen shrubs included Rhododendron lapponicum and Empetrum nigrum. There were only two forbs, Tofieldia pusilla and an unknown forb, both of which were under 1 %.

5.2 Taiga And Tundra Snow Conditions

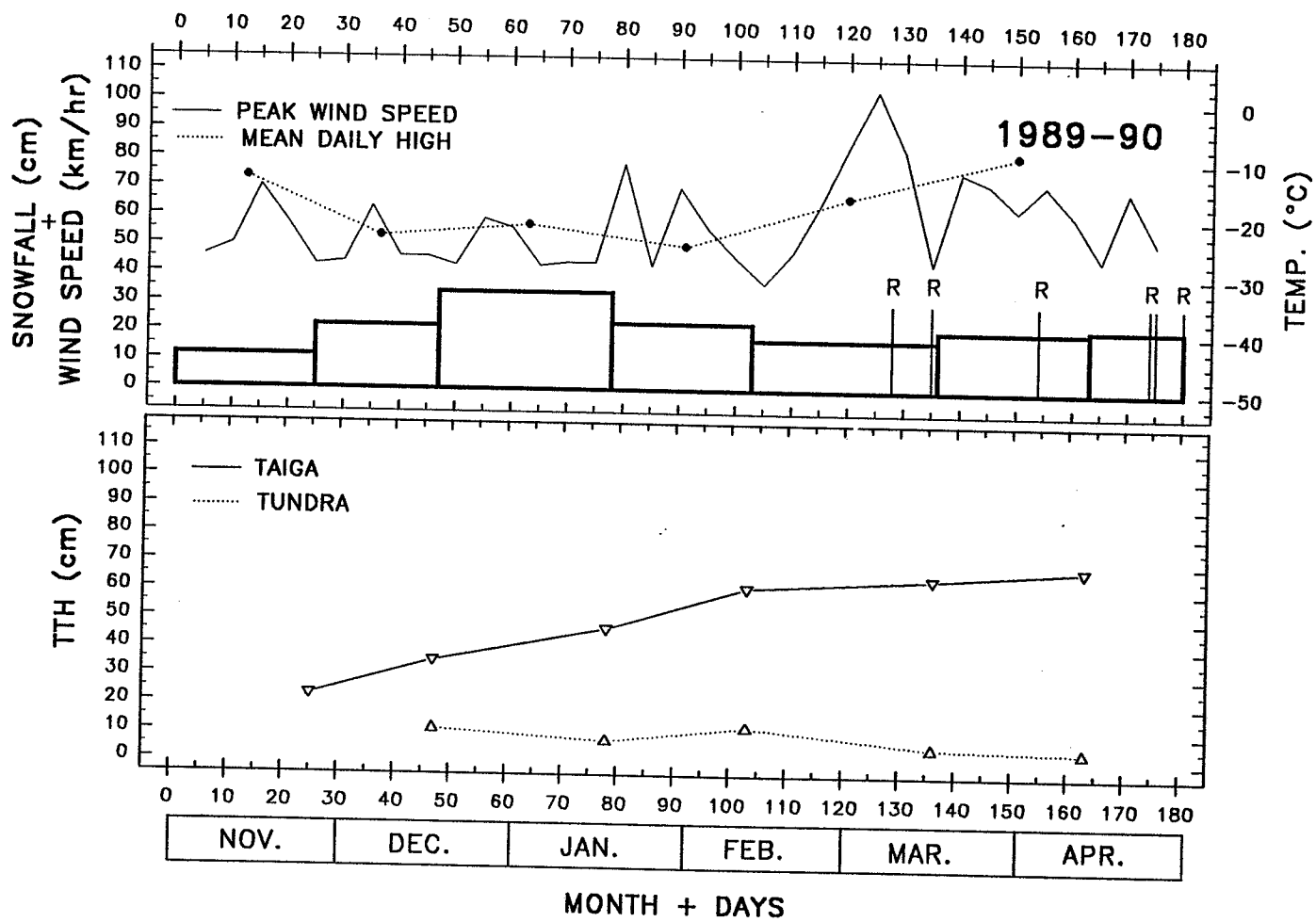
5.2.1 1989-1990

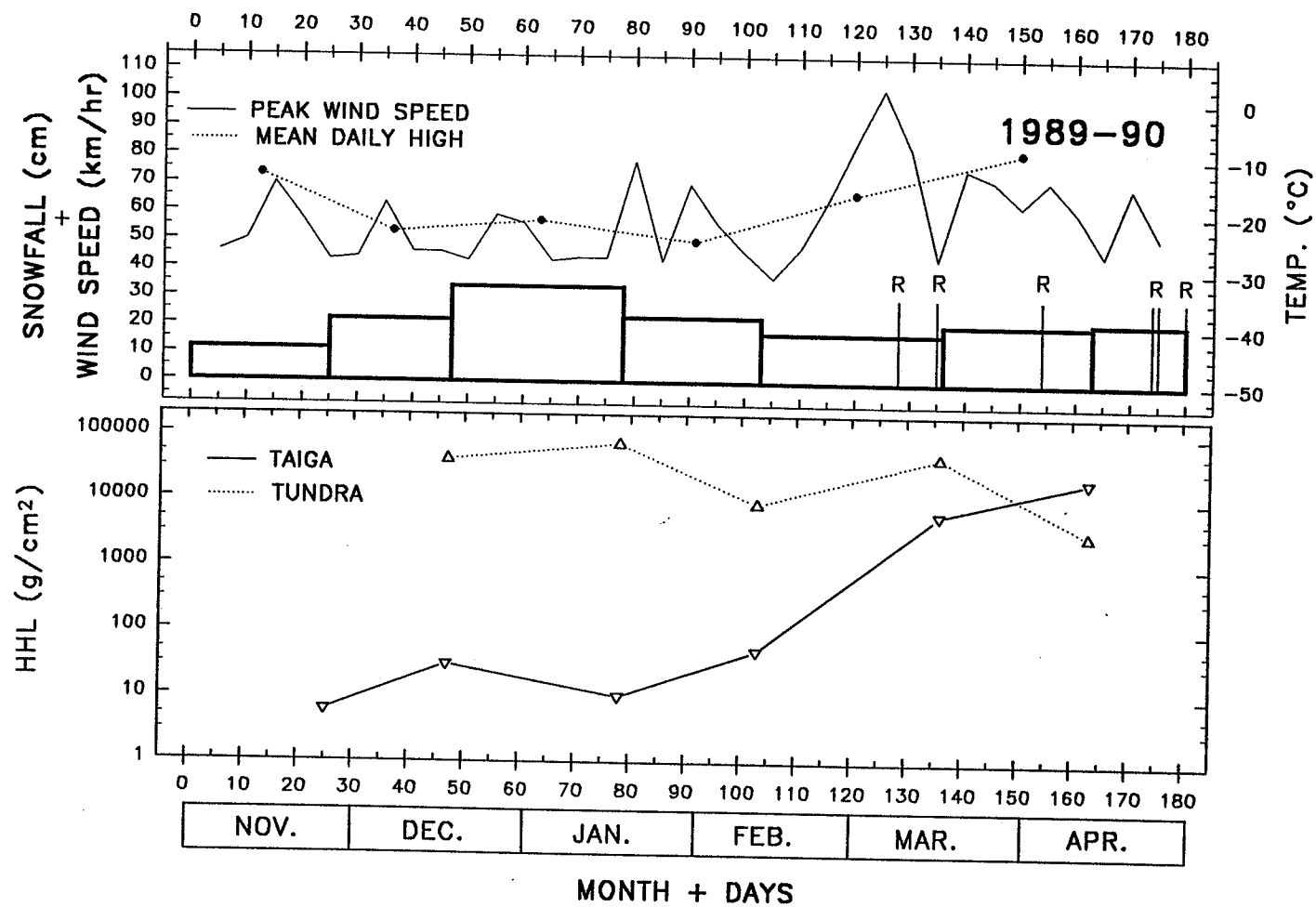
During the 1989-90 snow season changes in tundra community hardness and thickness served to create significantly higher ($p < 0.05$) median VSI's on December 17th (4.49), January 17th (3.89), and February 11th (3.80) sampling intervals, than corresponding taiga values of 1.27, 1.0, and 1.96 (Figure 12). Over the March 16th and



April 12th sampling periods, taiga VSI's significantly climbed ($p < 0.05$) above tundra VSI's to 4.88 and 5.03 respectively, while tundra VSI's dropped off sharply to 2.88 and 1.70 respectively.

Snow thickness values on the tundra remained relatively steady with taiga values displaying a steady increase between November and April (Figure 13). Hardness values, however, showed dramatic fluctuations within both taiga and tundra communities, the most dramatic of which was observed between the February and March sampling intervals (Figure 14). During this period both taiga and tundra hardness values climbed apparently in response to the occurrence of freezing precipitation on March 15th (Appendix D). With this increase in hardness came a corresponding increase in taiga log VSI's to 4.88 by the March 16th sampling interval. Despite the rise of tundra hardness values corresponding tundra VSI's dropped below taiga values and continued to drop into April. This unexpected drop appears to be related to a steady rise in mean monthly temperatures beginning in early February. These higher temperatures penetrated the thinner tundra snow cover and effectively reduce basal hardness values and thus the overall VSI (Appendix A). Drops in basal hardness were not seen within the thicker taiga snow cover as its insulative qualities effectively halted the movement of



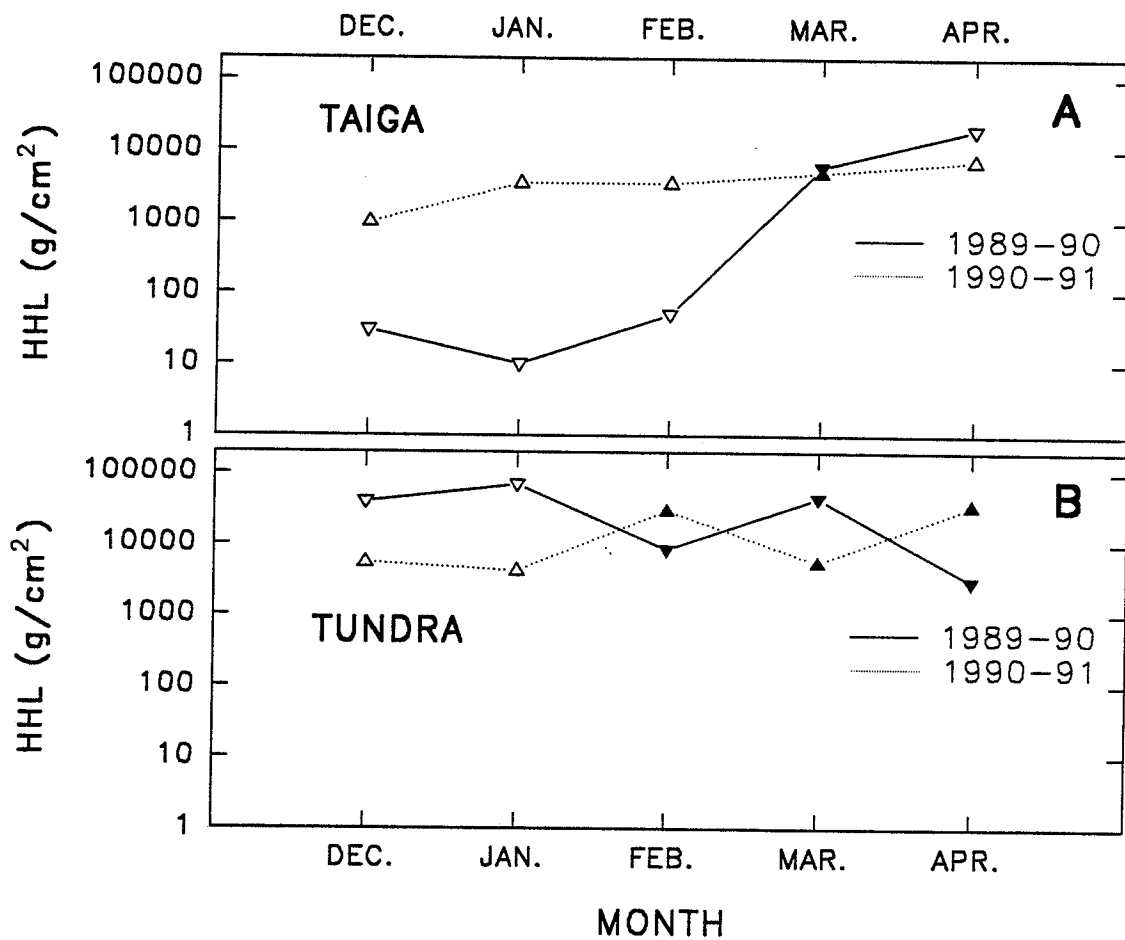


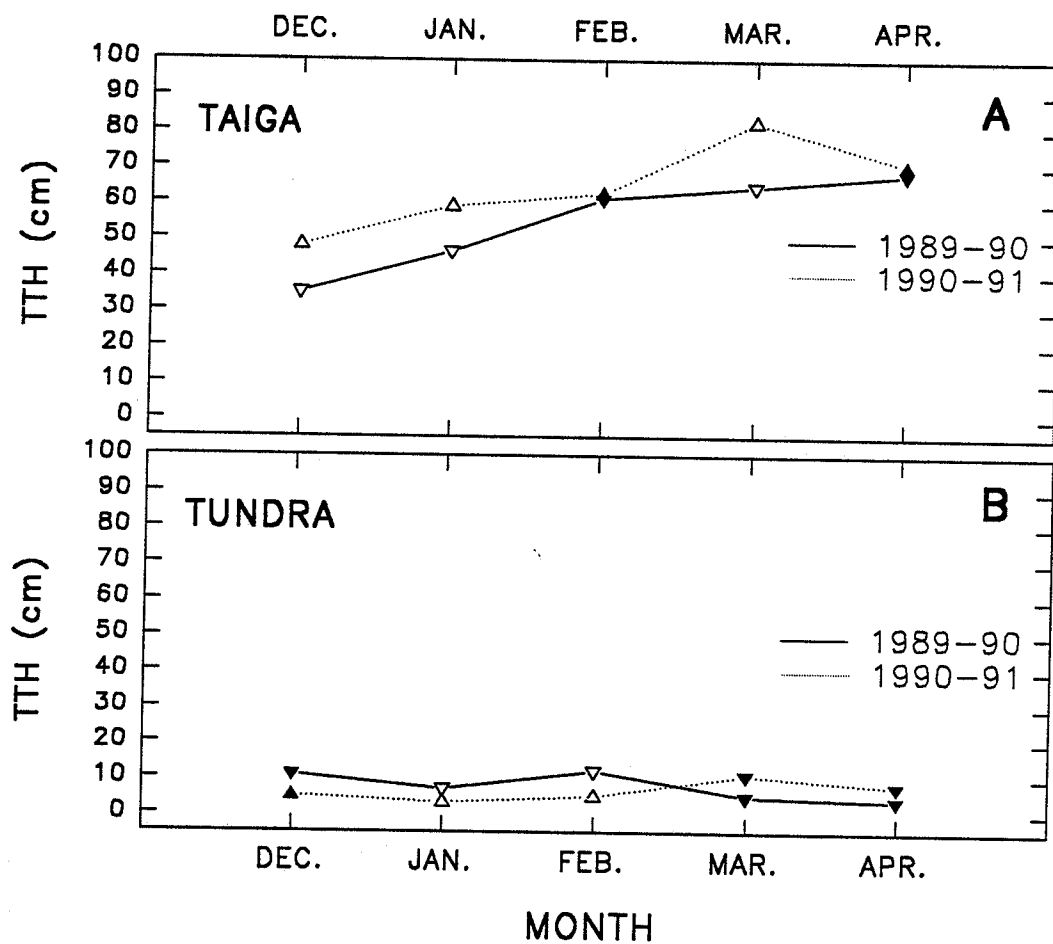
heat into the basal layers of the snow cover.

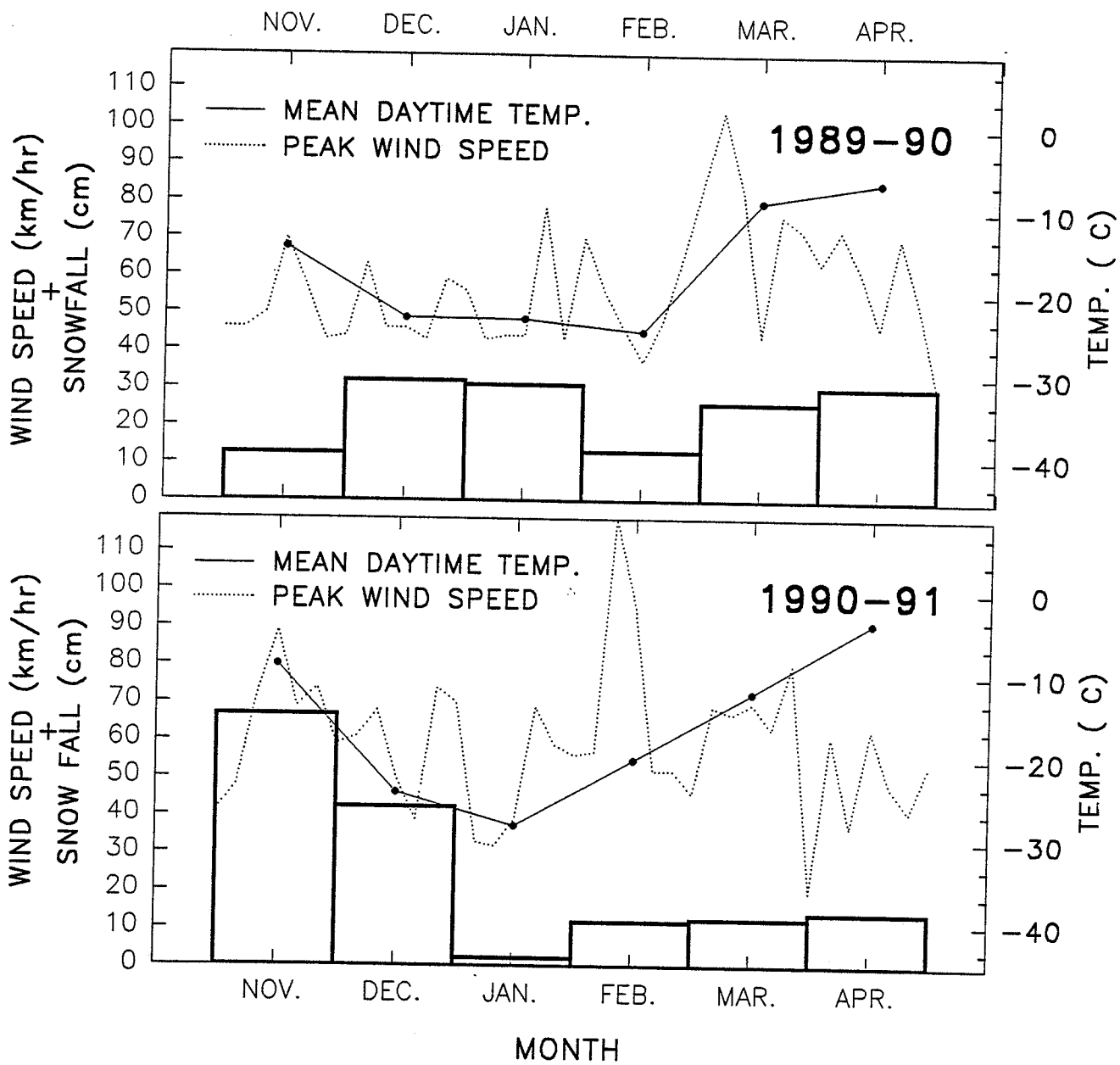
Preceding the reduction of tundra VSI's between February and March was the most dramatic drop in tundra hardness values recorded over the 1989-90 snow season. Between 17 January and 11 February tundra hardness values dropped by 61500 g/cm² largely the result of high peak wind speed and the associated ice crystal abrasion serving to abrade relict hard surface layers deposited as a freeze-thaw crust in early winter. This net drop in hardness was proportionately greater than the net gain observed between February and March and yielded a net loss of 16500 g/cm² by the March sampling interval. These observations may explain the reduction in tundra VSI's observed during this period.

