THE ALPINE VEGETATION ECOLOGY AND REMOTE SENSING OF TERESA ISLAND, BRITISH COLUMBIA

by

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE STUDIES

Department of Botany

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

October, 1978

Department of Botany

The University of British Columbia
2075 Wesbrook Place
Vancouver, Canada
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Date 2 October 1978

ABSTRACT

The alpine zone, encompassing a considerable portion of the land surface of British Columbia, is one of our major natural resources providing extensive areas for recreation, mineral resources, and needed habitat for many wildlife species including caribou, grizzly bear, mountain goat and mountain sheep. Such an extensive and important natural resource warrants careful research to provide a solid base for proper management and planning decisions.

The aims of this study are: 1) To define and describe the vegetation units of an alpine area in northwestern British Columbia; 2) To relate these units to the major environmental factors acting in the alpine zone; 3) To further refine a currently used hierarchical classification suitable for the multi-scale cartographic representation of alpine and forest vegetation; 4) To show the value of remotely sensed data for multi-scale vegetation mapping; and 5) To produce multi-scale maps of the alpine study area, suitable for the requirements of today's land planners and managers. The alpine zone of Teresa Island, within Atlin Provincial Park, was chosen as the study area for its accessibility and representativeness.

One hundred fifty-one sites, selected on the basis of species homogeneity, uniform appearance and uniform ecological conditions, were sampled during the summers of 1974, 1975 and 1976. On the basis of dominant species, physiognomic similarity and similar environmental conditions, sixteen community types are described: 1) Umbilicaria blockfield; 2) Cetraria nivalis - Vaccinium uliginosum fellfield; 3) Cetraria nivalis - Carex microchaeta fellfield; 4) Carex microchaeta meadow; 5) Festuca altaica - Potentilla diversifolia rich meadow; 6) Festuca altaica - Cladina dry meadow; 7) Betula glandulosa - Cetraria cucullata shrubfield; 8) Cassiope tetragona -

Cladina mitis heath; 9) *Cassiope stelleriana* - *Phyllodoce empetriformis* snowbed; 10) *Sibbaldia procumbens* - *Polytrichum piliferum* snowbed; 11) *Anthelia juratzkana* - *Luzula arcuata* snowbed; 12) *Carex pyrenaica* - *Luetkea pectinata* - *Juncus drummondii* snowbed; 13) *Salix planifolia* - *Empetrum nigrum* - *Sphagnum* runoff; 14) *Calamagrostis canadensis* - *Plagiomnium rostratum* runoff; 15) *Aulacomnium palustre* - *Salix polaris* - *Claytonia sarmentosa* - *Carex microchaeta* runoff; and 16) *Ranunculus* - *Carex podocarpa* - *Saxifraga nelsoniana* - moss runoff.

Observations and the results of four transects indicate that the local distribution of these communities is primarily controlled by topography, snow duration and moisture. Four habitat types are recognized as a result of major combinations of these factors. These are: 1) Fellfields and blockfields, which occur on the most exposed areas of the mountain where snow is blown off during the winter, and the vegetation is exposed to severe winds and temperatures and xeric conditions year-round; 2) Snowbeds, which protect vegetation from extreme winter temperatures but, at the same time, restrict species occurrence by reducing the length of the growing season; 3) Runoff sites, which include spring-lines, stream edges, pond margins, bog-like areas and other water-saturated sites; and 4) Meadows and shrub-fields which encompass the mesic areas of the mountain where drainage is good and snow cover moderate. The sixteen community types are distributed within the four habitat types and reflect the environmental variation within each.

The communities, all of which appear to be in equilibrium with their environment, are compared with other alpine communities described from British Columbia, southern Yukon and southeastern Alaska.

Remote sensing is a valuable tool for the cartographic representation of plant communities. An ecologically based hierarchical classification

and legend system, designed to be used with remote sensing data, was expanded to incorporate the alpine communities of Teresa Island. Using satellite imagery, black-and-white, color, and color-infrared photographs, the alpine zone of Teresa Island was mapped at four scales: 1:180,000; 1:80,000; 1:29,000; and large-scale (greater than 1:20,000). The hierarchical ecological classification system was shown to be effective at all scales, and to incorporate all features visible on the image. The hierarchical nature of the system allows maps to be as general or as detailed as information and scale allow without changing the logic of the classification.