5.2.2 1990-1991

Over the 1990-91 snow season taiga snow was harder and thicker than 1989-90 values (Figure 15 + 16). These differences were largely the result of weather patterns unique to each of the 1989-90 and 1990-91 snow seasons (Figure 17). By December 1990, 64.5 cm more snow had fallen than previously recorded in 1989. In addition, two days, November 21st and 22nd, recorded 11.2 cm of wet snow, 0.6 mm of rain or freezing rain, and daily highs of -0.9°C and -0.7°C respectively. During this period near zero



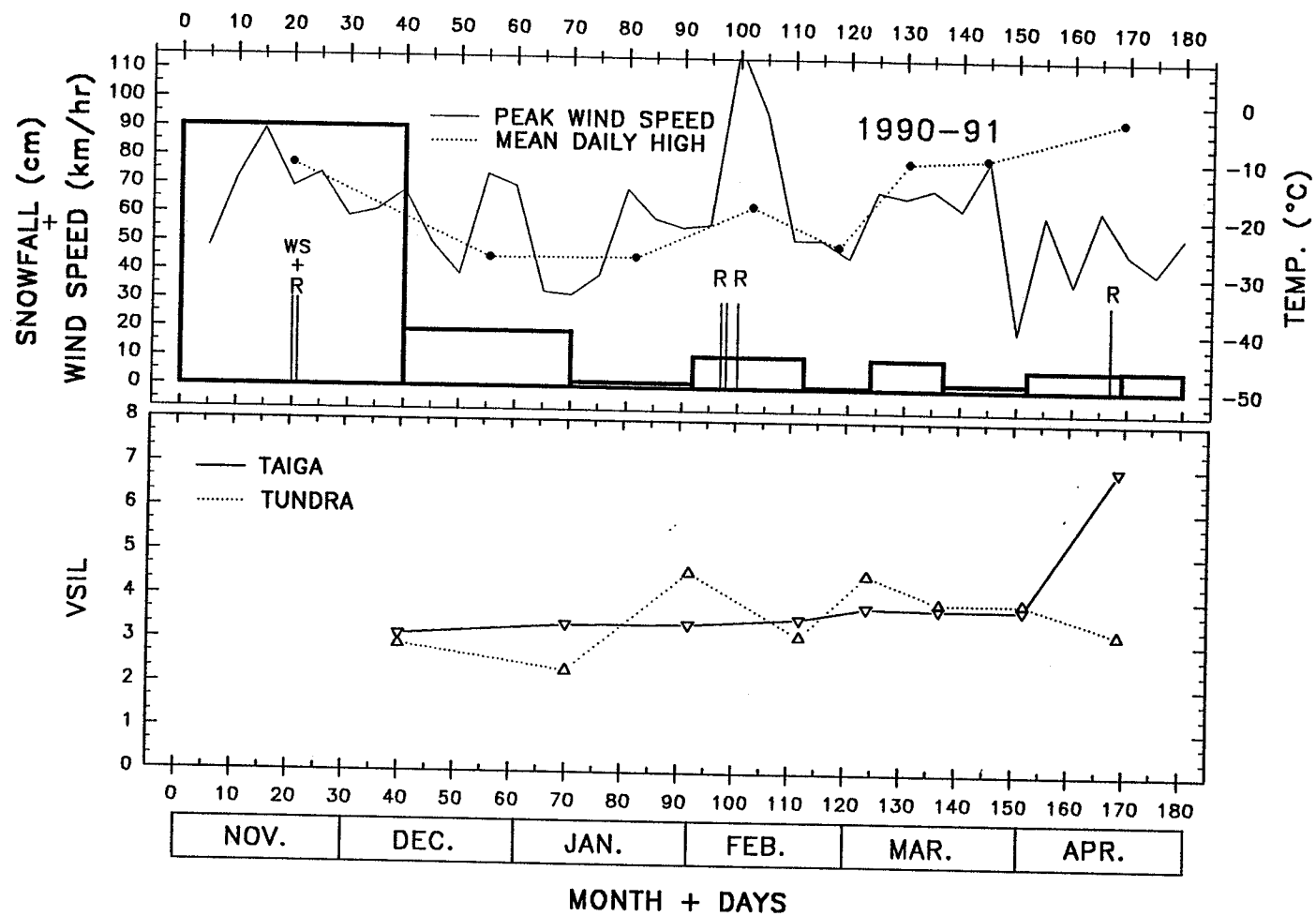


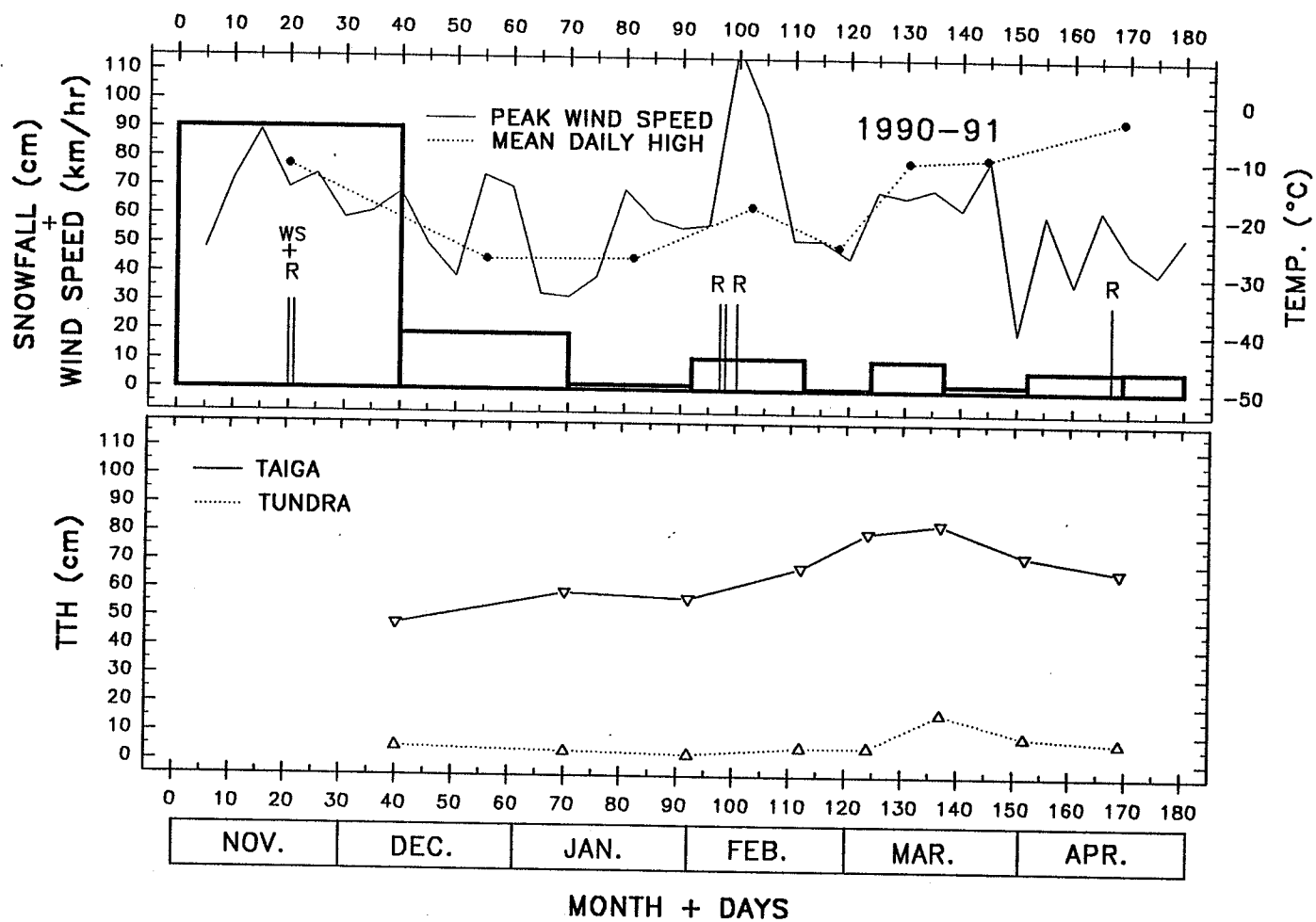


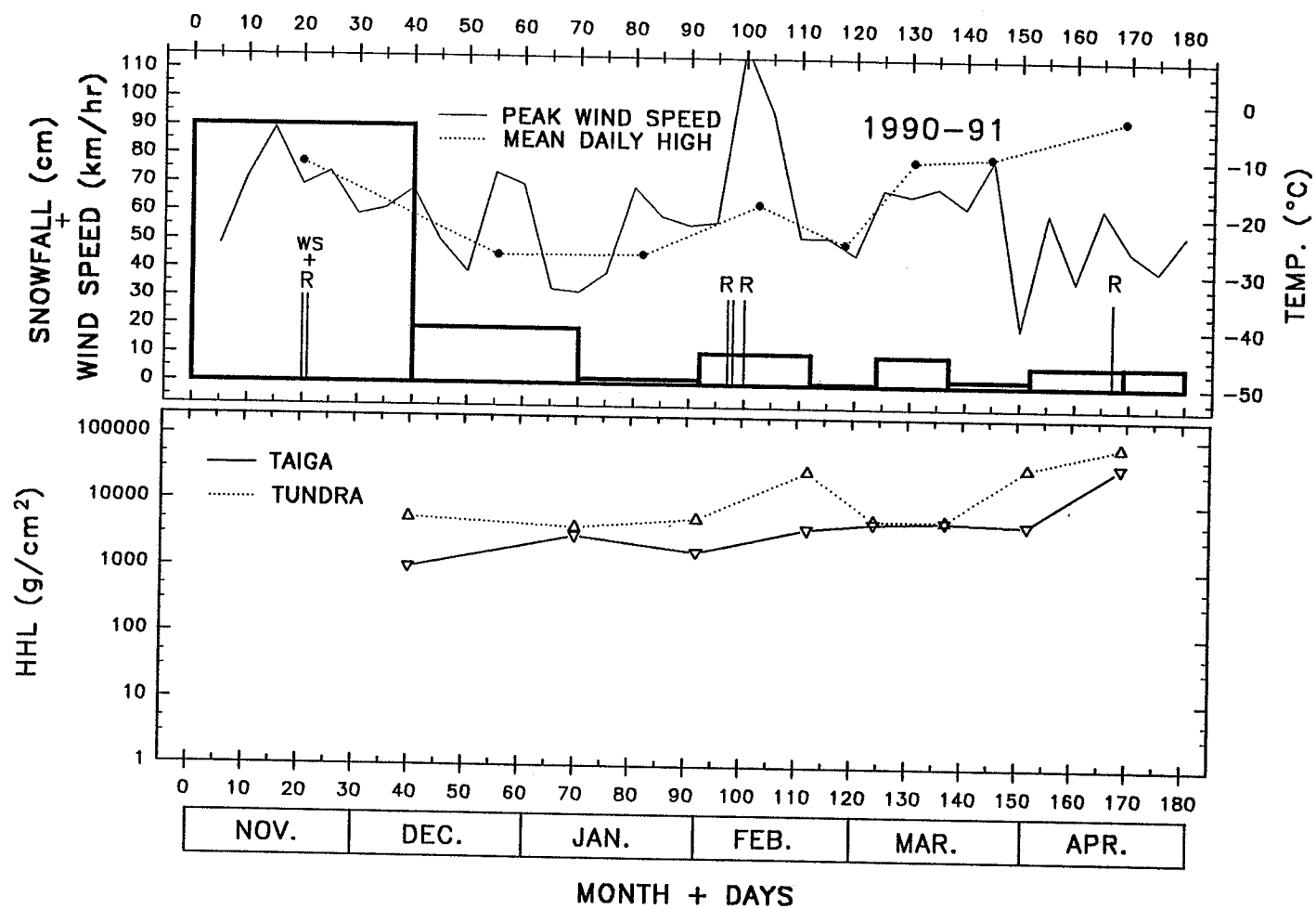
temperatures, wet snow, and freezing rain served to saturate at least the upper layers of the 1990-91 taiga snow cover, which, when subsequently frozen, as temperatures steadily dropped into late November, formed persistent hard dense layers (sigulik). The covering of these layers by subsequent snow fall further protected them well into late winter. As a result taiga VSI's climbed significantly above ($p < 0.01$) tundra values on the January 9th, February 20th, and April 18th sampling periods, and were not significantly different than tundra VSI's over the remaining sampling periods (Figure 18).

Tundra snow thickness and hardness values, although subjected to the same November conditions, did not react in kind. In fact 1990-91 tundra thickness and hardness values were at times significantly lower than corresponding 1989-90 values. The reasons for this are once again the product of November 21st and 22nd. The warm temperatures, rain, and wet snow, effectively melted the relatively thin layer of deposited snow, the results of which were extensive patches of open ground. Although these patches were subsequently covered by snow, hardness and thickness values remained relatively low well into February (Figures 19 + 20).

All these events served to push taiga VSI's significantly above tundra VSI's into the February sampling







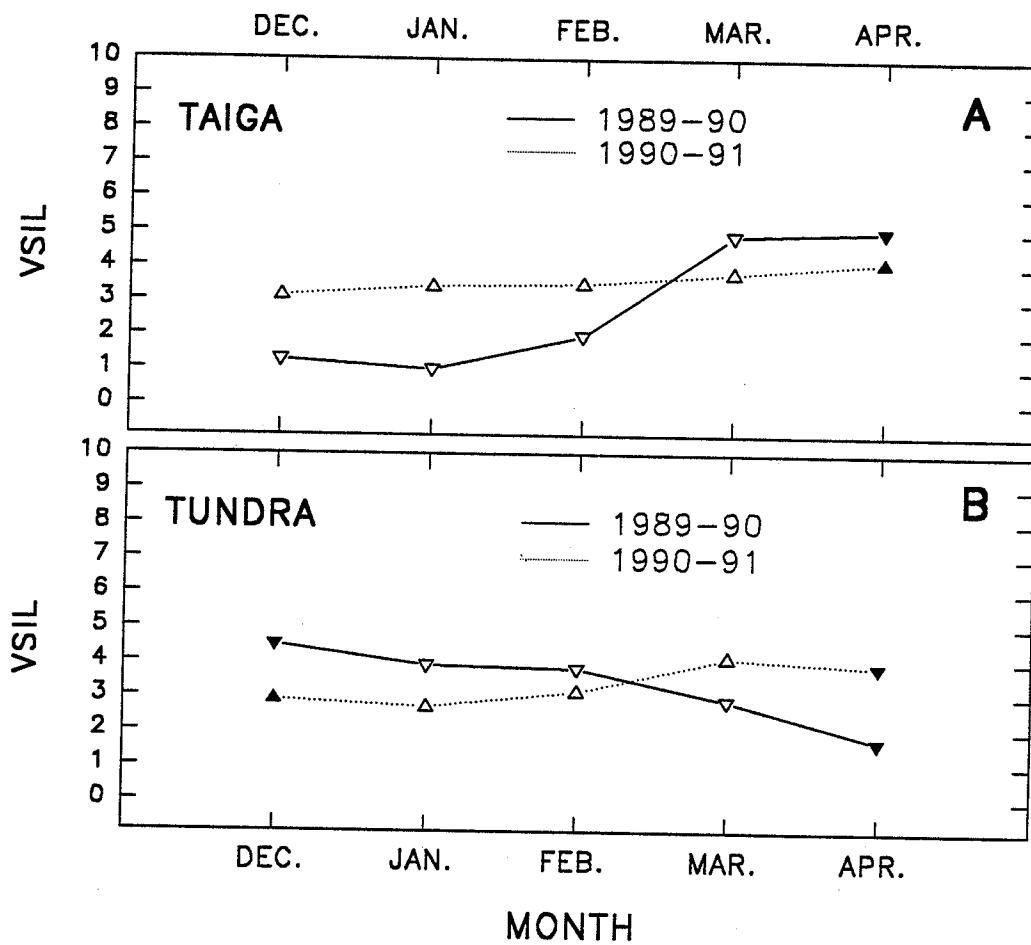
period. The appearance of freezing rain and near zero temperatures on February 5th, 6th, and 8th, served to elevate, only temporarily, tundra VSI's to 4.57, significantly higher than taiga values. High winds and the accompanying ice crystal abrasion served subsequently to reduce tundra VSI's significantly below those of the taiga by the February 20th sampling period. A similar increase was seen again by the March 4th sampling period and was again a response to the appearance of rain or freezing rain just prior to sampling. From this point tundra hardness values again dropped in response to high winds and, from March 16th, remained relatively stable throughout the remainder of the snow season. Taiga VSI's varied little up until the April 18th sampling period when sun crusts and ice lenses, (forming from the melting of surface snow and the re-freezing of this melt water upon its collection along the frost line located within the more basal layers of the snow cover), dramatically elevated hardness values to 37500 g/cm². This lack of variation in taiga VSI's prior to April 18th, is a testament to the taiga's thicker snow cover, and its ability to insulate and protect relict ice layers from steadily increasing air temperatures and other environmental conditions. These same conditions can have a dramatic effect in the modification of the comparatively thin tundra snow cover.

The above patterns were evident when comparing the two snow seasons, as the 1990-91 taiga communities maintained significantly higher ($p < 0.05$) VSI's over December, January, and February 1989-90, while the 1990-91 tundra communities recorded lower VSI's in December and significantly lower VSI's over January and February 1989-90 (Figure 21).

5.3 Community Snow Conditions

5.3.1 Early Winter

The individual examination of 1989-90 and 1990-91 community snow conditions was conducted within both the taiga and tundra during early, mid, and late winter (Table 1). During early winter 1989-90 tundra communities recorded consistently higher VSI and hardness values, and lower snow thickness values than taiga communities. Of the tundra communities ST recorded the highest VSI (5.14), and thickest snow cover (17.0 cm) while maintaining hardness values (45000 g/cm²) equal to the BR community and greater than HLT. Over the same period the BR community recorded the lowest VSI (2.75) and thinnest snow cover (2.5 cm). Early winter HLT sites recorded snow conditions mid-range between the ST and BR communities.



COMMUNITY AND SNOW SEASON	EARLY WINTER			MID WINTER			LATE WINTER		
	VSIL	HHL (g/cm ²)	TTH (cm)	VSIL	HHL (g/cm ²)	TTH (cm)	VSIL	HHL (g/cm ²)	TTH (cm)
1989-1990									
BSP	0.65	7.3	28.5	1.27	17.5	52.8	4.70	4000.0	82.0
WSF	1.20	30.0	35.0	2.17	30.0	56.5	4.64	7000.0	56.0
TWS	1.51	65.0	34.0	1.12	25.0	38.0	5.47	5000.0	81.0
TF	0.64	12.0	28.3	1.61	35.0	46.5	5.03	7000.0	44.5
ST	5.14	45000.0	17.0	6.78	42250.0	23.0	4.36	90000.0	26.0
BR	2.75	45000.0	2.5	3.04	30000.0	5.5	0.01	3.0	2.5
HLT	4.55	30000.0	12.5	3.62	20000.0	10.8	1.50	10000.0	5.0
1990-1991									
BSP	3.15	750.0	49.0	3.51	4000.0	65.0	3.75	6000.0	85.0
WSF	3.33	3000.0	64.0	3.51	4500.0	72.0	3.75	5750.0	75.0
TWS	3.16	2000.0	39.0	3.36	4000.0	47.0	3.85	7000.0	59.5
TF	2.11	500.0	34.5	2.64	600.0	37.0	5.93	4500.0	72.0
ST	4.85	3500.0	15.0	3.86	10000.0	17.0	5.32	37500.0	24.0
BR	5.08	15000.0	3.5	2.49	10000.0	4.0	3.14	6500.0	4.5
HLT	2.23	4500.0	4.0	1.79	10000.0	1.5	2.16	3750.0	4.0

Of early winter taiga communities TWS maintained the highest VSI (1.51) and Hardness (65.0 g/cm²) values, while WSF recorded the thickest snow cover (35.0 cm). Both the BSP and TF communities recorded the lowest VSI's (0.65 and 0.64 respectively) and snow thickness values (28.5 cm and 28.3 cm respectively). In addition the BSP community recorded the lowest hardness values (7.3 g/cm²) of all communities.

5.3.2 Mid-Winter

During mid-winter tundra communities once again displayed considerably higher VSI and HHL values than observed on taiga sites. The ST community again recorded the highest VSI (6.78), HHL (42250 g/cm²), and TTH (23.0 cm) of the tundra sites, and the highest VSI's and HHL of all communities. The BR site once again recorded the lowest VSI and thickness values while HLT recorded the lowest hardness values (20000 g/cm²) of the 3 tundra communities. Over the same period taiga sites maintained their relatively low VSI and Hardness values while showing an increase in the already thick snow cover. Of the taiga communities WSF recorded the highest mid-winter VSI's likely the result of this community also recording the second highest HHL values (30.0 g/cm²) and the thickest snow cover (56.5 cm) of all 7 communities. The highest HHL

values (35.0 g/cm^2) were recorded within the TF a factor which when in combination with relatively high TTH values gave the TF community the second highest VSI's (1.61) of the taiga. Interestingly, TWS, recording the highest VSI in early winter, now recorded the lowest (1.12). Of all the taiga communities, the TWS recorded both the least amount of change in snow thickness, and the thinnest snow cover (38.0 cm) while at the same time showing a reduction in HHL, all responsible for the maintenance of the relatively low VSI value into mid-winter. The BSP community once again maintained the softest snow cover, although the relatively thick snow cover kept VSI's above those of the TWS.

5.3.3 Late Winter

Late winter community snow conditions showed dramatic changes from mid-winter. Taiga community VSI's, on all sites, climbed above tundra values and would stay that way for the remainder of the winter. The TWS recorded the highest VSI's (5.47) of all 7 communities likely resulting from the dramatic increase in snow thickness to 81.0 cm 43.0 cm greater than recorded during mid-winter, in addition to the elevation of hardness values to 5000.0 g/cm^2 , a 200 fold increase from mid-winter values. In fact all taiga communities displayed a similar increase in

hardness which in combination with the already thick snow cover drove VSI's above mid-winter values.

On tundra sites the BR community now recorded the lowest VSI's (0.01) followed by the HLT (1.50) while the ST community maintained the highest VSI (4.36) recorded on the tundra. The reasons for the reductions in specifically BR and HLT VSI's appears to be due to a drop in hardness from mid-winter values to 3.0 g/cm² on the BR and 10000 g/cm² on HLT. This in combination with an additional drop in snow thickness to 4.5 cm and 5.0 cm, respectively, caused the observed reduction in VSI's.

5.3.4 Differences Between Snow Seasons

Largely due to differing meteorological conditions (see " taiga and tundra snow conditions "), snow conditions recorded over the winter of 1990-91 were considerably different than those recorded over 1989-90. The appearance of wet snow, freezing rain, and relatively high temperatures during November 1990 served to create and subsequently preserve ice layers within the thicker taiga snow cover while melting and removing much of the accumulated snow on tundra sites. As a result early winter taiga communities recorded VSI's which on all but the TF site were above those recorded specifically on the HLT (2.23) community (Table 1). In addition the HLT community

also recorded the second thinnest snow cover (4.0 cm) of the 7 communities. In fact all taiga sites recorded an approximate 100 fold elevation in HHL, and a 2 to 3 fold increase in VSI over 1989-90 values. Although the TF community did display the lowest VSI and HHL of all seven communities, it was relatively inaccessible because of the TWS and WSF communities commonly surrounding these sites potentially locking out their nival attributes from caribou occupying tundra sites. The BR community, though recording the highest VSI (5.08) and hardness (15000 g/cm²) values of both taiga and tundra communities, maintained the lowest snow thickness values (3.5 cm) an observation likely due to its exposed nature.

Mid-winter snow conditions also varied considerably from the 1989-90 results, an observation once again due primarily to the higher hardness values in combination with a thicker snow cover. Of the taiga sites both BSP and WSF recorded the highest VSI's (3.51) with WSF alone recording the hardest (4500.0 g/cm²) and thickest (72.0 cm) snow cover. The TF once again recorded the lowest VSI (2.64), HHL (600.0 g/cm²), and TTH (37.0) of the taiga communities, changing little from early winter values, but still maintained VSI above those of HLT (1.79), and following a significant reduction in snow hardness, BR (2.49). Once again HLT maintained the lowest VSI's and snow thickness of

all sites, values considerably lower than recorded in early winter or over the same period during the 1989-90 snow season.

The dramatic elevation of taiga VSI's and corresponding reduction in tundra VSI's observed in late winter 1989-90 was not apparent in 1990-91 despite similarities specifically within the taiga communities. Although the same processes likely occurred, the ice layers formed in November 1990 appeared to take on similar attributes to the freeze-thaw crust formation inevitably acting on the same communities during late winter. As the measurement of HHL only records the hardest layer, additional ice layers (commonly present during both snow seasons), whatever their formation, would not come into the equation. Once again HLT recorded the lowest VSI's (2.16) but in late winter also recorded the lowest hardness (3750.0 g/cm²) and thickness (4.0 cm) values as well. The highest values were found within the taiga on TF. Within the TF VSI's climbed to 5.93, HHL to 4500.0 g/cm², and TTH to 72.0 cm. This dramatic change in TF snow conditions from mid to late winter was likely related to its exposed nature and the resulting increased activity of freeze-thaw crust formation. It would be expected that the 1990-91 snow season would create, within taiga sites, less desirable snow conditions to caribou throughout the entire

winter while similar conditions only became a factor during late winter over the 1989-90 snow season.

The results of these differing conditions in terms of the Cape Churchill caribou's use of taiga and tundra communities both within and between the two snow seasons are discussed in the following section.

5.4 Plant Community Use Based On Tracking

Between December and April 1989-90 and 1990-91 468 caribou were tracked, generating a total of 2812.2 caribou-km (ie; number of caribou in group tracked X the total number of km tracked) (Schaefer 1988). During the tracking sessions the analysis of 195 feeding craters for vegetative content was also completed. For comparative purposes, habitat use was examined over three winter periods after Russell and Martell (1984): 1) Early winter (November and December), 2) Mid-winter (January and February), and 3) Late winter (March and April). Most of the tracking took place within six survey areas, three from the taiga (the Twin Lakes, Warkworth Lake, and Ritchie Lake survey areas) and three from the tundra, (the Cape Churchill, White Whale River, and Fletcher Lake survey areas) (Figure 3).

5.4.1 1989-1990

During the 1989-90 snow season Cape Churchill caribou entered the taiga communities in late December. The December tracking session revealed exclusive use of taiga communities by Cape Churchill caribou evident within each of the Twin Lakes, Ritchie Lake, and Warkworth Lake survey areas. Of the four taiga communities examined, two were used most frequently by caribou, the TF and BSP. Over the same period BSP recorded the lowest overall VSI's while TF recorded the second lowest (Table 2). Tundra VSI's in all cases exceeded taiga values during early winter.

Mid-winter once again displayed exclusive use of taiga with, however, an obvious shift onto taiga communities more closely associated with the forest ecotone, suggesting a general movement towards the tundra. During this period ground surveys revealed caribou sign within only the Twin Lakes and Ritchie Lake survey areas. According to tracking data alone, caribou sign (Measured linearly with an odometer, and including both tracks and feeding activity) was most common within the TF community, while BSP communities displayed only 3.2 % use (8.4 % down from December values). WSF and TWS communities, in association with the taiga-tundra tree line, received 11.3 % and 17.2 % use by caribou, much of which was documented in late

COMMUNITY AND SNOW SEASON	EARLY WINTER			MID WINTER			LATE WINTER		
	% USE (FEED)	% USE (TRACK)	VSIL	% USE (FEED)	% USE (TRACK)	VSIL	% USE (FEED)	% USE (TRACK)	VSIL
1989-1990									
BSP	80.0	11.6	0.65	5.9	3.2	1.27	--	--	4.70
WSF	--	1.0	1.20	17.7	11.3	2.17	--	--	4.64
TWS	10.0	--	1.51	14.7	17.2	1.12	--	--	5.47
TF	10.0	88.4	0.64	47.1	55.7	1.61	--	--	5.03
ST	--	--	5.14	--	--	6.78	<1.0	10.0	4.36
BR	--	--	2.75	--	--	3.04	38.1	3.8	0.01
HLT	--	--	4.55	14.7	--	3.62	61.9	82.5	1.50
1990-1991									
BSP	N/D	N/D	3.15	--	--	3.51	--	--	3.75
WSF	N/D	N/D	3.33	--	0.1	3.51	--	--	3.75
TWS	N/D	N/D	3.16	--	0.5	3.36	--	--	3.85
TF	N/D	N/D	2.11	--		2.64	--	--	5.93
ST	N/D	N/D	4.85	15.4	36.0	3.86	<1.0	35.1	5.32
BR	N/D	N/D	5.08	10.3	<1.0	2.49	15.4	7.9	3.14
HLT	N/D	N/D	2.23	74.4	56.8	1.79	84.6	46.7	2.16

January. The reduction in the use of BSP communities was coincidental with a rise in VSI's to 1.27 by mid-winter while TWS VSI's dropped from 1.51 in early winter to 1.12 by mid-winter. Over the same period TF VSI's climbed, although snow thickness within this community remained significantly lower than all but the TWS community (Table 1). The use of ponds and lakes by Cape Churchill caribou became a factor in mid-winter, recording 12.9 % use. In addition, their use of BSP and inland WSF was exclusively related to the proximity of snowmobile trails to these communities. Caribou would remain on these trails, occasionally leaving them for short distances, until the trails cut through WSF or BSP communities, at which time caribou would leave the trail to excavate feeding craters.

Late winter recorded a dramatic shift in community use from exclusively taiga to exclusively tundra communities, a switch coincidental with a reduction of HLT and BR VSI's below taiga community values. The last series of tracks within the three taiga survey areas were followed in early February. Despite extensive ground surveys throughout the remainder of the snow season, no other sign was found within taiga communities. Abundant caribou sign, on tundra communities, began appearing within the White Whale River and Cape Churchill survey areas by the first of March, 1990. The tundra communities used included BR, HLT, and a

Salix bluff/thicket community, (a tundra community not included in the vegetation or snow analysis). Ponds were also used (3.8 %), likely in response to their general abundance within the tundra communities. These aquatic sites were closely associated with sedge tundra communities.

5.4.2 1990-1991

During the 1990-91 snow season the Cape Churchill caribou remained in the southern half of the CCWMA. From this region the animals slowly proceeded north until early January, 1991, at which time the first signs of caribou were evident within the Cape Churchill, White Whale River and Fletcher Lake survey areas. Conversations with local hunters, trappers, and pilots revealed that prior to their movement into the study area, Cape Churchill caribou were observed on taiga communities within the southern half of the CCWMA, through late November and early December, moving onto the tundra between mid and late December. Tracking data collected over January and February found caribou using HLT 56.8 % of the time, ST 36.0 % of the time, ponds 6.5 % of the time, Salix bluffs 0.5 % of the time, and WSF, in association with the forest ecotone, 0.1 % of the time (Table 2). This apparent shift in habitat use from 1989-90 patterns was coincidental with lower mid-winter tundra

VSI's.

Over mid-winter 1990-91, tundra VSI's, specifically HLT and BR community types, recorded lower values than all taiga communities over the same period. The ST community, however, recorded the highest VSI's of all communities and produced median surface hardness values of 10000 g/cm² suggesting its use, by caribou, for travel (Table 1).

The exclusive use of tundra, by caribou, continued through late winter, within the Cape Churchill and White Whale River survey areas, but was generally lacking within the Fletcher Lake study area. During this period caribou use of the tundra expanded onto the BR community. HLT still received the highest use (46.7 %) (Down 10.1 % from the mid-winter value), ST recorded the second highest use (35.1 %) (down 0.9 % from the mid-winter value), while BR received 7.9 % use. The HLT community once again recorded the lowest VSI's of all communities while the BR recorded the second lowest. The ST community maintained its high VSI and surface hardness values and as a result was likely used, once again, for travel. In addition Salix bluffs received 2.1 % use and ponds, 8.2 % use.

5.5 Plant Community Use Based On Feeding Sites

5.5.1 1989-1990

During early winter, 1989-90, 80 % of all feeding craters were found within the BSP community while only 10 % were found within TF suggesting that the BSP was exploited more frequently ($X^2 = 53.8$, 1 DF, $p < 0.01$) than would be expected from tracking data alone (Table 2). The TF community on the other hand was used less frequently for feeding ($X^2 = 7.84$, 1 DF, $p < 0.01$) than expected from tracking data alone, suggesting the use of this community as access to BSP feeding sites. Feeding craters within the BSP were generally restricted to the characteristically elevated sides of this community in direct transition with the TF. Craters were excavated along these sides where fruticose lichens, predominantly Cladina stellaris and C. rangiferina, grow in thick mats with relatively little canopy. Craters found within the TF were generally of sedge content and associated with the commonly occurring sedge hummocks. The remaining 10 % use was concentrated within a very small area of TWS.

The use of the BSP for feeding dropped by 74.1 % to 5.9 % by mid-winter while the use of the TF community for feeding climbed from 10 % to 47.1 %. An additional 17.7 % of mid-winter feeding craters were found within WSF, 14.7 % within TWS, and 14.7% within HLT. Once again caribou spent less time feeding within TF than would be expected ($X^2 =$

6.95, 1 DF, $p < 0.01$) from tracking data alone while the remaining three communities displayed no significant differences. These data also suggest a shift from more desirable and/or abundant forage, as the frequency with which BSP was encountered during mid-winter tracking did not change. The species of fruticose lichens within the BSP are similar to, though more abundant than, those found in TWS and WSF, suggesting that these communities were used to replace the BSP as a suitable, though not as desirable, lichen source. This shift from the BSP lichen source is likely in response to increased snow thickness within the BSP (Table 1).

During late winter the location of feeding sites exclusively switched to tundra communities recording 61.9 % of feeding craters within the HLT community, and 38.1 % of late winter craters within the BR community. The results of late winter tracking found the BR community to have received 44.4 % more, and HLT 64.4 % less use than feeding site community use alone would predict ($X^2 = 5.00, 5.25$ respectively, $p < 0.05$). This suggests that the often bare, gravel-topped BR community, was used primarily to access HLT feeding sites, commonly found in association with the BR community. Once again it appears that rising snow thickness and hardness values drove VSI's above caribou tolerance levels during late winter. Though HLT

lichen species were once again similar to those recorded within taiga feeding sites, their abundance was considerably reduced, suggesting a forced shift into less desirable communities.

5.5.2 1990-1991

During 1990-91, feeding site community selection was dramatically different from those selected in 1989-90. Tundra communities were used exclusively for feeding through mid-winter as compared to taiga sites in 1989-90. Specifically, 74.4 % of all mid-winter feeding craters were recorded in HLT, 10.3 % on the BR community, and 15.4 % on the ST community. Community use based on tracking data displayed similar proportions to community use based on feeding sites with the exception of ST and BR communities. The proportionately higher use of these two communities, indicated by tracking, suggest that both these communities were used, to a greater degree, for travel. In the case of Salix bluffs and frozen ponds, the absence of feeding craters suggest that these sites were exclusively used for travel.

Late winter feeding sites were exclusively on HLT (84.6 %) and BR (15.4 %) and in both cases were exploited for feeding more frequently ($X^2 = 46.69$, 1 DF, $p < 0.01$, and $X^2 = 6.45$, 1 DF, $p < 0.01$) than tracking data alone

would suggest. Use of the ST community was significantly less ($\chi^2 = 6.45$, 1 DF, $p < 0.01$) than would be expected from tracking data alone suggesting its use primarily for travel along with Salix bluffs and ponds. BR feeding sites were in all cases highly concentrated on the sloping sides and generally within 20 m of HLT. As a result much of the tracking-based use of the BR can still be attributed to travel, particularly to HLT, used extensively for feeding. This exclusive use of tundra versus taiga communities throughout most of the 1990-91 snow season was likely in response to more desirable snow conditions indicated by the comparatively lower VSI's recorded within the HLT and BR communities. The ST community, used primarily for travel, once again recorded some of the highest VSI's of all communities over 1990-91.

5.6 Feeding Site Snow Conditions

Over 1989-90, snow measurements were made at 57 caribou feeding craters, 21 in early winter (November and December), 21 in mid-winter (January and February), and 15 during late winter (March and April). Over the 1990-91 snow season mid-winter snow measurements were made within 45 feeding craters, and in late winter, within 87 craters.

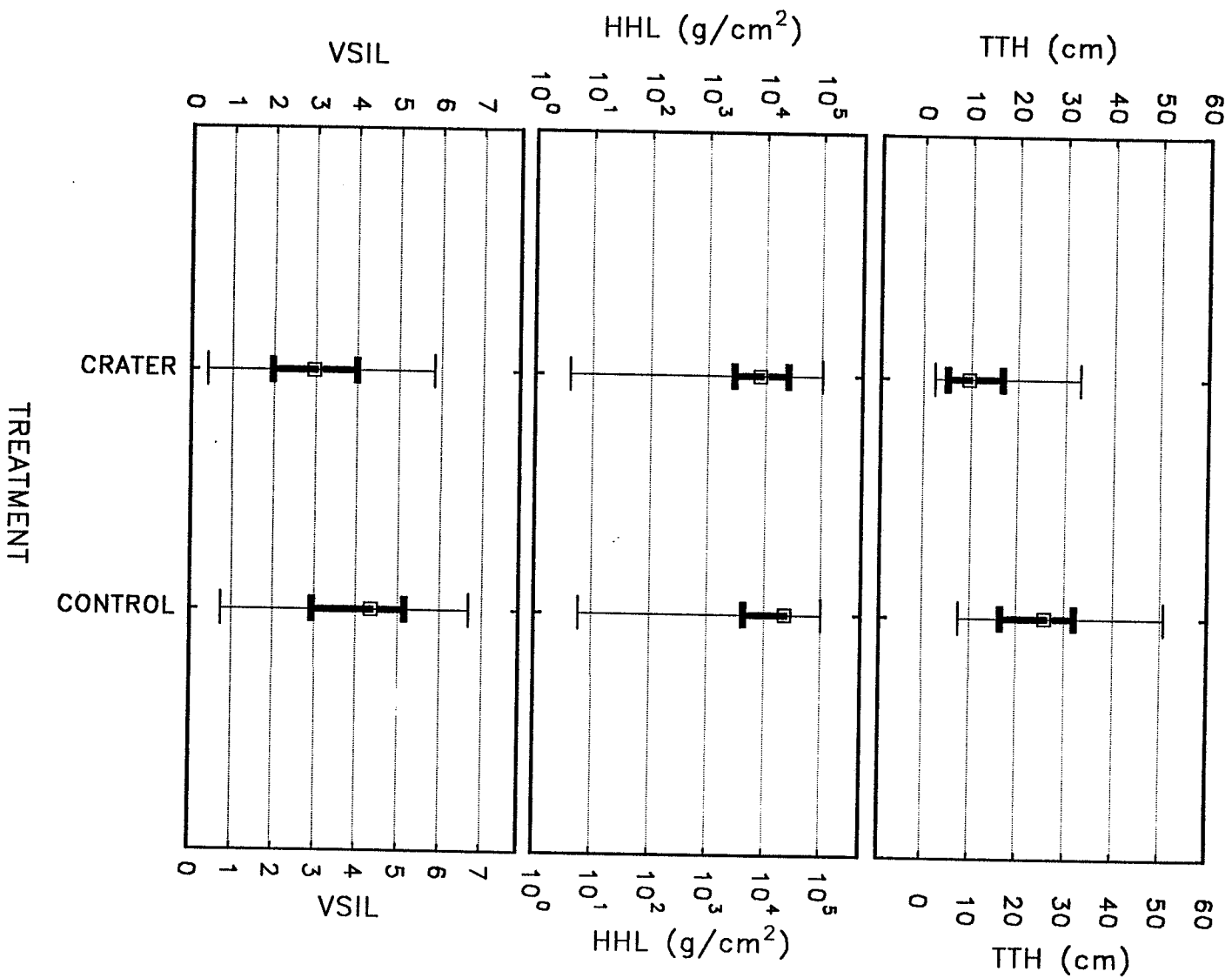
In total, 189 feeding craters and 378 corresponding control sites were examined over both the 1989-90 and 1990-91 snow seasons.

Craters pooled over both the 1989-90 and 1990-91 snow seasons recorded significantly lower overall hardness ($p < 0.05$), thickness ($p < 0.01$), and VSI ($p < 0.01$), than their corresponding controls (Figure 22). Temporal differences, apparent during both 1989-90 and 1990-91, prompted closer examination of early, mid, and late winter differences in crater snow conditions.

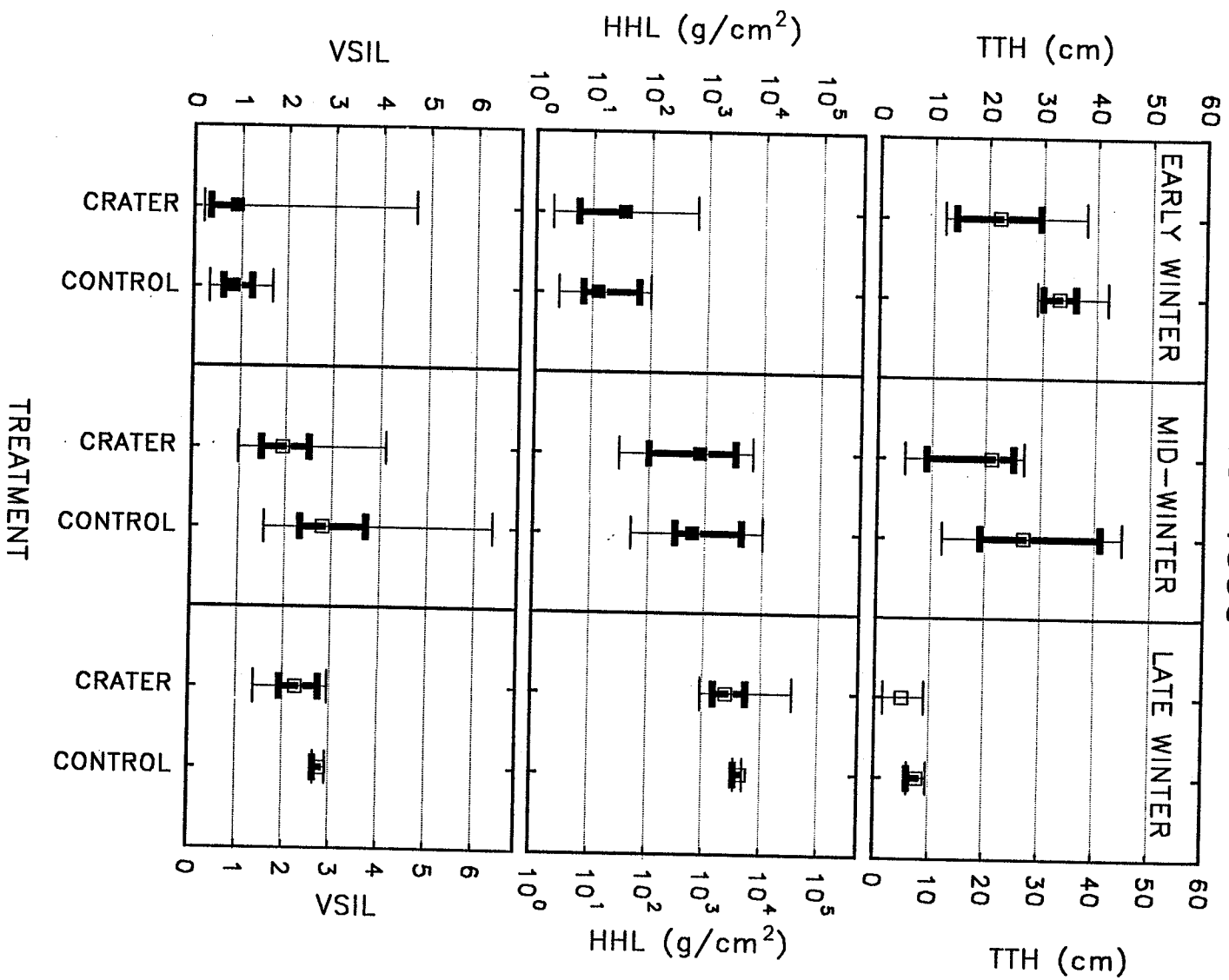
5.6.1 1989-1990

During 1989-90, early winter feeding craters appeared to be chosen on the basis of snow thickness as only thickness values were significantly lower ($p < 0.01$) within craters versus controls, while HHL and VSIL showed no significant change (Figure 23). Among mid-winter feeding craters both VSIL and TTH values were significantly lower ($p < 0.01$) than corresponding control values while hardness values did not differ significantly. Late winter values indicate a preference for cratering sites with lower thickness, hardness, and VSI. Crater snow conditions for the above values were significantly lower ($p < 0.01$, $p < 0.05$, and $p < 0.01$ respectively) than their corresponding control values. The temporal change in HHL, TTH, and VSI

1989-1991



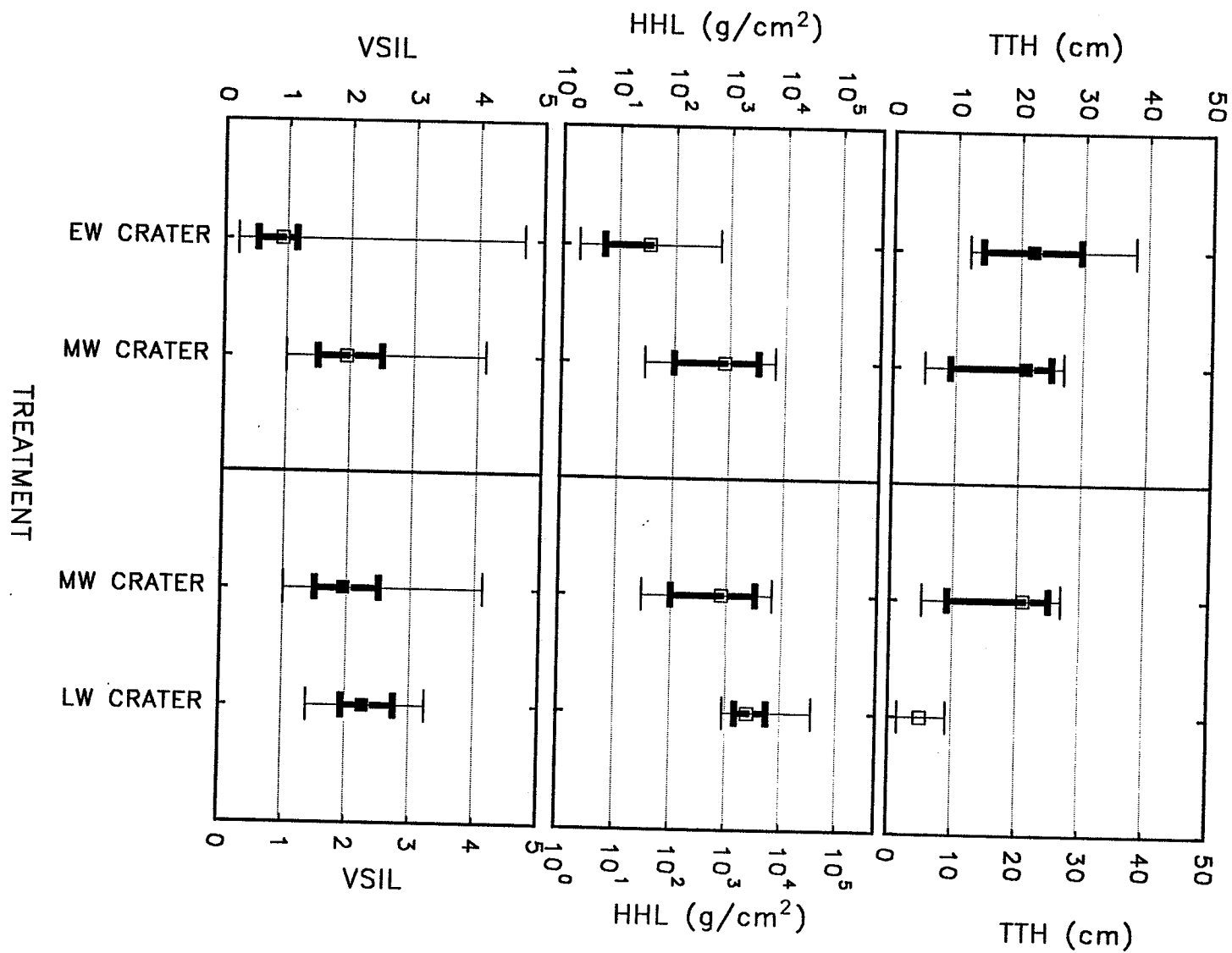
1989-1990



thresholds to sensitivity are evident when comparing feeding craters between early, mid, and late winter. Mid winter feeding craters recorded significantly higher VSI and hardness values ($p < 0.01$) than observed in early winter, while thickness values did not significantly change (Figure 24). From mid to late winter hardness values rose significantly ($p < 0.01$) while overall crater thickness dropped significantly ($p < 0.01$).

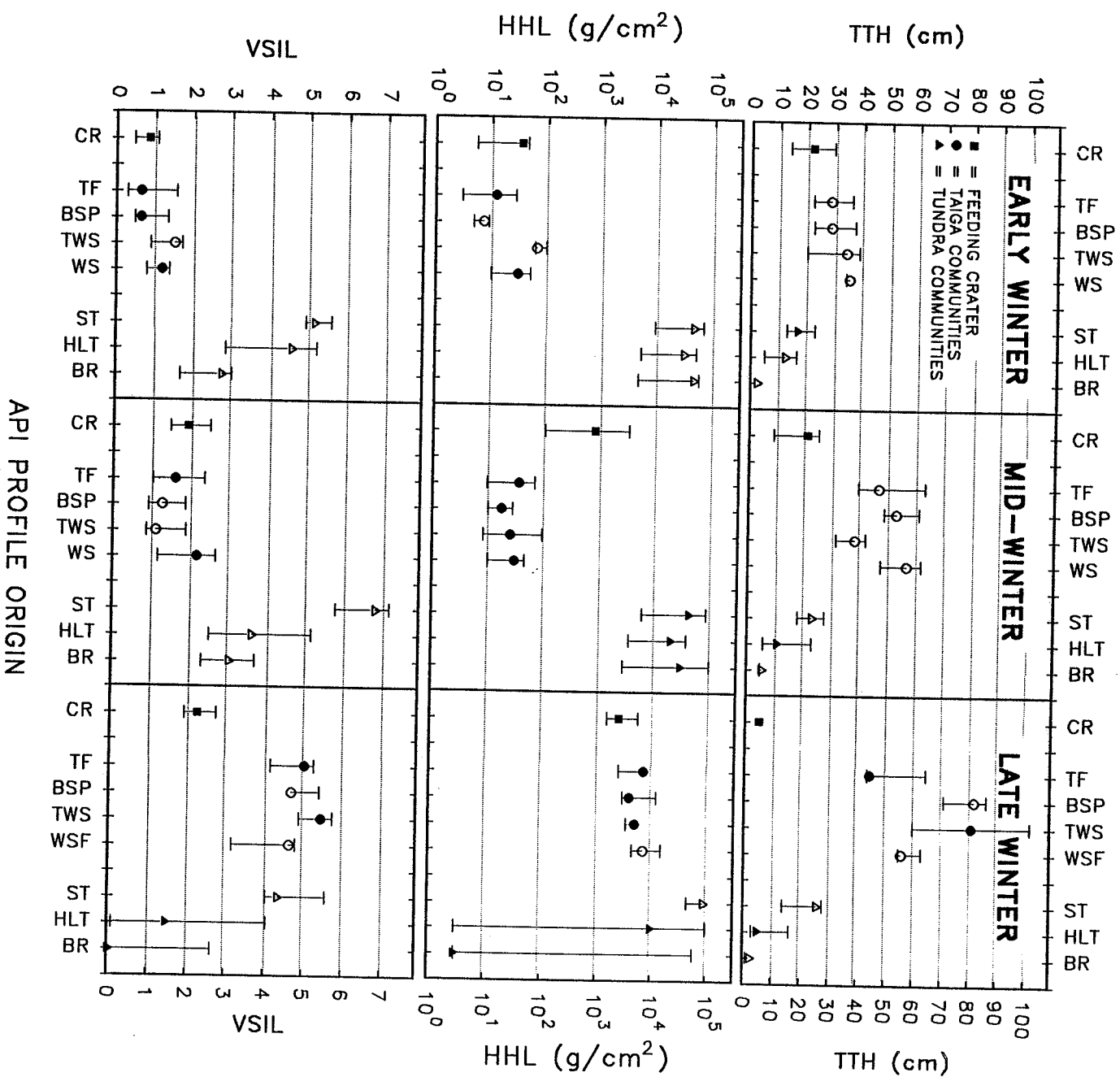
The net effect of lower thickness and higher hardness values are the likely reasons why VSI values did not significantly vary between these periods. A comparison between each of early, mid, and late winter feeding crater snow conditions and those of the seven representative community snow stations, found early winter feeding crater VSI's to be significantly lower ($p < 0.05$) than values recorded within the TWS community, ST community, HLT community, and BR community, (Figure 25). The remaining taiga communities, BSP, WSF, and TF, displayed no significant differences. Mid winter feeding crater VSI's were once again significantly lower than ST, HLT, and BR, and climbed significantly above both BSP and TWS. It should be noted, however, that snow thickness values within the taiga communities had risen significantly from early winter records in all but the TWS community and ranged between 40 and 60 cm by mid-winter. Only HLT showed no

1989-1990



1989-1990

API PROFILE ORIGIN



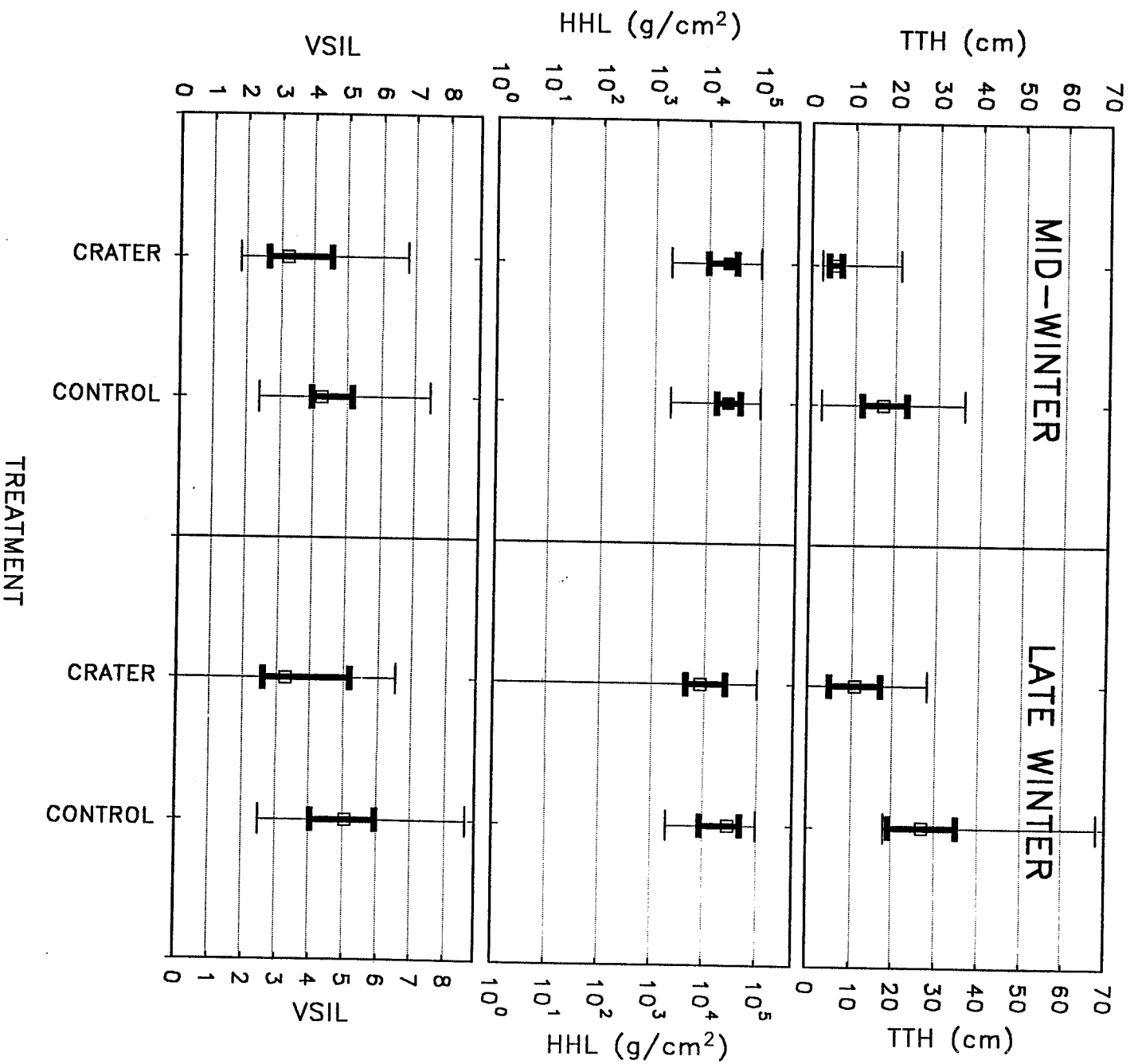
significant difference in total thickness when compared to mid-winter feeding craters.

In terms of VSIL, only TF and WSF did not differ significantly from feeding craters. During late winter all taiga communities recorded higher VSI values, significantly so in the case of WSF and BSP, than recorded on late winter feeding craters. Crater VSI's closely matched the HLT community type, while the ST community remained significantly above, and the BR community dropped significantly below, feeding crater values.

5.6.2 1990-1991

The 1990-91 mid-winter and late winter analysis of crater snow conditions showed the same general pattern of selection as corresponding 1989-90 findings. Once again caribou appeared to choose mid-winter cratering sites with significantly ($p < 0.01$) lower overall thickness and VSI values than observed within control sites, while hardness values between control sites and actual craters did not vary significantly (Figure 26). Late winter values, again, showed a selection towards feeding sites with lower hardness, thickness, and VSI as indicated by the significantly lower ($p < 0.01$) values within craters versus controls. Temporal changes in crater snow conditions between mid and late winter were expressed as a

1990-1991

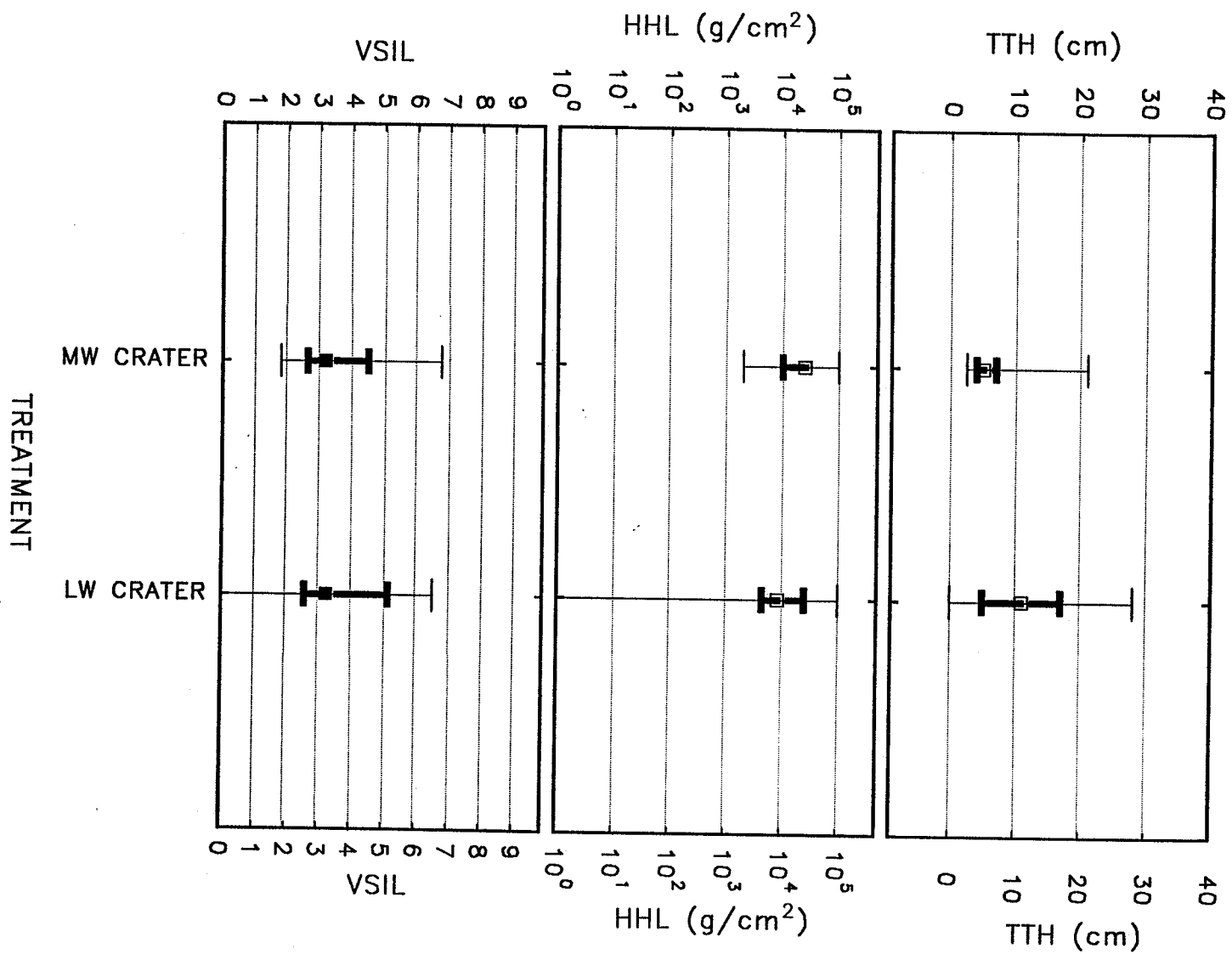


significant reduction ($p < 0.01$) in late winter crater hardness values, and a significant increase in late winter thickness values (Figure 27). Once again offsetting hardness and thickness trends, opposite to the 1989-90 late winter result, stabilized VSI's through mid and late winter.

A comparison between feeding crater snow conditions and those of the seven community snow stations during mid-winter displayed no significant differences between feeding crater VSI's and those values recorded within TF, TWS, and WS (Figure 28). Significantly higher VSI's were recorded within BSP (3.51, $p < 0.05$) and ST (3.86, $p < 0.01$), while significantly lower values were recorded within HLT (1.79, $p < 0.01$) and BR (2.49, $p < 0.05$): Although VSI's within the taiga communities were similar to those of feeding craters, taiga community thickness values were significantly greater ($p < 0.01$) than crater thickness in all cases while HLT and BR tundra communities recorded significantly lower thickness values of 1.5 cm ($p < 0.01$) and 4.00 cm ($p < 0.01$) respectively. Over the same period tundra community hardness values were all significantly lower than crater hardness values ($p < 0.01$) within all but the ST community snow station.

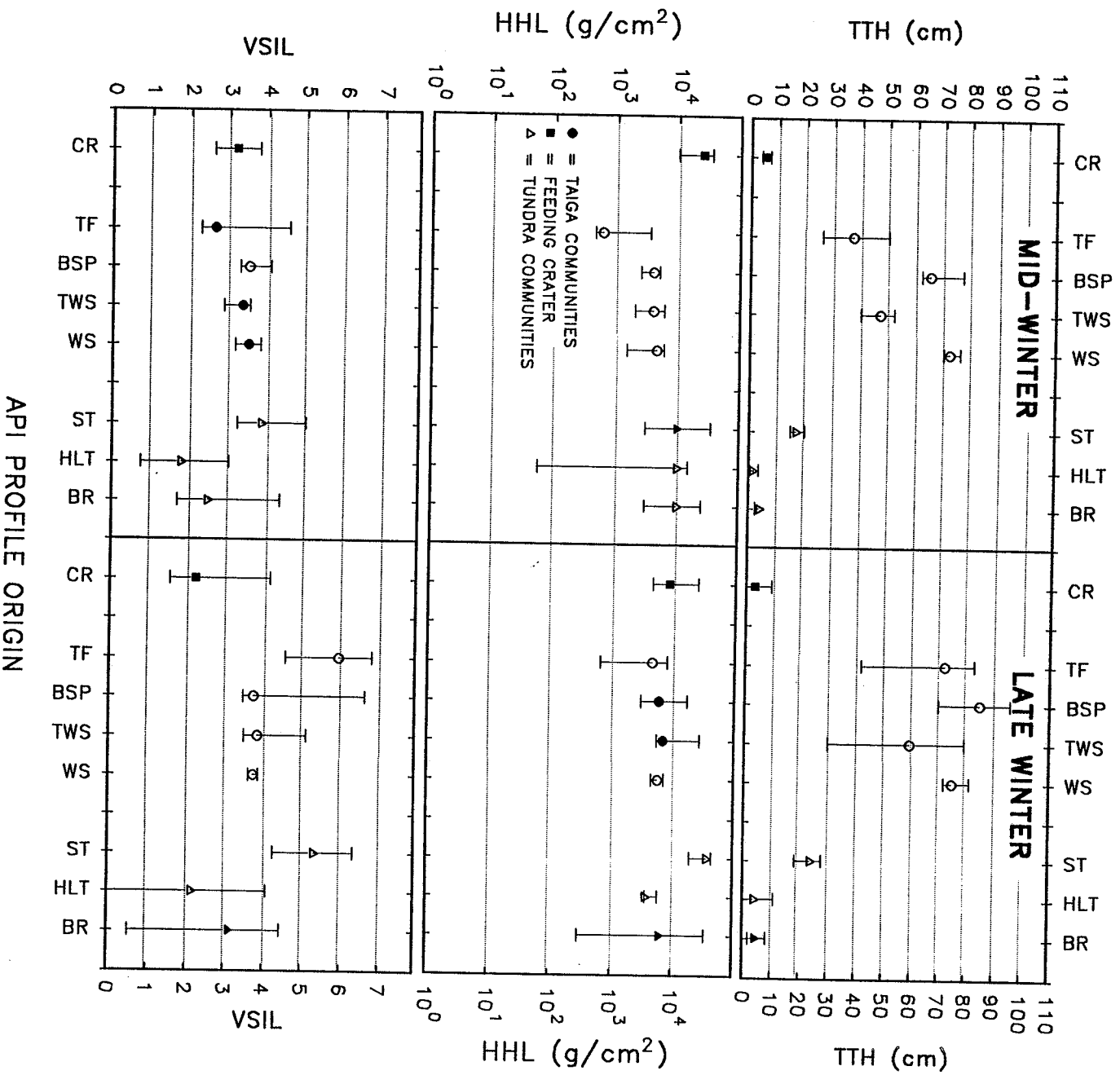
Late winter comparisons displayed a closer relationship between feeding crater snow conditions and

1990-1991



1990-1991

API PROFILE ORIGIN



those of the BR and HLT communities, which in the case of BR community VSI's, were not significantly different, and in the case of HLT values, were significantly lower (2.16, $p < 0.01$) than feeding crater values. All late winter taiga community VSI's including TF, BSP, TWS, and WSF were significantly greater ($p < 0.01$) than those of feeding craters. During late winter taiga community snow hardness and thickness was greater than mid-winter values while hardness values within the BR and HLT communities dropped considerably in late winter.

5.7 Feeding Habits

The analysis of Cape Churchill caribou feeding habits, over the 1989-90 snow season, were based on the contents of 65 feeding craters, 10 from early winter (November and December), 34 from mid-winter (January and February) and 21 from late winter (March and April). In addition six pellet group samples were analysed, three from mid-winter, and three from late winter. Data from 1990-91 were based on the examination of 130 feeding craters, 39 from mid-winter and 91 from late winter. In addition, the contents of 12 rumens, five from January (mid-winter) and seven from April (late winter), and six pellet group samples, three from

mid-winter and three from late winter were also examined. Crater and rumen analysis did not differ significantly from one another despite the fact that scat and rumen samples were collected from different animals in different locations and at different times during the collection periods. The fact that rumen and scat contents have a closer physical link to what caribou actually select would suggest a more accurate means of determining caribou feeding habits than crater contents alone.

5.7.1 1989-90 Craters

Based on 1989-90 crater contents, terrestrial lichens made up 68.0 %, evergreen shrubs 12.6 %, mosses 8.4 %, graminoids 6.2 %, and deciduous shrubs 3.5 % of early winter feeding craters (Table 3). Of the terrestrial lichens Cladina spp. were the most common. The most common evergreen shrubs included Ledum spp., Vaccinium spp., and Andromeda polifolia. The common deciduous shrubs including Salix spp. and Betula glandulosa.

Mid-winter examinations revealed a reduction, though not significant (Friedman Statistic = 1.00, $p < 0.31$), in the total percentage of lichens to 32.1 %. During this period the most common terrestrial lichens were of the genus Cladina spp. (14.3 %). The appearance of graminoids in feeding craters climbed to 30.0 % of which Cyperaceae

SPECIES LIST (1989-1990)	E-WINTER			M-WINTER			L-WINTER			WINTER MEAN		
	SC	RU	CR	SC	RU	CR	SC	RU	CR	SC	RU	CR
TERRESTRIAL LICHENS												
Alec/Bryoria/Bryocaulin	---	---	---	8.2	---	0.6	7.2	---	9.0	7.7	---	3.2
Cetraria spp.	---	---	---	5.8	---	5.5	1.7	---	13.9	3.8	---	6.5
Cladonia/Cladina	---	---	67.3	11.1	---	24.1	6.4	---	8.7	8.8	---	33.4
Evernia/Usnea	---	---	---	1.7	---	---	0.7	---	---	1.2	---	---
Hypogymnia spp.	---	---	---	---	---	---	0.3	---	---	0.2	---	---
Peltigera spp.	---	---	0.7	3.1	---	1.9	7.4	---	---	5.3	---	0.9
Ramalina spp.	---	---	---	1.4	---	---	1.1	---	---	1.3	---	---
Stereocaulon spp.	---	---	---	6.8	---	---	2.6	---	---	4.7	---	---
Thamnolia spp.	---	---	---	4.4	---	---	3.5	---	0.6	4.0	---	0.2
Sphaerophorus globosus	---	---	---	---	---	---	---	---	---	---	---	---
Other	---	---	---	---	---	---	---	---	0.6	---	---	0.2
Totals:	---	---	68.0	42.5	---	32.1	30.9	---	32.8	37.0	---	44.4
GRAMINOIDS												
Cyperaceae	---	---	6.2	15.7	---	26.9	15.9	---	8.9	15.8	---	14.0
Gramineae	---	---	---	1.4	---	3.1	2.6	---	---	2.0	---	1.0
Juncaceae	---	---	---	0.6	---	---	2.3	---	---	1.5	---	---
Totals:	---	---	6.2	17.7	---	30.1	20.8	---	8.9	19.3	---	15.0
HERBACEOUS DICOTS												
Pedicularis spp.	---	---	---	---	---	---	0.1	---	---	0.1	---	---
Pyrola spp.	---	---	---	0.9	---	---	1.9	---	---	1.4	---	---
Saxifraga spp.	---	---	---	0.4	---	---	0.8	---	0.5	0.6	---	0.2
Tofieldia pusilla	---	---	---	0.6	---	---	0.8	---	---	0.7	---	---
Other	---	---	---	0.2	---	---	1.5	---	---	0.9	---	---
Totals:	---	---	---	2.1	---	---	5.1	---	0.5	3.7	---	0.2
PTERIDPHYTA												
Equisetum spp.	---	---	---	0.6	---	---	1.0	---	---	0.8	---	---
Lycopodium spp.	---	---	---	2.2	---	---	---	---	---	1.1	---	---
Totals:	---	---	---	2.8	---	---	1.0	---	---	1.9	---	---
EVERGREEN SHRUBS												
Andromeda polifolia	---	---	1.4	0.4	---	1.7	0.2	---	4.0	0.2	---	2.4
Arctostaphylos spp.	---	---	---	---	---	---	1.6	---	0.5	0.8	---	0.2
Empetrum nigrum	---	---	1.0	0.1	---	0.7	0.4	---	0.7	0.2	---	0.8
Ledum spp.	---	---	6.5	1.2	---	2.1	0.8	---	5.3	1.0	---	4.6
Oxycoccus microcarpus	---	---	0.7	---	---	---	---	---	---	---	---	0.2
Rhododendron lapponicum	---	---	---	---	---	0.9	5.6	---	13.2	2.8	---	4.7
Vaccinium spp.	---	---	3.0	1.6	---	3.6	6.5	---	6.7	4.1	---	4.4
Totals:	---	---	12.6	3.3	---	9.0	15.1	---	30.6	9.1	---	17.2
DECIDUOUS SHRUBS												
Betula glandulosa	---	---	1.9	---	---	2.2	2.3	---	---	1.2	---	1.4
Dryas integrifolia	---	---	---	0.1	---	0.7	0.1	---	10.8	0.1	---	3.8
Salix spp.	---	---	1.6	0.8	---	3.7	3.1	---	0.5	2.0	---	1.9
Shepherdia canadensis	---	---	---	---	---	---	1.7	---	---	0.9	---	---
Totals:	---	---	3.5	0.9	---	6.6	7.2	---	11.3	4.2	---	7.1
CONIFERS	---	---	2.5	2.5	---	---	---	---	---	1.3	---	---
MOSSES	---	---	8.4	27.4	---	19.7	21.6	---	15.4	24.5	---	14.5
SEAWEED	---	---	---	0.7	---	---	0.2	---	---	0.5	---	---

represented 26.9 %. A net reduction in evergreen shrubs to 9.0 % was also apparent, of which Vaccinium spp. (3.6 %), Ledum spp. (2.1 %) and Andromeda polifolia (1.7 %) were the most common. Deciduous shrubs increased slightly over early winter values to 6.6 %, of which Salix spp. represented 3.7 % and Betula glandulosa 2.2 %.

The results of late winter crater analysis revealed little difference in total lichens over mid-winter values. Nonetheless a switch to lichen species characteristic of the tundra was obvious. The most common kinds of terrestrial lichens included Cetraria spp., Cladina spp. and Cladonia spp., while Graminoids, specifically Cyperaceae, dropped to 8.9 %. Evergreen shrubs displayed a significant change ($p < 0.05$, $n = 8$, $df = 1$) from mid-winter values which was likely related to their greater abundance (30.6 %) within late winter craters. The most common evergreen shrubs included Rhododendron lapponicum (13.2 %), Vaccinium spp. (6.7 %), and Ledum spp. (5.3 %). The percentage of deciduous shrubs within late winter feeding craters climbed to 11.3 % though not significantly.

5.7.2 1989-90 Pellet Groups

The mid-winter 1989-90 analysis of lichens within pellet group samples was significantly different ($p < 0.05$, $n = 11$, $df = 1$) than corresponding crater values. Of

the 42.5 % lichens recorded, 11.1 % were of the genus Cladina, while 8.2 % were a combination of Alectoria spp., Bryoria spp., and Bryocaulon spp., and 6.8 % of the genus Stereocaulon spp.. Mosses displayed the second highest cover value, while graminoids were third highest.

Cyperaceae was the dominant graminoid. Evergreen shrubs made up a total of 3.3 % of mid-winter scat samples and were significantly different ($p < 0.05$, $n = 8$, $df = 1$) than mid-winter craters. Vaccinium spp. (1.6 %) and Ledum spp. (1.2 %) were the dominant evergreen shrubs, but were found in lower concentrations than corresponding feeding craters. Pteriphytes, conifers, herbaceous dicots, and seaweed made up the remainder of mid-winter fecal samples.

Lichen species within late winter fecal samples did not vary significantly from their respective feeding craters. Nonetheless, percent lichen composition did drop from mid- to late winter. In addition, dominant lichen species did change to a more typical tundra flora.

Dominant lichens included Peltigera spp., Alectoria spp., Bryoria spp., and Bryocaulon spp., and Cladonia spp. and Cladina spp.. Mosses once again made up the second most common plant group. Graminoids within late winter scats were the third most dominant plant group at 20.8 %, 3.1 % up from mid-winter values. The dominant graminoids, Cyperaceae, displayed virtually no variation from mid-

winter values.

The percentage of evergreen shrubs within late winter fecal samples, and their dominant species, were significantly different ($p < 0.05$, $n = 8$, $df = 1$) than corresponding crater values. Like the crater analysis, however, late winter pellet groups did show greater use of evergreen shrubs when compared to mid-winter values. The dominant evergreen shrubs included Vaccinium spp., Rhododendron lapponicum, absent in mid winter pellet groups, and Arctostaphylos spp., again absent within mid-winter craters and pellet groups. The remaining plant groups found within late winter fecal samples include deciduous shrubs (7.2 %) (up from 0.8 % in mid-winter), herbaceous dicots (5.1 %), Pteridophytes (1.0 %) (less than half mid winter values), and seaweed (0.2 %). Conifers were completely absent from late winter craters and pellet groups.

5.7.3 1990-91 Craters

The analysis of 1990-91 feeding craters began on mid-winter tundra sites and showed terrestrial lichens to make up 45.7 % of all craters (Table 4). The most common lichen species included Cetraria spp., and Cladina spp.. Graminoids, specifically Cyperaceae, made up 24.7 % of feeding craters while evergreen shrubs made up 27.5 %, of

SPECIES LIST (1990-1991)	E-WINTER			M-WINTER			L-WINTER			WINTER MEAN		
	SC	RU	CR	SC	RU	CR	SC	RU	CR	SC	RU	CR
TERRESTRIAL LICHENS												
Alec/Bryoria/Bryocaulin	--	--	--	8.0	7.3	9.5	4.0	4.5	3.2	6.0	5.9	6.4
Cetraria spp.	--	--	--	2.9	4.7	17.2	5.3	3.0	8.1	4.1	3.9	12.7
Cladonia/Cladina	--	--	--	10.5	7.8	14.6	8.4	4.9	38.9	9.5	6.4	26.8
Evernia/Usnea	--	--	--	0.4	0.5	--	0.4	--	--	0.4	0.3	--
Hypogymnia spp.	--	--	--	--	0.9	--	--	1.1	--	--	1.0	--
Peltigera spp.	--	--	--	5.5	10.2	--	7.6	9.4	--	6.6	9.8	--
Ramalina spp.	--	--	--	1.6	1.4	--	1.0	0.9	--	1.3	1.2	--
Stereocaulon spp.	--	--	--	7.6	8.0	--	2.4	2.6	--	5.0	5.3	--
Thamnia spp.	--	--	--	1.5	16.4	--	1.4	10.3	--	1.5	13.4	--
Sphaerophorus globosus	--	--	--	--	--	3.9	--	--	2.1	--	--	3.0
Other	--	--	--	--	--	0.5	--	--	--	--	--	0.3
Totals:	--	--	--	38.0	54.8	45.7	30.5	36.7	52.3	34.4	47.2	49.2
GRAMINOIDS												
Cyperaceae	--	--	--	29.8	8.3	24.7	15.8	14.5	7.2	22.3	11.4	16.0
Gramineae	--	--	--	4.6	3.0	--	1.5	6.4	--	3.1	4.7	--
Juncaceae	--	--	--	2.8	0.9	--	1.5	1.1	--	2.2	1.0	--
Totals:	--	--	--	37.2	12.2	24.7	18.8	22.0	7.2	27.6	17.1	16.0
HERBACEOUS DICOTS												
Pedicularis spp.	--	--	--	--	--	--	0.4	--	--	0.2	--	--
Pyrola spp.	--	--	--	2.2	1.7	--	3.3	1.1	--	2.8	1.4	--
Saxifraga spp.	--	--	--	--	0.8	1.0	0.1	--	--	0.1	0.4	0.5
Tofieldia pusilla	--	--	--	0.4	0.5	--	--	1.1	--	0.2	0.8	--
Other	--	--	--	2.2	1.1	--	1.7	2.1	--	2.0	1.6	--
Totals:	--	--	--	4.8	4.1	1.0	5.5	4.3	--	5.3	4.2	0.5
PTEROPHYTES												
Equisetum spp.	--	--	--	0.2	0.5	--	1.5	--	--	0.9	0.5	--
Lycopodium spp.	--	--	--	--	--	--	--	--	--	--	--	--
Totals:	--	--	--	0.2	0.5	--	1.5	--	--	0.9	0.5	--
EVERGREEN SHRUBS												
Andromeda polifolia	--	--	--	--	--	1.8	--	--	1.2	--	--	1.5
Arctostaphylos spp.	--	--	--	0.1	--	--	0.8	--	--	0.4	--	--
Empetrum nigrum	--	--	--	0.7	--	0.8	0.6	--	1.8	0.7	--	1.3
Ledum spp.	--	--	--	1.3	0.6	1.1	1.5	2.1	3.6	1.4	1.4	2.4
Oxycoccus microcarpus	--	--	--	--	--	--	--	--	--	--	--	--
Rhododendron lapponicum	--	--	--	1.9	1.4	12.3	3.2	4.7	8.5	2.6	3.1	10.4
Vaccinium spp.	--	--	--	2.6	1.0	2.8	3.1	3.2	5.9	2.9	2.1	4.4
Totals:	--	--	--	6.6	3.0	27.5	9.2	10.0	21.0	8.0	6.6	20.0
DECIDUOUS SHRUBS												
Betula glandulosa	--	--	--	0.2	--	--	1.0	--	0.9	0.6	--	0.5
Dryas integrifolia	--	--	--	--	1.7	2.1	0.9	1.0	2.8	0.5	1.4	6.8
Salix spp.	--	--	--	1.8	1.4	1.1	1.6	4.0	3.2	1.7	2.7	2.2
Shepherdia canadensis	--	--	--	0.1	0.6	1.2	0.9	--	--	0.5	0.3	0.6
Totals:	--	--	--	2.1	3.7	4.4	4.4	5.0	6.9	3.3	4.4	10.1
CONIFERS												
	--	--	--	0.2	--	--	--	--	--	0.1	--	--
MOSESSES												
	--	--	--	10.5	16.6	6.1	30.4	17.8	11.3	20.5	17.2	8.7
SEAWEED												
	--	--	--	0.6	3.2	--	0.4	2.3	--	0.5	2.8	--

which Rhododendron lapponicum, Vaccinium spp., and Andromeda polifolia were the most common. Deciduous shrubs made up only 4.4 % of all mid-winter feeding craters of which Shepherdia canadensis represented 1.2 % and Salix spp., 1.1 %.

Late winter feeding craters were 52.3 % terrestrial lichen, 7.2 % graminoid, 21.0 % evergreen shrubs, and 6.9 % deciduous shrubs. The most common lichen species included Cladina spp., and Cetraria spp.. The most common evergreen shrubs included Rhododendron lapponicum, Vaccinium spp., and Ledum spp., while Salix spp. and Dryas integrifolia made up the most common deciduous shrubs.

5.7.4 1990-91 Pellet Groups And Rumens

Over the 1990-91 snow season pellet group and rumen compositions did not vary significantly. Both scat and rumen analysis revealed mid-winter lichen compositions of 38.0 % and 54.8 % respectively, graminoid compositions of 37.2 % and 12.2 %, herbaceous dicot compositions of 4.8 % and 4.1 %, pteridophyte compositions (specifically Equisetum spp.) of 0.2 % and 0.5 %, evergreen shrub compositions of 6.6 % and 3.0 %, deciduous shrub compositions of 2.1 % and 3.7 %, moss compositions of 10.5 % and 16.6 %, and seaweed compositions of 0.6 % and 3.2 % respectively (Table 4). Nonetheless mid-winter rumens and

scats did vary in the dominant species recorded for each. Dominant lichen species within fecal samples included Cladina spp., Alectoria spp., Bryoria spp., and Bryocaulon spp., and Stereocaulon spp. while rumen samples recorded Thamnolia spp., Peltigera spp., Stereocaulon spp. and Cladina spp. and Cladonia spp.. Common graminoid species within both scats and rumens included members of the Cyperaceae family, which in rumens were considerably lower than that of the fecal samples. Pellet Group and rumen analysis were very similar in evergreen shrub compositions. Both fecal and rumen samples were composed predominantly of Vaccinium spp. and Rhododendron lapponicum. Dominant deciduous shrubs in fecal and rumen samples included Salix spp. and in rumens, Dryas integrifolia.

Late winter pellet group and rumen analysis revealed little variation in plant group preferences. Lichen composition within late winter pellet groups and rumens recorded 30.5 % and 36.7 % respectively. Late winter lichen composition within rumens, however, were significantly different ($p < 0.05$, $n = 11$, $df = 1$), in terms of species selected, than those of mid-winter. Compositions of the remaining plant groups found within scat and rumen samples included graminoid compositions of 18.8 % and 22.0 % respectively, herbaceous dicot compositions of 5.5 % and 4.3 %, Pteridophyte compositions

(specifically Equisetum spp.) of 1.5 % and 0.0 %, evergreen shrub compositions of 9.2 % and 10.0 %, deciduous shrub compositions of 4.4 % and 5.0 %, moss compositions of 30.4 % and 17.8 %, and seaweed compositions of 0.4 % and 2.3 % respectively. Common lichen species within fecal samples included Cladina spp. and Cladonia spp., Peltigera spp., and Cetraria spp., while dominant lichen species within rumen samples included Thamnolia spp., Peltigera spp., and Cladina and Cladonia spp.. Common graminoid species within both pellets and rumens once again included members of the family Cyperaceae. Dominant evergreen shrubs within both fecal and rumen samples included Rhododendron lapponicum and Vaccinium spp., while the dominant deciduous shrubs included Salix spp..

5.7.5 Pooled Winter Feeding Habits

Seasonal totals of percent species composition within crater, rumen, and fecal samples were also recorded to provide greater comparability with available literature (Table 4). During the 1989-90 snow season Cape Churchill caribou excavated craters composed of 44.4 % lichens, 15.0 % graminoids, 0.2 % herbaceous dicots, 26.8 % evergreen shrubs, 3.3 % deciduous shrubs, and 14.5 % mosses.

Fecal analysis summarized over the same period displayed lower overall lichen compositions (37.0 %) than

indicated within feeding craters, higher graminoid compositions (19.3 %), higher compositions of herbaceous dicots (3.7 %), and Pteridophytes (1.9 %), considerably lower compositions of evergreen shrubs (8.5 %), and similar compositions of deciduous shrubs (2.8 %), conifers (1.3 %), mosses (24.5 %), and seaweed (0.5 %).

Species compositions within 1990-91 feeding craters displayed little variation from 1989-90 results, recording 49.2 % lichens, 16.0 % graminoids, 0.5 % herbaceous dicots, 20.0 % evergreen shrubs, 10.1 % deciduous shrubs, and 8.7 % mosses. Seasonal tallies based on scat samples recorded lower overall lichen compositions, considerably higher percent graminoid composition, herbaceous dicot composition, and moss composition; and considerably lower evergreen shrub and deciduous shrub compositions, when compared to the feeding crater analysis. Plant groups not found within feeding craters included pteridophytes (0.9 %), seaweed (0.5 %), and conifers (0.1 %).

The 1990-91 rumen samples varied little from the crater analysis when examining the lichen and graminoid plant groups. Evergreen shrubs, Pteridophytes, and mosses closely matched the results of the pellet group analysis. Seaweed was, however, considerably higher than indicated in scat samples alone. The consensus from each of the crater, scat, and rumen analysis, both seasonally and over early,

mid, and late winter, suggests that Cape Churchill caribou prefer lichen species of the genera Cladina (Cladina rangiferina, C. mitis, and C. stellaris), Peltigera spp., and Alectoria (A. ochroleuca), Bryoria (B. nitula), and Bryocaulon (B. divergens) over members of all other plant groups. This preference generally declined, though not below any other group, from December through April. Although mosses were at times found in considerably higher percentages, graminoids, specifically Carex spp. and Eriophorum spp. appear to be the second most important plant group specifically during mid-winter and perhaps early winter. The high percentages of mosses, particularly within scats and rumens are likely the result of incidental ingestion with more preferred forage.

6.0 DISCUSSION

6.1 Taiga And Tundra Snow Conditions

The formation of snow and its eventual accumulation and dissipation are extremely variable. This variability can be attributed in part to the plant communities in which it collects, and the ever-changing weather acting upon it both in the air and on the ground. When combined, these conditions change the snow cover, minute to minute, day to day, and year to year (Pruitt 1965, 1984, Stardom 1975). Caribou are highly adapted to these changing snow conditions and as a result have the ability to progress down a gradient to regions with api of lower thickness, hardness, density or VSI (Bergerud 1974a, Carruthers et al. 1986, Formozov 1946, Laperriere and Lent 1977, Loughrey and Kelsall 1970, Miller et al. 1982, Pruitt 1979, 1981, 1985, Stardom 1975, Thomas 1990). This ability of caribou to seek out plant communities of lower snow hardness and thickness suggests the need for a comparison between taiga and tundra snow conditions. Both these ecosystems are used by the Cape Churchill caribou during winter.

6.1.1 Taiga Snow

Snow thickness is determined by several factors, however, wind is the most important factor in determining differences in the properties of taiga and tundra plant community snow covers. Pruitt (1984) found taiga snow to occur in two forms: 1) api or the snow on the ground and 2) qali or the snow on the trees. Both forms were a direct result of the taiga's sheltered nature, reducing the level to which the snow is modified by wind. These views held true within the Cape Churchill Study area; however, the proximity of the taiga communities to tundra communities had an added ecotonal effect. Along the forest ecotone, and particularly within the TWS community, the appearance of both white spruce and tamarack, acted as a snow fence along which large amounts of wind-borne snow, originating on the tundra, are deposited. This large deposition is the result of a canopy-induced reduction in wind speed and as a result, its ability to carry snow crystals.

Taiga communities are, nonetheless, not completely protected from the wind, an observation also made by Pruitt (1984). Tamarack fens, lakes, and streams, common within the Cape Churchill taiga, often allow winds to transport snow from these more exposed areas to regions of higher tree densities. When this occurs, large drifts often form

along the ecotonal borders, while in the specific case of the tamarack fen, areas of snow erosion were common following severe winds, particularly within sedge meadows and ponds. A study by Kershaw (1991) demonstrated these ideas when they found exposed areas or "rights of way", within dense taiga, to display consistently lower overall thickness values than undisturbed forest. This observation would be analogous to the deciduous nature of tamarack within the TF, a community of low tree densities. Understandably then, wind within the more open taiga communities was often the main contributor to the overall variability of the Cape Churchill taiga snow cover. Thickness values did however follow a relatively consistent increasing trend throughout both snow seasons within the Cape Churchill study area, a finding significantly different than observed on the tundra.

Fluctuations in hardness, recorded on the Cape Churchill taiga over both snow seasons, were largely related to the formation of ice layers deposited during periods of both rain and freezing rain, sun crust formation, and thaw crust formation. These processes all serve to melt the surface layers of the snow which subsequently freeze into a layer of extremely hard snow or ice. Within the taiga, these layers (sigulik) are commonly covered and preserved by layers of relatively unmodified

snow. The frequencies of of these ice forming processes are most common during early (November) and late (April) winter.

The relative lack of wind within the taiga was obvious over both snow seasons resulting in a characteristically steady climb in hardness, and thickness. In addition the shaded nature of the taiga communities reduced the amount of solar radiation and thus the severity of freeze-thaw crusts.

6.1.2 Tundra Snow

The tundra offers little or no protection from the wind (Formozov 1946, Kershaw 1991, Pruitt 1959, 1979, 1980, 1984, Soprovich 1989). Colder substrate temperatures and ice crystal abrasion reduce the vertical profile of tundra plant species resulting in a reduction of their snow collective properties (Scott, pers. comm., 1989). Pruitt (1984) described two main types of tundra snow relations: 1) Upsik-Siqoq, where upsik is wind re-worked snow that becomes consolidated into a mass, and siqoq, moving or wind-borne snow. 2) Zaboi-Vyduv, where zaboi form when a concave topographic surface fills with siqoq resulting in a large mass which persists well into the summer, and vyduv representing a convex surface blown clear to reveal the substrate (ground surface). All these forms of tundra snow

were apparent within Cape Churchill tundra communities. It is through these processes that the Cape Churchill tundra communities were initially "charged" as depressions leeward to the prevailing winds and shrub thickets along river margins and lake shores, fill with sigoq to form upsik, while more exposed communities formed vyduv. Once "charged" the tundra lost much of its surface texture, and allowed the winds to remove freshly fallen snow, creating sigoq, which, was largely deposited into the forest ecotone region. In addition, reductions in overall tundra snow thickness, observed over both the 1989-90 and 1990-91 snow seasons, were on all occasions coincidental with high wind speeds and snowfall suggesting a net removal of the surface layer of the tundra snow through abrasion by wind driven ice crystals.

Fluctuations in snow hardness, recorded on Cape Churchill tundra communities over both snow seasons, were again related to the formation of ice layers deposited during periods of rain, freezing rain, sun crust formation, and thaw crust formation. These processes, as in the taiga, would subsequently cause the surface layer to freeze and harden into extremely hard snow or ice. Unlike the taiga, however, this hard surface layer is often scoured by the processes of abrasion by wind driven ice crystals, and only in rare cases, covered and preserved by upsik or wind

hardened snow (Pruitt 1965).

Spring time tundra hardness values are very unpredictable, an effect directly related to the constant fluctuation of temperatures between freezing and thawing. This is the time of year when the formation of sun and/or thaw crusts (ice layers formed by the thawing and re-freezing of a layer or layers of snow) are most active. Miller et al. (1982) discussed these conditions as they related to the High Arctic. Miller found that as the tundra snow cover began to melt, ground fast ice and ice lenses would accumulate under and in the snow cover. This phenomenon is a result of the change in the flow of energy from the substrate into the snow, occurring during subzero temperatures, to a flow of energy from the atmosphere into the snow cover. With this flow of energy comes moisture, and upon refreezing, layers of ice. This process makes the prediction of late winter tundra hardness values difficult. Consequently any change in temperature would more directly affect tundra snow hardness because of its exposure and relative thickness, and to a lesser degree the taiga due to the effect of shading and greater snow thickness values. The effect of shading, reducing the extent and timing of sun and/or thaw crust formation was also noted by Schaefer (1988).

Within the CCWMA tundra hardness values were typically

erratic, steeply climbing in response to surface ice layer formation and wind hardening and subsequently dropping in response to the removal of these ice deposits through ice crystal abrasion. One should not neglect the ability of the wind, on tundra sites, to harden snow. During the present study, surface hardness values in excess of 10000 g/cm², in the absence of ice layers, were common in December and February of 1989-90, and over January and March 1990-91. This process has to do with the wind's ability to break down snow crystals into their component ice fragments through the collision of the snow crystals with the snow surface and objects. Once broken down, these component ice crystals fit closer together to form a very hard and dense layer of snow, or upsik (Pruitt 1984).

6.1.3 Taiga And Tundra VSI's

Up until 1979, the effects of a snow cover on caribou movement and foraging activity, was based primarily on the establishment of both hardness and thickness thresholds, set values beyond which a particular subspecies of caribou would not transgress (Henshaw 1968, Laperriere and Lent 1977, Pruitt 1959, Stardom 1975). Schaefer (1988) found integral problems arising from the use of thresholds, as the parameters involved, thickness and hardness, act independently of one another. In addition to these

problems Soprovich (1989) added that the vertical position of layers of specific hardness varied temporally and should be used with caution. The advent of the Varrio Snow Index by Pruitt (1979), offered a means of avoiding these problems and therefore fundamentally changing the way we look at caribou and snow. While monitoring microclimatic changes on a community level, the ability of the VSI to predict changes in caribou activity relative to snow cover, falls into the realm of possibility. This ability of the VSI to model changes in Rangifer tarandus caribou, R.t. groenlandicus, and R.t. fennicus winter activity, has been demonstrated by Pruitt (1979, 1981, and 1985 respectively). Unfortunately little or no information exists comparing taiga VSI's to tundra VSI's, an essential comparison within the CCWMA. The following is an attempt to examine how changes in weather, thickness and hardness affect VSI's differently between taiga and tundra communities.

The dramatic increase in taiga VSI's within the Cape Churchill study area, between February and March, 1990, was likely in response to the occurrence of freezing rain, just prior to the sampling period, and the subsequent formation of a layer of ice within the taiga snow cover. Because of the significantly lower VSI's recorded on the tundra communities following the inversion (when taiga VSI's climbed above tundra VSI's), the VSI would predict a

habitat change by caribou from taiga to tundra communities. This in fact was the case. Tundra VSI's fell primarily in response to a dramatic drop in basal hardness values (Appendix A) but also in response to a drop in overall snow thickness resulting from the extremely high winds recorded during that period and their net effect of removing tundra snow. There was no indication that the formation of surface ice layers had any effect on tundra VSI's over either 1989-90 or 1990-91. Generally, taiga VSI's climbed throughout the 1989-90 snow season largely in response to the formation and preservation of ice layers within the snow cover, while tundra VSI's declined throughout the snow season, largely in response to the reduction in basal and surface hardness values, and between December and January, in response to the reduction in snow thickness.

During the 1990-91 snow season taiga VSI's remained relatively stable maintaining a subtly increasing trend until April 12 when values climbed sharply. As observed in 1989-90, preserved layers of ice or otherwise extremely dense and hard snow, appeared to maintain the stability of taiga VSI's, and also accounted for the sharp climb by the April 12th sampling period. The 1990-91 tundra VSI's were once again related to basal and surface hardness, although snow thickness did not appear to play a major role. The changes in basal hardness values, and thus the VSI,

observed on the tundra communities over both the 1989-90 and 1990-91 snow seasons, appears to be related to snow thickness. All drops in tundra VSI's were directly related to an increase in snow thickness over that same period while increases were in response to a thinning of the snow cover, a result of ice crystal abrasion, and shifts in wind out of the prevailing direction. Examples of this are seen between January 31st and February 20th, and between March 4th and 17th. These higher snow thickness values built up over days with relatively low wind speeds allowing fresh deposits of relatively unmodified snow to persist for several days before being removed by stronger winds. This layer of snow, acting to insulate the more basal layers of the snow cover, likely allowed for the acceleration of the process of pukakization (Pruitt 1984) along the ground-snow interface. With the added insulation at the top of the snow cover, energy would travel farther up through the snow cover before being dissipated (Pruitt 1959). The movement of this energy also drives the process of sublimation in the same direction, a process which removes ice crystals from basal layers (by sublimation) and redeposits them in the upper regions where the progressive reduction in available energy can no longer drive the process (Pruitt 1959). The corresponding removal of ice crystals from the basal layers weakens them and reduces their hardness,

forming the characteristic pukak layer and a predictable drop in VSI (Pruitt 1959).

6.1.4 Differences Between Snow Seasons

The characteristics of snow cover are largely governed by the precise succession of meteorological events that bring the correct mass of moist air into contact with cold air making the arrival of a snow cover highly variable from year to year (Pruitt 1965). The extremes of this variation have in the past been linked with dramatic fluctuations in ungulate populations (Edwards 1956, Ferguson and Mahoney 1991). On a smaller scale variations brought about by frontal activity have been linked to massive changes in winter range use by caribou (Gavin 1975). Caribou are intimately tied to these meteorological cycles which, in turn, were largely responsible for the differences observed between the 1989-90 and 1990-91 snow seasons within taiga and tundra communities. In fact differential snow accumulation in successive years may reduce the impact of grazing within sheltered sites, and as a result have a significant impact on community structure (Inglis 1975).

The onset of the 1990-91 snow season recorded significantly greater amounts of snowfall compared to 1989-90 values, an observation likely responsible for the greater snow thicknesses recorded over the 1990-91 snow

season. Although these elevated thickness values contributed to higher taiga VSI's recorded over the same period, they were not solely responsible. The occurrence of freezing rain and wet snow in November 1990, and absence in 1989, were directly responsible for the maintenance of 1990-91 taiga hardness values, and thus VSI's, significantly above 1989-90 values over December, January, and February. The persistence of these layers of ice was also related to the significantly greater amounts of snow falling in November and December, 1990, subsequently covering and preserving them. Taiga VSI's, from 1989-90, remained relatively unchanged over December, January and February, and climbed dramatically by the March sampling period in response to the occurrence of above zero temperatures and rain just prior to the sampling period.

Tundra VSI's from 1989-90 remained higher than 1990-91 values over December, January, and February despite the greater amounts of snowfall in addition to the occurrence of freezing rain and wet snow recorded during November and December 1990-91. The relatively warm temperatures, rain, freezing rain, and wet snow, effectively melted the relatively thin layer of early winter tundra snow, resulting in extensive patches of open ground. Although these patches were subsequently covered by snow, hardness, thickness, and thus VSI, remained considerably lower than

1989-90 values well into February.

The tundra communities initially displayed a trend opposite to that observed in the taiga. Snow hardness, sampled in December and January, 1989-90, was significantly higher than corresponding values sampled in 1990-91. The higher winds and greater amounts of blowing snow, recorded over November and December, 1990-91, likely served to scour away much of the surface ice layer deposited in early November yielding the corresponding drop in VSI by December. By February 1990, peak wind speeds had climbed high enough to begin abrading the surface layer once again, causing VSI's to drop, while the occurrence of freezing rain in February 1991 elevated VSI's once again. From this point alternating surface ice layer formation, formed by either rain, thaw and/or sun crusts, and wind and ice crystal abrasion, served to create the alternating pattern in hardness evident on the tundra throughout the remainder of both snow seasons.

All yearly differences recorded on the taiga were most sensitive to the timing of freezing rain or rain, freeze-thaw, and sun crusts. Tundra VSI's appeared to be driven by both wind and its abrasive effects, and once again the occurrence of rain or freezing rain, and more intensive thaw and sun crust formation, a result of the tundra's more exposed nature. The significantly higher 1990-91 taiga

VSI's during December, January, and February suggest that snow conditions within the taiga, over December, January, and March 1989-90, were much more favorable to caribou foraging and movement. Through March and April this prediction would be reversed as 1990-91 values were below those of 1989-90. On the tundra, however, the lower 1990-91 VSI's would have provided more favorable conditions over December, January, and February, and less favorable conditions during March and April.

As the Cape Churchill caribou characteristically use the taiga communities over the first half of the snow season and tundra communities over the second half (Kearney and Thorleifson 1987), one would predict that the 1990-91 snow season was more energetically demanding for the Cape Churchill caribou, largely the result of one month, November, whose conditions persisted throughout the winter.

6.2 Plant Community Use

Caribou are extensive rather than intensive feeders, a characteristic which suggests that their use of any one part of their range is constantly changing throughout the snow season, changes which in part depend on snow conditions and how they affect access to, and procurement

of winter forage (Baskin 1990, Bliss et al. 1973, Pruitt 1959). During the present study the analysis of winter plant community use was subject to four potential forms of bias: tracking efforts were restricted in range which was further dependent on base camp location; both visibility and tracking efforts were hampered within taiga ecosystems, a difficulty not encountered within tundra ecosystems; tracking sessions within areas of high caribou densities were not assured as camp locations were based on first sightings and information provided by local hunters; plant community identification, within tundra habitats, was at times difficult due to the lack of any visual vegetative clues. In order to at least partially counter-balance these biases: base camp location was moved as frequently as logistically practical; tracking surveys within taiga habitats were carried out at least twice as often as those on the tundra; base camp location was moved, during the tracking session, to areas visually perceived to have greater caribou densities than the initial location; when time allowed, excavations were made within tundra habitats of questionable community composition.

The Cape Churchill caribou generally utilized elevated communities with relatively high lichen cover values and low VSI values for feeding. Elevated communities with both high lichen cover values and tree densities, were used most

often during early winter before snow thickness values reached threshold levels. Low lying hydric communities characteristically high in graminoid cover generally produced higher VSI's (including lakes and ponds) and as a result were used primarily for travel. Opportunistic use of the latter communities for foraging was also apparent, primarily during early winter and the first half of mid-winter (January) when VSI's were at their lowest. These findings were not entirely consistent with the available literature.

Geographically, the Penn Island herd of woodland caribou, closely associated with the more northerly situated Cape Churchill herd, were found to use ombrotrophic raised bogs, rich in terrestrial lichens, throughout the snow season (Darby et al. 1989). Darby et al. (1989) went on to suggest that lichen woodlands, lichen heaths, palsa bogs, and sinuously patterned peat lands were not selected by Penn Island caribou. Cape Churchill caribou did, however, display extensive use of palsa bogs during early winter 1989 when VSI's were still low. These communities were used primarily for feeding, as the number of feeding craters found within them were significantly greater than the tracking data alone would suggest. Lichen woodlands or forest ecotone communities, represented by TWS, TF, and WS (in proximity to tundra communities) in the

present study, although generally not used during early winter, displayed extensive use during mid-winter 1990, and limited use over the same period in 1991. This shift in community use appears to be related to the elevation of VSI's within the BSP and inland WS communities over early winter values. TWS VSI's, over the same period dropped below those of the BSP making these sites more desirable for feeding. The elevation of TF VSI's into mid-winter likely had the greatest effect on the reduction of incidental foraging. The use of these sites for travel would have been enhanced by the thinner, harder snow cover. These differing results are likely related to the general lack of raised bog communities within the Cape Churchill study area.

The Cape Churchill caribou use of mid-winter tundra communities, particularly during the 1990-91 snow season, was apparent on HLT (for both feeding and movement), and ST (primarily for movement). Once again HLT was used primarily for feeding while the ST and BR communities were used primarily for travel. Low VSI's within HLT, and the considerably higher VSI's within the ST and BR communities again appeared to govern the patterns of plant community use during late winter. These observations appear to be uncommon amongst barren-ground caribou (Baskin 1990, Carruthers et al. 1986, Loughrey and Kelsall 1970, Telfer

and Kelsall 1979). Nonetheless, similar situations have been reported by Thompson and Klassen (1980). They found the highest winter densities of the Kaminuriak barren-ground caribou herd (periodically sharing a common winter range with the Cape Churchill herd) were also within lichen heath tundra communities. The fact that both the Kaminuriak and Cape Churchill herds occupy ranges in association with the Hudson Bay coast line may account for these similar findings. Strong northeasterly winds with the ability to carry correspondingly high snow loads, often form over the Bay, move across the coastal tundra, and deposit their loads within the forest-ecotone where wind velocities are effectively reduced. Within the Cape Churchill study area, these events, though not common, still had a major influence on associated taiga community VSI's, elevating them to levels considerably higher than those experienced within the tundra communities. It would follow then that the caribou would likely respond to these conditions by shifting to tundra sites.

The increased use of lakes during mid-winter, and the exclusive use of tundra communities during late winter, by Cape Churchill caribou, may also be related to the characteristically harder and thinner snow covers found there. The increased use of lakes and exposed ridges for their harder and thinner snow cover to facilitate travel

and improve visibility has been described for woodland caribou (Darby and Pruitt 1984). Both ease of travel and improved visibility, characteristic of taiga lakes and tundra communities, also play an important role in predator avoidance (Bergerud 1985). These findings would account for the nearly exclusive use of elevated BR communities by cow-calf groups apparent during the latter half of late winter. The results of this study and others would suggest that the differences in winter community use by various caribou herds are not simply related to plant community structure but also geographically and temporally related to weather and its effects on snow conditions, predation, and other biotic and abiotic factors, both within any given snow season and between any two snow seasons.

As low VSI's favor caribou activity, it would follow that caribou would use, during the 1989-90 snow season, taiga communities, up until the February-March inversion of taiga and tundra VSI's (when taiga VSI's climbed above Tundra VSI's). During this period they shifted onto tundra communities to take advantage of lower VSI's, largely the result of increasing snow thickness. During the 1990-91 snow season, it would follow that caribou would have favored the tundra habitats over most of the snow season. There are, however, exceptions to these observations. Brown and Theberge (1990) documented the wintering of

Labrador woodland caribou in areas with mean snow depths of 176.7 cm, cratering through up to 123.1 cm to reach forage. These findings lend some support to Bergeruds (1974c) conclusion that woodland caribou select habitats primarily for suitable forages and secondarily for acceptable nival conditions.

The degree to which any one group of caribou respond to snow conditions depends largely on the severity of those conditions (Pruitt 1959). Moving through thick snow (relative to brisket height) can impose exponential increases in energy expenditure (Fancy and White 1987, Parker et al. 1984). This factor in turn would present a significant driving force, especially during mid to late winter, when taiga snow thicknesses reach their seasonal maximum, eventually moving caribou out onto the thinner snow of the tundra. In addition caribou generally seek feeding sites with relatively low hardness values (Collins and Smith 1991, LaPerriere and Lent 1977, Skogland 1978). Pruitt (1959, 1981) specifically found that a hard layer in the upper half of the snow cover seems to be more important in deterring R.t. caribou and R.t. groenlandicus feeding than a layer of equal hardness in the lower half. The previously discussed fluctuations in hardness, recorded on the Cape Churchill taiga, and to a greater degree, tundra communities, over both snow seasons, would account for

these observations within the Cape Churchill study area. Fancy and White (1985) found the formation of hard surface layers or "crusted snow" to be energetically demanding to caribou. During their study Fancy and White (1985) found the cost per digging stroke in light uncrusted snow by caribou to be 118 J, while in dense snow with a thin hard crust it climbed to 219 J/stroke. In the case of a snowmobile trail, compressing even basal layers, the energetic cost rose dramatically to 418 J/stroke. In addition, the energy costs of locomotion in crusted snow were often twice that of uncrusted snow at the same sinking depths (Fancy and White 1987).

The dramatic increase in taiga VSI's within the Cape Churchill study area, between February and March, 1990, was likely in response to the occurrence of freezing rain just prior to the sampling period, and the subsequent formation of a layer of ice (sigulik) within the taiga snow cover. In this instance the VSI accurately modeled the effects of increased energy expenditure for both locomotion and crater excavation discussed in the sections on taiga and tundra snow snow conditions. The relatively high use of the BR community during both the 1989-90 and 1990-91 late winter periods is likely related to the extremely thin or entirely lacking snow cover characteristic of these sites (Soprovich 1989). Their use primarily by females and yearlings during

late winter is supported by studies suggesting a sexual segregation of adult males from adult females with calves and yearlings especially towards calving (Baskin 1990, Caruthers et al. 1986). These observations are thought to be largely the result of the larger males' ability to crater and move through thicker and harder snow.

6.3 Feeding Site Availability

Significantly greater snow thicknesses observed in taiga compared to tundra and their corresponding effect on VSI's, were important factors in feeding site selection. Cape Churchill caribou generally sought cratering sites with thinner snow throughout the winter and softer snow specifically during late winter. As a result VSI's were consistently lower within craters than found generally in the feeding site. Such findings were consistent with the literature (Bergerud and Nolan 1970, Collins and Smith 1991, LaPerriere and Lent 1977, Miller et al. 1982, Russell and Martell 1984). This in fact did not always hold true within the Cape Churchill study area. During early winter, 1989-90, Cape Churchill caribou feeding crater VSI's did not vary significantly from the lowest community snow station VSI's. Without exception, communities displaying

significantly higher VSI's were not used by caribou. Similar results were also found for North American barren-ground caribou, woodland caribou, and semi-domesticated Finnish reindeer (Darby and Pruitt 1984, Pruitt 1979, 1981, Schaefer 1988).

The BSP community, favored during early winter, 1989, was all but abandoned by mid-winter, despite significantly lower VSI's than recorded within feeding craters. The reasons appear to be related to thicker snow cover in addition to a significant elevation in basal layer hardness values, particularly within the BSP community. Towards the latter half of mid-winter (late February), caribou feeding craters were found within the HLT community, which over this period displayed significantly higher VSI's (based on snow station results) than recorded within feeding craters. This shift in habitat use from taiga to tundra during the latter half of mid-winter did not appear to be accurately modeled by the VSI, and suggests some problems in the VSI's ability to cross the gradient between taiga and tundra simultaneously.

A dramatic reduction in late winter tundra hardness and corresponding VSI values, within the HLT community, matched values recorded within late winter feeding craters. Late winter VSI's within the BR community were significantly lower than their corresponding feeding crater

VSI's but did not display the extensive feeding activity recorded in HLT. During late winter Cape Churchill caribou were found to have excavated craters predominantly within HLT communities, and to a lesser extent, BR communities.

Early and, to a certain degree, mid-winter findings, support the conclusions that caribou select habitats primarily for suitable forages and secondarily, for acceptable nival conditions (Bergerud 1974c, Pruitt 1959). Crater VSI's and hardness values were, in fact, significantly higher in late winter versus early winter while crater thickness values dropped significantly over the same period. Nonetheless, the late winter findings show a convincing shift in community use based primarily on significant changes within community snow conditions first, and suitable forage second, which would suggest a temporal influence on the selection of feeding sites based on community snow conditions. A similar pattern was apparent, though not recorded, between early and mid-winter 1990-91.

6.4 Api Thresholds

According to feeding site snow conditions the Cape Churchill caribou at no time during either the 1989-90 or 1990-91 snow seasons excavated craters within sites having

snow thickness values of 40 cm or greater. These findings are generally consistent with, though slightly lower than, the 50 to 60 cm indicated in the literature for barren-ground caribou (Henshaw 1968, LaPerriere and Lent 1977, Pruitt 1959, 1965, 1981, Russell and Martell 1984; Thomas 1990). Threshold values below those indicated in the present study were generally restricted to barren-ground and Peary caribou populations of higher latitudes, exclusively occupying tundra sites (Adamczewski et al. 1988, Miller et al. 1982). Thickness thresholds (thickness values above which tend to inhibit cratering activity) above 60 cm were generally restricted to woodland caribou populations of which one extreme example, 123.1 cm, was recorded in Labrador (Brown and Theberge 1990, Henshaw 1968, Pruitt 1959, Russell and Martell 1984, Stardom 1975). It is generally agreed that the larger woodland subspecies have a greater threshold of sensitivity to thickness (the ability to excavate and move through thicker snow) than barren-ground caribou (Henshaw 1968, Pruitt 1959, Russell and Martell 1984, Stardom 1975).

The Cape Churchill caribou threshold of sensitivity to hardness on tundra sites reached 35000 g/cm² in late winter 1990, and reached maximum values (100000 g/cm²) during both mid and late winter 1991. On taiga communities, these thresholds of sensitivity to hardness were considerably

lower (6500 g/cm^2). The caribou's lower tolerance to snow hardness within taiga communities appears to be related to the location of the hardened layer within the snow cover. Collins and Smith (1991) and LaPerriere and Lent (1977) found that under conditions incorporating a relatively thin tundra snow cover with a wind hardened surface layer vegetation could be more easily accessed, with less expended energy than hardness values alone would suggest. This was achieved through the fracturing of the surface layer into slab-like pieces. Wind-hardened snow is often easily fractured with one third to one fourth the amount of force required in undisturbed snow (Collins and Smith 1991). Taiga snow, on the other hand, remains relatively un-worked by wind, and characteristically preserves hard dense layers within the snow cover, not necessarily restricted to the snow surface (Pruitt 1959, 1984). These preserved layers were found restrictive to caribou when located at or above 25 cm from the substrate (Stardom 1975). These conclusions were consistent with the findings of the present study. Conditions of a relatively thin tundra snow cover with a hard surface layer and softer basal layers were common on mid and late winter Cape Churchill tundra communities. As taiga snow thickness values changed little between mid and late winter, it would appear that caribou movements out of taiga habitats by late

winter was largely governed by rising hardness and thickness values within these ecosystems. These conditions would also explain a caribou preference for tundra communities over the 1990-91 snow season. By mid-winter, 1991, taiga hardness values had already exceeded the proposed 1989-90 threshold to taiga hardness of 6500 g/cm².

Hardness thresholds for caribou activity within taiga communities have been reported below 400 g/cm² for woodland caribou, and as high as 9000 g/cm² for barren-ground caribou (Adamczewski et al. 1988, Stardom 1975). There is, however, little or no work available with which to compare the extremely high VSI's encountered within Cape Churchill caribou feeding craters. Nonetheless the results of this study and others indicate a distinct drop in the caribou threshold to hardness sensitivity with increasing snow thickness (Adamczewski et al. 1988, Pruitt 1959, Skogland 1978, Stardom 1975).

6.5 Crater site selection

Pooled data from both the 1989-90 and 1990-91 snow seasons suggest that the Cape Churchill caribou exclusively choose microsites, within selected communities, of significantly lower thickness, hardness, and VSI, in which

to excavate feeding craters. These findings are consistent with a number of studies acknowledging the ability of caribou to select cratering locations with more desirable snow conditions than generally available within the feeding site (Collins and Smith 1991, LaPerriere and Lent 1977, Pruitt 1979). A closer examination of the data set for early, mid, and late winter does reveal that differences in hardness appear to be less important to caribou than those of thickness. In all cases, except early winter 1989-90, VSI's were significantly greater within the surrounding community versus the feeding crater. This seemingly precise selection of crater sites could be related to factors not entirely independent of snow thickness as plant communities are often highly correlated with mean duration and thickness of the snow cover (Lent 1986). In addition crater site selection has been shown to be limited to the ability of caribou to detect forage items, through sight and smell, beneath the snow cover, findings that would be consistent with the selection of a thinner snow cover, and largely independent of snow hardness (Bergerud 1974a, Bergerud 1974b, Bergerud and Nolan 1970, Brown and Theberge 1990, Helle 1981).

6.6 Feeding Habits

There are many inherent biases concerning rumen, scat, and crater analysis. Generally rumen and scat analysis may tend to over-estimate the more undigestible, and as a result, more discernible plant fragments as they would remain within the rumen for a much longer period of time (Bergerud and Russell 1964, Thomas et al. 1984). Craters, on the other hand, tend to show what the caribou did not eat, yielding a bias towards more undesirable species. As undesirable forages tend to have lower digestibilities, a combination of these three forms of analysis may tend to increase the magnitude of the bias. Nonetheless, there are few alternatives for the analysis of caribou feeding habits. For the present study both rumen and scat samples were analysed at the cellular level, a method considered more reliable than plant fragment identification, as a much broader range of digested plant material can be identified.

The feeding habits of barren-ground caribou are well documented. There is, however, a general lack in the temporal analysis of feeding habits. The available literature suggests that lichens generally make up 41 to 68.5 % of barren-ground caribou diets, evergreen shrubs 5 to 6 %, forbs 7 %, graminoids 0.6 to 11 %, and mosses 4.9 to 10 %, of winter diets (Boertje 1984, Reimers 1980, Scotter 1964, Shank et al. 1978, Thomas and Hervieux 1986).

Of the lichens, Cladina mitis, C. rangiferina, Stereocaulon tomentosum, Cetraria spp. and Peltigera spp. are the most commonly sought by caribou, likely the result of their higher digestibilities, especially during periods when rumen turn-over times are at their maximum (Thomas and Kroeger 1980, Thomas et al. 1984). Vaccinium vitis-idaea, Equisetum spp., Salix spp., Betula spp., and dried forbs, have all, at one time or another, been recognized as important in the diets of overwintering barren-ground caribou (Reimers 1980, Scotter 1964, 1967, Shank et al. 1978, Thomas and Hervieux 1986).

The results of the current study are relatively consistent with the literature. Prominent lichen species, however, also included Thamnolia spp., an observation also made by White and Trudell (1980a) in their study of Alaskan caribou (Rangifer tarandus granti). Peltigera spp. was also found in greater abundance than indicated in the literature, particularly within mid-winter scats and rumens. In addition Stereocaulon spp. was surprisingly absent from feeding craters, despite the 4.3 to 5.3 % seasonal composition within rumens and scats respectively. Graminoids were more prominent in the Cape Churchill caribou diet yielding 19.3 % and 15.0 % composition within 1989-90 scats and feeding craters respectively, and 27.6 % and 16.0 % within 1990-91 scats and feeding craters

respectively. Rumen samples recorded 17.1 % in 1990-91.

Evergreen shrubs were also found in much greater abundance within scat, rumen, and crater contents specifically towards late winter. Both Vaccinium spp. and Rhododendron lapponicum, made up the bulk of the evergreen shrubs found within both late winter feeding craters and scats during 1990, and mid and late winter craters, scat, and rumen samples collected during 1991. This relatively high use of R. lapponicum was not consistent with the literature. Evergreen shrubs within both 1989-90 and 1990-91 craters indicated 21.1 % and 26.8 % respectively while 1989-90 and 1990-91 scat samples recorded 9.2 % and 8.5 % respectively. Evergreen shrubs within 1990-91 rumen samples were found at 8.0 % composition.

Mosses also displayed much higher frequencies within 1989-90 craters and scats, and 1990-91 craters, scats, and rumens than was apparent in the literature. These relatively high values are likely greater than incidental ingestion alone would suggest. The closest example of similar intake values can be found amongst Peary caribou (Miller et al. 1982, Thomas and Edmonds 1983).

Another inconsistency with the literature was the appearance of seaweed within nearly all 1990-91 caribou scat and rumen samples. It is commonly believed that barren-ground caribou obtain minerals from ice and soil

licks (Heard and Williams 1990). The apparent use of seaweed by Cape Churchill caribou, specifically females and young, offers an alternate explanation. This use would likely provide essential macro and micro elements in addition to supplying, perhaps, levels of nitrogen and available energy otherwise unavailable within ice and soil licks. The use of seaweed was likely related to the increasing mineral requirements of female caribou especially towards the calving season (Jacobson et al. 1981). Personal observations of CCC over mid and late winter 1990-91 showed an east to west movement, often daily, between the treeline and the coast. Although direct observations of caribou feeding on seaweed were not made, these movements could still be in response to accessing coastal seaweed beds stranded inland during summer storms. In addition, the dark color of these beds tend to clear them of snow (through the absorbtion of solar radiation) late in mid-winter creating a striking contrast easily visible at considerable distances. Obtaining their mineral requirements from the seaweed may have had an effect on the use of evergreen shrubs as a source of essential minerals and could have potentially reduced their selection and percent content within caribou scat and rumen samples.

The Kaminuriak caribou herd often occupies the same winter range as Cape Churchill caribou. Miller (1976)

found the Kaminuriak caribou to have changed from predominantly terrestrial lichens and grass-like plants (primarily Equisetum spp. and Carex aquatilis) in early winter to arboreal lichens and woody browse in late winter. The Cape Churchill caribou feeding habits varied considerably from these observations. Although early winter feeding craters suggested a relatively high use of both lichens and sedges (Carex aquatilis and Eriophorum spp.), late winter feeding craters and scats, and, in 1990-91, scat and rumen samples, suggested continued high use of terrestrial lichen species and a relatively high use of evergreen shrubs. The 1990-91 rumen analysis, alone, suggested a continued preference for lichen species between mid and late winter, while the 1989-90 feeding craters suggested a significant increase in the selection of evergreen shrubs from mid to late winter. The use of woody browse such as Salix spp., Betula glandulosa, and Shepherdia canadensis was relatively low (0.5 % to 7.1 %). Scat and rumen analysis also suggested the use of arboreal lichens by Cape Churchill caribou throughout the winter although compositions seldom exceeded 3 %, and did not vary significantly from mid to late winter 1991.

Proceeding from early to late winter, Cape Churchill caribou generally displayed a reduction in their preference for lichen species, an increase in their preference for

evergreen shrubs and a general decrease in their preference for graminoids with the exception of mid-winter 1991, when graminoids showed a resurgence within scat and rumen samples. As craters within sedge tundra communities were rare during mid-winter, the reasons for this resurgence are largely unknown, but could be related to the caribou's selection of the more dry land Carex species such as Carex scirpoidea, Carex capillaris, Carex rupestris, and Carex vaginata, all common within HLT and associated BR communities, both of which were used by caribou during mid and late winter.

The selection, by Cape Churchill caribou, of various plant groups and their associated species during mid and late winter did not vary significantly between the two snow seasons. Nonetheless, the use of typically taiga species such as Lycopodium spp., conifers, and the absence of typically tundra species such as Rhododendron lapponicum, during mid-winter 1989-90, support the extensive use of taiga communities, by caribou, over mid-winter 1989-90 and the lack thereof during mid-winter 1990-91. The overlap of typically taiga and typically tundra species was likely a result of caribou movement into the forest ecotone at the end of March. These sites, as the name implies, typically share vegetative components of both the taiga and tundra.

7.0 CONCLUSIONS

To conclude the results of this study the 4 general null hypothesis introduced at the beginning of this manuscript are reviewed and their acceptance or rejection summarized:

1. Cape Churchill caribou do not display a preference for one plant community type over another from December through April, and that this lack of preference is also apparent on a year-to-year basis.

Cape Churchill caribou did in fact shift from one plant community to another during the 1989-90 snow season when the animals moved from taiga communities to tundra communities in early February. More specifically Cape Churchill caribou moved from BSP and TF communities (for feeding and movement respectively) in early winter, to WSF, TWS, and TF (within the forest-ecotone) used equally for both movement and feeding.

The general movement of the caribou from pure taiga plant communities to the forest ecotone culminated in their exclusive use of tundra communities, specifically HLT for feeding, BR for both feeding and movement, and ST for movement, during late winter.

The Cape Churchill caribou's use of primarily tundra

communities (HLT for feeding, BR for feeding and movement, and ST for movement) over early, mid, and late winter 1990-91, identifies the fact that Cape Churchill caribou did not necessarily choose the same plant communities year to year during the winter months.

Summary: Cape Churchill caribou did display a preference for one community type over another throughout the 1989-90 snow season and that this preference changed between the winters of 1989-90 and 1990-91.

2. Forage groups chosen by Cape Churchill caribou do not change throughout the 1989-90 and 1990-91 snow seasons, or between the two snow seasons.

The data collected and analysed during this study failed to reject the null hypothesis suggesting that despite plant community shifts, Cape Churchill caribou sought the same plant groups both throughout the snow seasons and between the two snow seasons.

Plant groups in order of preference to Cape Churchill caribou include terrestrial lichens (primarily Cladina spp. and Cetraria spp.), Graminoides (primarily Eriophouum spp., and Carex spp.), mosses, and evergreen shrubs (primarily Ledum spp., Vaccinium spp., and Rhododendron spp.).

Compositions of evergreen shrubs in scats and rumens did increase (though not significantly) from early to late

winter, and Rhododendron spp. entered diets while the animals were occupying the tundra ecosystem. Work has yet to be done concerning individual plant species preferences.

Summary: Forage groups chosen by Cape Churchill caribou did not change throughout the 1989-90 and 1990-91 snow seasons, or between the two snow seasons.

3. Snow conditions within the Cape Churchill Wildlife Management Area do not vary between December and April or between the two snow seasons (1989-90, 1990-91).

The data collected during the study failed to accept this null hypothesis. Snow conditions in both the taiga and tundra plant communities were dynamic, displaying distinct changes in their respective snow covers during both the 1989-90 and 1990-91 snow seasons in addition to between these two snow seasons. The primary difference was due to the lack of wind modification within the taiga snow cover.

Typically the tundra is initially charged with snow during early winter. The removal of excess snow during the remainder of the winter served to maintain relatively constant tundra snow thicknesses. Hardness values within tundra communities were once again controlled largely by wind and the ability of wind driven ice crystals to abrade surface ice layers of various origin.

Within taiga communities the structure of the vegetation largely controlled the level to which wind modified individual communities. Taiga snow thickness (significantly greater than that of the tundra) increased throughout the winter until above zero spring temperatures began breaking down the snow cover. The thicker taiga snow cover served as an excellent insulator (as snow crystal structure remained relatively unmodified) protecting and preserving layers of hard dense snow deposited generally through brief thaws and periods of rain or freezing rain. Taiga hardness values typically rose from early to late winter.

Yearly change in snow conditions was obvious and intrinsically tied to climatic events particularly during early winter.

Summary: Snow conditions within the Cape Churchill Wildlife Management Area did vary between December and April and between the two snow seasons (1989-90, 1990-91).

4. Cape Churchill caribou do not change their movements, plant community use or forage selection to agree with changes in snow cover conditions within the 1989-90 or 1990-91 snow seasons or between them.

The abandonment of one plant community or ecosystem for another, in all cases, followed a change in the snow

cover most obviously related to increasing snow thickness values primarily, and increasing basal hardness values secondarily. These findings do not, however, take into account the role predation, snowmobile trails, hunting practices, and other biotic and abiotic factors, play in modifying the use of plant communities by Cape Churchill Caribou throughout the winter.

The most significant evidence of Cape Churchill caribou responding to changes in snow cover was highlighted by the VSI's ability to model, using snow parameters, the Cape Churchill caribou movement from taiga habitats to tundra habits in 1989-90, and their exclusive use of tundra habitats in 1990-91. Generally, when taiga VSI's climbed above those of the tundra, Cape Churchill caribou moved onto tundra sites.

These changes from taiga to tundra plant communities are not solely related to forage availability but also to the energetic demands of movement through a snow cover. As tundra sites typically maintain hardness values in excess of the foot loading of an individual caribou, it would seem likely that the movement from taiga to tundra communities is at least in part related to increased mobility.

As forage selection changed little within either the 1989-90 or 1990-91 snow seasons or between them, it is the conclusion of this study that (at least over the 1989-90

and 1990-91 winter field seasons) Cape Churchill Caribou selected feeding sites primarily for suitable forage groups and secondarily for suitable snow conditions.

Once on an appropriate feeding site, however, Cape Churchill caribou choose cratering sites of significantly lower thickness, and in most cases VSI, then generally found within the feeding site. In fact the choice of thinner snow in which to crater was often at the expense of increased snow hardness. These same findings were evident when comparing the two snow seasons.

Summary: Cape Churchill caribou do change their movements and plant community use, in part due to changing snow conditions, and generally choose communities on the basis of vegetative content first and snow conditions second (based on the 1989-90 and 1990-91 snow seasons within the Cape Churchill Wildlife Management area).

8.0 MANAGEMENT RECOMMENDATIONS

These management recommendations are pertinent specifically to the resident Cape Churchill population of caribou and generally to the Kaminuriak Caribou Herd when occupying the CCWMA. The managers of Caribou populations occupying the taiga and forest-ecotone during the snow season may also find the conclusions of this study useful.

1. Taiga and tundra community snow conditions

Several attempts have been made to assess snow cover over the short term and within limited geographical areas. Although the results may be valid for these limited criteria, the results of this study clearly show that the variability of a snow cover not only from year to year but also within any given snow season or between any two communities is extremely high and difficult to predict. Given these findings I would strongly recommended that management decisions made within boreal environments during winter be based on a comprehensive analysis of community based snow conditions monitored on a continual basis over a wide geographical area. To make management decisions within boreal environments without taking into account the ever evolving snow cover would be analogous to managing a

wet land without taking into account the water. The addition of intensive snow cover analysis as a management tool is long overdue, and its need is clearly shown in this study.

2. The management of caribou range.

Cape Churchill caribou shifted from taiga to forest-ecotone, to tundra communities in 1989-90, while during 1990-91 they used predominantly tundra communities. This shift in community use both within and between snow seasons was largely driven by changing snow conditions. The net effect of these shifts in community use suggests that these animals rely on a diversity of communities progressing from the most desirable to the least desirable depending on environmental conditions. It is for these reasons that caribou are extensive rather than intensive feeders, requiring enormous ranges with a mosaic of community types. Unfortunately much of boreal management today relies on information gathered through a "peep hole" in time over any given winter season. Often early winter or late winter community preferences and conditions are not addressed. Based on the present study I would strongly recommend that a comprehensive analysis of community use by caribou during winter be made before introducing management strategies. I would also strongly recommend that caribou populations not

be assigned finite ranges which can dangerously under estimate the importance of "poor quality" range especially during winters of severe icing and thick snow accumulations when they may contain the only available food source.

3. Snow conditions and Cape Churchill caribou

Although the Cape Churchill caribou responded to changing snow conditions it is not clear as to the energetic cost of such a change. Generally Cape Churchill caribou feeding craters did not exceed 40 cm in thickness on either taiga or tundra sites. Thresholds of sensitivity to hardness were considerably higher in tundra (up to 100000 g/cm²) versus taiga (6500 g/cm²). These findings call for more intensive study between the characteristics of tundra versus taiga snow covers. It is apparent, however, that large amounts of snow coupled with freezing rain and/or wet snow and/or warm temperatures, occurring particularly during early winter, tends to push Cape Churchill caribou into less desirable communities in terms of forage. Although ice layers within the taiga snow cover may be partially responsible for these shifts, increasing snow thicknesses are more closely associated with the observed movements out of the taiga. Once again continual monitoring of tundra snow conditions over this period would provide wildlife managers with critical information

concerning winter survival or major movements of the Cape Churchill population.

The ability of certain snow conditions to lock in preferred forage species was evident within the thicker and harder snow of late winter taiga communities. On tundra sites less preferred forage species are sought by caribou only when taiga snow conditions become severe enough to make the excavation of forage, or locomotion, energetically impractical. During years when these same severe snow conditions affect both taiga and tundra sites caribou must move out of the region until energetically accessible forage is found. All these observations point to the fact that Cape Churchill caribou, react to severe snow conditions by first changing geographically, and second by changing floristically. If we as managers do not maintain a large enough range to accommodate these periodic habitat shifts we stand the risk of losing this vital resource. To have planned far enough ahead in order to provide the Cape Churchill caribou or any group of animals with ample habitat to move to is, after all, the wildlife managers ultimate test.

9.0 SOME FINAL WORDS

Based on the readings of dozens of scientific papers and my own research it is becoming distressingly clear that wildlife management today spends the bulk of its time desperately trying to quantify one question "how much?". In some instances researchers have actually claimed to have grasped this elusive prize giving detailed descriptions of finite ecosystems in which their subjects of study could quite happily exist indefinitely. Another disturbing development involves the rapidly growing desire to study ecological processes by remote control, which will ultimately allow the researcher to avoid the "unpleasantries" of the field in exchange for the "comfort" and sterility of the lab. This, however, is not entirely the researchers fault. In many instances a masters degree is a potential ecologists first introduction to research, yet as each academic year passes more and more emphasis is being placed on the quick and clean approach to field biology where students are given strict time limitations in which to complete the learning process. These time limitations are becoming incompatible with field studies, and when field studies are implemented it will almost

certainly be during the summer months as the winter months are academically spoken for.

These ideas are not the views of a disgruntled student as I've had nothing but the finest support both from my University and others. These views are, however, a product of the University system. As an ecology student I have been taught the fundamentals of the scientific method which among other things delivers you into a mental environment in which the formulation, interpretation, and communication of scientific questions fuels a progressive thirst for knowledge. It is with this training that I ask: 1. Why in a predominantly boreal environment, do we habitually ignore a time of year when entire ecosystems, and the delicate organisms that dwell within them, are subjected to temperatures that could freeze an un-clothed human being in a matter of minutes, create mineral deposits of ice and snow that can halt the most powerful all terrain vehicles in their tracks, and produce winds that can deposit literally tons of snow over the duration of just one of many winter storms and in the process paralyze the largest cities. 2. Why do we as wildlife managers, strive to gain complete control over wildlife populations when their very survival depends on their ability to adapt to uncontrollable biotic and abiotic conditions.

It is also with this training that I ask how such a

complex environmental condition can be understood with simplified field techniques lacking in their ability to address the myriad of biotic and abiotic factors infinitely modifying these conditions minute by minute, or century to century. If I were to religiously follow my training in an attempt to answer these questions, I would first have to admit that I nor anyone else will ever find a final solution. I would also conclude, however, that in order to gain as complete an understanding as possible we will have to, at one time or another, get back into the field in order to remove the rapidly growing buffers between ecology, wildlife management, and science.

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9.0 Appendices

Appendix A

Snow parameters for 1989-90 and 1990-91 snow stations.

Table A.1. Summarized snow station snow parameters for the 1989-90 snow season. Variables examined include: the hardest layer more than half way up the profile (HHH); hardness of the hardest layer (HHL); total thickness (TTH); vertical hardness (VH); basal hardness (BHD); basal thickness (BTH); thickness of the hardest layer (THHL); surface thickness (STH); and log Varrio Snow Index (VSIL). Dashes (--) indicate missing values. Data entries indicate mean values for each of n=9 profile sets.

Variable	Date	BR	BSP	HLT	ST	TF	TWS	WSF
HHH (g/cm ²)	891125	--	0	--	--	0	--	--
	891220	0	7	11833	3022	26	7	7
	900120	222	1	16500	87222	5	2	10
	900210	222	29	2667	5611	21	160	31
	900315	1	7277	7222	8909	6056	4666	13055
	900411	22	6500	0	35594	32333	43888	51666
HHL (g/cm ²)	891125	--	7	--	--	7	--	--
	891220	33666	7	31222	45111	30	60	32
	900120	53944	9	24944	87222	16	8	13
	900210	39166	31	21666	6388	68	202	42
	900315	23889	7277	40001	77777	6055	4666	13055
	900411	22734	6500	12222	44111	43222	43888	51666
TTH (cm)	891125	--	22.4	--	--	21.6	--	--
	891220	2.7	35.6	11.2	17.9	35.8	38.0	35.3
	900120	4.8	48.8	8.7	18.4	49.8	32.8	49.0
	900210	7.1	59.8	20.1	27.3	48.9	49.4	62.4
	900315	2.3	80.2	8.2	22.9	51.3	80.6	58.4
	900411	4.1	71.7	1.4	26.6	57.8	57.8	59.1
VH (g/cm ²)	891125	--	1	--	--	1	--	--
	891220	42888	6	11222	1722	21	7	7
	900120	67055	0	28666	36055	24	6	5
	900210	32224	2	3569	1864	3	3	0
	900315	12780	42	9471	42	1847	23	5
	900411	355	32	11	1233	2167	24	3
BHD (g/cm ²)	891125	--	1	--	--	1	--	--
	891220	1	4	628	750	3	1	1
	900120	1683	2	2128	1200	4	1	4
	900210	377	3	978	811	14	14	28
	900315	1	9	1	3745	18	61	4
	900411	112	4	1	1855	21	386	11
BTH (cm)	891125	--	1.0	--	--	1.0	--	--
	891220	1.0	11.2	4.8	7.6	6.6	1.0	1.0
	900120	1.6	11.1	4.1	10.3	15.1	2.3	8.1
	900210	2.4	13.3	5.8	10.2	8.2	4.6	13.9
	900315	1.0	22.6	1.0	9.9	17.2	18.8	15.3
	900411	1.1	21.5	1.0	12.2	17.4	11.3	13.4

Table A.1. (continued)

Variable	Date	BR	BSP	HLT	ST	TF	TWS	WSF
THHL (cm)	891125	--	14.7	--	--	10.7	--	--
	891220	2.7	13.1	3.4	4.6	12.7	12.0	11.4
	900120	3.6	15.8	4.3	5.8	16.2	15.0	13.3
	900210	3.3	7.3	5.8	6.3	13.8	6.6	11.6
	900315	2.0	13.8	4.4	5.6	4.2	5.7	2.4
	900411	2.7	5.6	5.2	5.7	5.3	1.5	1.0
STH (cm)	891125	--	2.4	--	--	3.1	--	--
	891220	2.7	11.4	3.4	4.2	9.3	15.0	10.3
	900120	3.6	16.7	3.7	5.0	16.9	8.7	7.3
	900210	3.6	7.8	7.9	6.8	8.5	10.5	9.3
	900315	1.7	11.2	3.1	1.7	5.8	5.4	4.2
	900411	2.9	2.6	1.1	3.3	2.9	4.9	7.4
VSIL	891125	--	0.50	--	--	0.35	--	--
	891220	2.52	1.21	4.32	5.21	1.48	1.51	1.15
	900120	3.04	0.91	3.65	7.21	1.39	0.83	1.38
	900210	2.94	1.86	3.92	5.58	2.20	2.00	2.80
	900315	0.92	4.94	1.96	4.76	4.84	5.34	4.28
	900411	1.31	4.48	0.56	6.37	5.32	6.62	5.11

Table A.2. Summarized snow station snow parameters for the 1990-91 snow season. Variables examined include: the hardest layer more than half way up the profile (HHH); hardness of the hardest layer (HHL); total thickness (TTH); vertical hardness (VH); basal hardness (BHD); basal thickness (BTH); thickness of the hardest layer (THHL); surface thickness (STH); and log Varrio Snow Index (VSIL). Dashes (--) indicate missing values. Data entries indicate mean values for each of n=9 profile sets.

Variable	Date	BR	BSP	HLT	ST	TF	TWS	WSF
HHH (g/cm ²)	901211	9444	116	444	3250	217	34	34
	910109	0	125	0	444	66	44	34
	910131	13777	149	2833	4111	35	62	8
	910219	1666	3666	0	5000	4058	321	116
	910304	7555	4833	1944	27222	3805	2495	66
	910316	83	85	6972	2906	3150	2056	22
	910401	3333	1194	0	26111	1089	1106	76
	910418	19444	47777	0	14888	48722	23888	25389
HHL (g/cm ²)	901211	15000	1578	6556	3500	456	2500	2506
	910109	7444	4444	8278	8000	988	4196	2000
	910131	13833	1856	5278	6056	511	3028	12111
	910219	22888	4278	18339	47222	4722	5944	3611
	910304	7833	5444	3333	27500	4078	5722	4833
	910316	3433	1461	12722	20500	3956	6333	6111
	910401	58333	6056	9666	40555	1644	12666	5167
	910418	19444	47777	12777	45555	48722	38555	26222
TTH (cm)	901211	4.4	50.8	4.3	13.4	33.3	41.2	64.2
	910109	2.9	66.8	1.9	22.7	31.7	45.1	70.8
	910131	2.4	63.6	1.1	17.8	37.7	48.3	72.1
	910219	4.3	75.4	3.8	16.2	69.9	41.4	75.2
	910304	3.2	111.9	3.2	21.0	86.2	58.2	72.6
	910316	6.7	86.8	19.2	29.0	66.7	68.1	84.2
	910401	6.3	77.8	2.9	19.6	56.7	66.1	79.0
	910418	13.0	53.7	2.6	25.5	70.9	39.7	70.3
VH (g/cm ²)	901211	13888	7	8444	4750	15	32	4
	910109	10888	33	7778	10261	103	45	43
	910131	14333	80	18555	7978	23	44	10
	910219	25555	8	21672	30000	51	589	7
	910304	9666	21	4111	25333	1798	29	5
	910316	637	7	383	1978	6	3	2
	910401	56500	4	5733	33333	17	36	19
	910418	17777	4167	72	26669	5944	0	0
BHD (g/cm ²)	901211	1033	101	1011	375	41	1	1
	910109	255	1	245	1294	157	1	1
	910131	1278	140	1278	489	217	1	1
	910219	477	617	2089	644	239	1	1
	910304	1227	256	322	594	828	1278	1
	910316	184	1	311	417	500	445	1
	910401	3278	1	234	950	195	217	1
	910418	78	1233	40	350	1022	1700	3445

Table A.2. (continued)

Variable	Date	BR	BSP	HLT	ST	TF	TWS	WSF
BTH (cm)	901211	2.6	5.0	1.2	4.8	3.6	1.0	1.0
	910109	1.2	1.0	1.0	6.7	3.1	1.0	1.0
	910131	1.8	3.0	1.2	7.9	9.6	1.0	1.0
	910219	1.7	7.4	1.7	6.4	22.1	1.0	1.0
	910304	2.2	14.1	2.2	8.7	10.0	3.9	1.0
	910316	1.1	1.0	4.2	5.0	6.7	1.8	1.0
	910401	2.2	1.0	1.7	8.1	10.2	1.8	1.0
	910418	1.6	11.4	1.3	7.1	6.2	5.3	7.4
THHL (cm)	901211	1.8	9.8	2.9	3.9	4.9	11.6	13.2
	910109	2.2	11.1	1.7	16.0	8.3	11.1	9.6
	910131	1.0	8.6	1.0	8.0	17.6	10.6	14.6
	910219	2.7	10.9	3.3	5.7	13.7	11.0	11.7
	910304	1.1	25.8	1.7	6.3	26.3	7.8	10.9
	910316	1.7	10.8	2.1	13.8	17.1	7.8	13.7
	910401	4.4	8.2	2.7	8.4	12.8	16.0	13.7
	910418	4.4	8.8	4.0	12.2	9.3	5.3	4.8
STH (cm)	901211	1.8	13.8	2.4	3.8	9.2	14.3	14.9
	910109	2.1	8.3	1.5	16.0	4.6	5.2	7.8
	910131	1.0	9.7	1.0	7.6	7.1	4.8	8.8
	910219	2.7	3.3	2.4	9.2	4.8	5.3	6.7
	910304	1.0	5.6	1.2	6.3	13.0	3.8	5.1
	910316	3.3	8.1	7.7	11.7	6.7	8.2	10.1
	910401	4.3	6.9	1.6	8.4	6.3	4.7	7.2
	910418	2.9	1.4	1.1	5.3	2.0	3.7	3.6
VSIL	901211	4.22	3.25	2.11	4.33	2.45	2.97	3.24
	910109	1.83	3.50	1.52	3.79	2.70	2.87	2.99
	910131	3.57	3.45	2.22	4.73	3.18	3.08	3.99
	910219	2.84	5.08	2.00	4.12	5.23	3.35	3.47
	910304	4.28	5.70	2.45	6.02	5.87	4.61	3.56
	910316	1.51	2.82	4.25	4.29	5.20	3.86	3.82
	910401	3.28	3.57	1.28	5.64	4.52	4.03	3.73
	910418	2.05	7.11	0.80	5.29	6.91	5.56	6.57

Appendix B.

Snow Parameters for the 1989-90 and 1990-91 crater and control profiles.

Table B.1. Summarized crater and control snow parameters. Variables examined include: the hardest layer more than half way up the profile (HHH); hardness of the hardest layer (HHL); total thickness (TTH); vertical hardness (VH); basal hardness (BHD); basal thickness (BTH); thickness of the hardest layer (THHL); surface thickness (STH); and log Varrio Snow Index (VSIL). Data entries indicate mean values.

Variable	Date	N	Crater	N	Control
HHH (g/cm ²)	891217	12	138	18	4
	891218	9	2	24	5
	900123	12	58	24	1358
	900124	9	61	18	1000
	900303	15	133	30	0
	910215	36	17279	72	5736
	910216	9	5000	18	11444
	910311	21	4835	42	9319
	910313	21	8030	42	2664
	910408	18	6668	36	40021
	910410	9	7456	18	19289
	910412	18	2864	36	8925
HHL (g/cm ²)	891217	12	146	18	7
	891218	9	38	24	52
	900123	12	925	24	1554
	900124	9	3267	18	3456
	900303	15	6927	30	4333
	910215	36	30653	72	30792
	910216	9	17222	18	26639
	910311	21	11619	42	19595
	910313	21	21500	42	29405
	910408	18	24506	36	66403
	910410	9	18444	18	28111
	910412	18	29500	36	33000
TTH (cm)	891217	12	24.7	18	35.0
	891218	9	18.6	24	32.5
	900123	12	21.3	24	31.2
	900124	9	11.8	18	25.3
	900303	15	5.4	30	7.7
	910215	36	5.9	72	17.3
	910216	9	5.4	18	22.5
	910311	21	15.3	42	27.8
	910313	21	15.5	42	26.9
	910408	18	4.4	36	35.5
	910410	9	6.0	18	14.7
	910412	18	12.3	36	29.7

Table B.1. (continued)

Variable	Date	N	Crater	N	Control
VH (g/cm ²)	891217	12	70	18	4
	891218	9	3	24	3
	900123	12	168	24	1579
	900124	9	2622	18	3028
	900303	15	8200	30	7500
	910215	36	32278	72	36104
	910216	9	20444	18	25778
	910311	21	11625	42	20202
	910313	21	5582	42	38
	910408	18	19424	36	3928
	910410	9	18761	18	8303
	910412	18	14756	36	11214
BHD (g/cm ²)	891217	12	68	18	1
	891218	9	1	24	1
	900123	12	9	24	95
	900124	9	145	18	967
	900303	15	17	30	1417
	910215	36	1184	72	989
	910216	9	461	18	2256
	910311	21	505	42	367
	910313	21	414	42	344
	910408	18	212	36	676
	910410	9	239	18	4041
	910412	18	567	36	511
BTH (cm)	891217	12	10.2	18	4.2
	891218	9	1.0	24	1.0
	900123	12	2.0	24	5.7
	900124	9	3.0	18	5.6
	900303	15	1.2	30	1.0
	910215	36	2.4	72	6.9
	910216	9	2.3	18	3.7
	910311	21	5.3	42	6.8
	910313	21	5.5	42	5.1
	910408	18	1.9	36	8.3
	910410	9	2.6	18	4.7
	910412	18	3.7	36	5.8
THHL (cm)	891217	12	6.6	18	12.3
	891218	9	8.7	24	12.7
	900123	12	8.6	24	8.3
	900124	9	5.6	18	11.4
	900303	15	4.8	30	7.2
	910215	36	2.8	72	10.2
	910216	9	3.1	18	12.5
	910311	21	5.7	42	13.7
	910313	21	5.0	42	8.0
	910408	18	4.1	36	9.2
	910410	9	5.1	18	4.9
	910412	18	4.8	36	10.9

Table B.1. (continued)

Variable	Date	N	Crater	N	Control
STH (cm)	891217	12	5.8	18	8.8
	891218	9	4.7	24	6.5
	900123	12	4.2	24	4.3
	900124	9	4.5	18	7.6
	900303	15	4.8	30	7.2
	910215	36	2.6	72	10.2
	910216	9	3.1	18	12.0
	910311	21	5.2	42	12.1
	910313	21	5.0	42	7.3
	910408	18	2.1	36	3.2
	910410	9	1.8	18	4.1
	910412	18	5.2	36	8.5
VSIL	891217	12	1.52	18	0.78
	891218	9	0.82	24	1.23
	900123	12	1.77	24	3.03
	900124	9	2.47	18	3.53
	900303	15	2.35	30	2.77
	910215	36	3.62	72	4.53
	910216	9	3.26	18	4.56
	910311	21	4.23	42	5.19
	910313	21	3.83	42	3.84
	910408	18	2.04	36	5.97
	910410	9	2.54	18	5.13
	910412	18	4.13	36	5.32

Appendix C.
Species composition of the four taiga and three tundra
plant communities.

Table C.1. Species compositions for the 7 outlined vegetative communities. Dashes indicate the absence of a species within sampled plots. All values represent % frequency summarized from 5000 sub-plots sampled within each of the 7 community types.

Plant Species	Frequency (%)						
	BR	BSP	HLT	ST	TF	TWS	WSF
<i>Alectoria nigricans</i>	1.4	--	0.3	--	--	--	--
<i>A. ochroleuca</i>	54.3	--	22.6	--	--	0.1	--
<i>Andromeda polifolia</i>	--	--	21.5	27.5	--	11.1	--
<i>Arctagrostis latifolia</i>	--	--	--	--	0.7	--	--
<i>Arctostaphylos</i> spp.	6.0	--	3.1	1.5	--	--	--
<i>Bartsia alpina</i>	--	--	--	2.6	--	2.2	--
<i>Betula glandulosa</i>	--	--	0.1	1.8	1.9	0.2	--
<i>Bryocaulon divergens</i>	19.7	--	21.3	--	--	--	--
<i>Bryoria nitidula</i>	3.0	--	7.0	--	--	--	--
<i>B. spp.</i>	--	--	--	--	--	--	0.6
<i>Calamagrostis stricta</i>	--	--	2.4	--	--	--	--
<i>C. neglecta</i>	--	--	3.2	--	--	--	--
<i>Carex aquatilis</i>	--	10.0	--	51.8	97.7	3.4	--
<i>C. atrofusca</i>	--	--	0.9	--	--	--	--
<i>C. capillaris</i>	--	--	--	0.9	--	0.2	--
<i>C. capitata</i>	--	--	--	2.0	--	0.1	--
<i>C. glacialis</i>	63.2	--	6.7	--	--	--	--
<i>C. gynocrates</i>	--	--	5.5	--	--	--	--
<i>C. limosa</i>	--	--	--	1.5	--	--	--
<i>C. microglochin</i>	--	--	0.1	--	--	--	--
<i>C. rariflora</i>	--	--	--	1.0	--	1.1	--
<i>C. rupestris</i>	--	--	17.5	--	--	--	--
<i>C. saxatilis</i>	--	--	--	0.1	--	--	--
<i>C. scirpoidea</i>	--	--	10.5	--	--	8.8	0.6
<i>C. vaginata</i>	3.9	--	22.0	--	--	36.7	--
<i>C. spp.</i>	3.1	--	1.5	2.4	3.8	--	--
<i>Castilleja raupii</i>	--	--	--	--	0.1	--	--
<i>Cetraria cucullata</i>	34.7	--	26.5	0.3	--	2.6	--
<i>C. islandica</i>	43.8	--	8.2	0.6	--	32.9	0.1
<i>C. nivalis</i>	71.1	0.3	36.6	0.2	--	11.8	0.6
<i>Cladina mitis</i>	6.7	7.9	32.1	--	--	13.0	21.8
<i>C. rangiferina</i>	0.1	25.7	44.5	--	--	36.0	23.4
<i>C. stellaris</i>	7.2	69.3	11.7	--	--	30.4	52.2
<i>Cladonia</i> spp.	12.0	3.3	1.0	--	--	2.5	7.8
<i>Dactylina arctica</i>	1.7	--	3.4	--	--	--	--
<i>Dryas integrifolia</i>	66.2	--	5.5	1.2	--	--	--
<i>Empetrum nigrum</i>	0.2	16.3	16.2	0.7	5.7	35.2	42.5
<i>Epilobium angustifolium</i>	--	--	--	--	--	--	0.1
<i>E. palustre</i>	--	--	--	--	6.2	--	--
<i>Equisetum</i> spp.	--	13.1	4.0	11.0	13.5	8.1	3.0
<i>Eriophorum</i> spp.	--	--	0.5	82.3	0.3	0.2	--
<i>Evernia mesomorpha</i>	--	0.1	--	--	--	--	--
<i>Fungi</i> spp.	0.3	0.1	--	--	0.1	0.1	0.2
<i>Gelatinus</i> lichen	--	0.1	2.4	0.3	--	--	--
<i>Geocaulon lividum</i>	--	--	--	--	--	--	1.2
<i>Habenaria hyperborea</i>	--	--	--	--	--	0.1	--
<i>H. obtusata</i>	--	--	--	--	--	0.1	--
<i>Hypogymnia physodes</i>	--	--	0.1	--	--	--	--
<i>Juncus balticus</i>	--	--	0.2	--	3.2	0.3	--
<i>Kalmia polifolia</i>	--	--	0.1	--	--	--	--

Table C.1. (continued)

Plant Species	Frequency (%)						
	BR	BSP	HLT	ST	TF	TWS	WSF
<i>Larix laricina</i>	--	0.2	--	--	0.3	1.0	--
<i>Ledum decumbens</i>	--	--	2.1	0.1	7.6	8.8	--
<i>L. groenlandicum</i>	--	25.6	--	--	--	0.5	--
Moss spp.	0.2	19.3	25.7	95.0	93.2	38.0	22.1
<i>Marchantia polymorpha</i>	--	--	--	--	0.3	--	--
<i>Orchis royundifolia</i>	--	--	--	--	--	0.5	--
<i>Oxycoccus microcarpus</i>	--	3.0	--	--	1.2	--	--
<i>Pedicularis</i> spp.	--	--	4.2	0.8	--	0.8	--
<i>Peltigera</i> spp.	0.1	1.8	--	--	--	2.2	13.1
<i>Picea glauca</i>	--	--	--	--	--	--	0.8
<i>P. mariana</i>	--	3.5	--	--	--	--	--
<i>Pinguicula vulgaris</i>	--	--	--	0.2	--	--	--
<i>Poa</i> spp.	--	--	0.2	--	--	--	--
<i>Polygonum viviparum</i>	--	--	2.2	1.8	--	0.7	--
<i>Primula stricta</i>	--	--	--	--	0.2	--	--
<i>Pyrola secunda</i>	--	--	--	--	--	0.6	--
<i>Parnassia palustris</i>	--	--	--	--	0.9	--	--
<i>Rhododendron lapponicum</i>	12.3	--	13.2	3.8	--	0.1	--
<i>Rubus chamaemorus</i>	--	2.1	--	--	--	10.3	--
<i>Salix arctophila</i>	--	--	4.9	21.6	--	--	--
<i>S. candida</i>	--	--	--	--	0.1	--	--
<i>S. lanata</i>	--	--	5.2	--	--	--	--
<i>S. myrtillifolia</i>	--	0.4	--	--	--	--	--
<i>S. planifolia</i>	--	--	--	--	--	--	0.1
<i>S. reticulata</i>	--	0.2	1.9	2.7	0.2	13.1	--
<i>S. spp.</i>	--	--	0.1	1.8	13.7	3.1	--
<i>Scirpus caespitosus</i>	--	--	20.4	30.5	--	11.2	--
<i>Shepherdia canadensis</i>	1.4	--	--	--	--	--	--
<i>Sphaerophorus globosus</i>	0.3	--	13.7	--	--	--	0.7
<i>Spiranthes romanzoffiana</i>	--	--	--	0.1	--	--	--
<i>Stereocaulon tomentosum</i>	--	--	0.4	--	--	--	0.1
<i>Thamnia subuliformis</i>	38.6	--	2.3	--	--	--	--
<i>Tofieldia pusilla</i>	0.4	--	2.6	0.5	--	0.9	--
<i>Triglochin maritimum</i>	--	--	--	--	5.0	--	--
Unidentified Forb	0.5	--	0.1	--	0.6	--	--
Unidentified Lichen	23.3	--	5.3	--	--	--	--
<i>Vaccinium uliginosum</i>	6.5	9.8	20.8	2.7	1.7	30.6	--
<i>V. vitis-idaea</i>	--	12.7	24.2	0.3	0.4	18.8	52.6
Water	--	--	0.8	--	11.6	--	--