Color-infrared transparencies are superior to conventional black-and-white and color photos for distinguishing vegetation types. The range of magenta tones associated with foliage is greater than the normally dark shades of green, therefore, changes in the vegetation are more easily detected. Conifers can readily be distinguished from hardwoods. Infrared film is capable of detecting isolated patches of vegetation that tend to blend into the background in black-and-white and color films.

Small-scale satellite imagery is valuable for generalized mapping of large areas, and is able to detect the biogeoclimatic zones occurring in northwestern British Columbia.

It is concluded that the description, classification and mapping of alpine vegetation in British Columbia is feasible and should be carried out as a prerequisite for any land management program so that we may obtain the maximum and lasting benefit of our alpine resources.

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ACKNOWLEDGEMENTS

The author expresses sincere thanks to thesis committee members Dr. Roy L. Taylor, Director of The Botanical Garden, The University of British Columbia, for his support and assistance throughout the study; Dr. Robert C. Brooke, Department of Biology, Simon Fraser University, for his assistance and advice; Dr. Peter A. Murtha, Faculty of Forestry and Department of Soil Science, The University of British Columbia, for his assistance and advice on remote sensing; Dr. Wilfred B. Schofield, Department of Botany, The University of British Columbia, for his advice and help with bryophyte identification; and Dr. Glenn E. Rouse, Department of Botany, The University of British Columbia, for his constant encouragement throughout the study.

Special thanks go to Mr. Allen Banner, Mr. David Galloway and Ms. Corinne Selby, for their assistance and companionship in the field; Dr. Maynard M. Miller and The Foundation for Glacier and Environmental Research, for logistic support; and Mr. Edward K. Watson, for his valuable assistance with the I^2S Color Additive Viewer. Finally, I wish to thank my wife, Susan, for her patience and help during the production of this thesis.

This work was supported by The Botanical Garden of The University of British Columbia and by the following grants made to Dr. Roy L. Taylor: NRCC operating grant No. A5705; NRCC special grant No. 0008, Flora of British Columbia Program; Univ. British Columbia Committee on Arctic and Alpine Research No. 65-0439; and Univ. British Columbia Committee on Research grant-in-aid No. 21-9616.

This thesis is dedicated to

the memory of my father

Rodney Colby Buttrick

A. INTRODUCTION

A.1 General Introduction

The alpine zone encompasses a considerable portion of the land surface of British Columbia. According to Krajina (1973), the alpine zone seems to cover over one-half of the land area of northwestern B. C.

As a natural resource the alpine areas are invaluable as wildlife habitat, and much of the research on alpine areas has revolved around large mammals such as caribou, mountain goat, mountain sheep and grizzly bear. Hunter and guide outfitting and fur trapping are the most common and traditional resource activities.

> "However, regardless of the vastness of the area involved, the sensitivity of the terrain and its inherent low productivity of food and cover impose constraints on animal populations not encountered in southern regions and thus demand careful management" (Young and Alley, in press).

Recreation is another major resource activity. Recently, wilderness areas have seen an increasing number of visitors. Backpacking is rapidly becoming a major pastime. Many of the alpine areas are rich in minerals, particularly gold, and have already experienced disturbance from mining.

Such an extensive area and important natural resource warrants careful research to provide a solid base for proper management and planning decisions. The results of poor planning and lack of ecological information can be very damaging. Hikers in the Black Tusk Meadows in Garibaldi Provincial Park can see such results, and revegetation efforts are currently underway to restore the natural vegetation. Willard and Marr (1970) discuss the adverse effects of human activities in the Rocky Mountains of Colorado and the time involved in natural recovery of these areas (1971). Their study indicates that some severely disturbed sites would require from 100 to 1000 years for full recovery. Hartley (1973) studied the effects of man on alpine vegetation in Glacier National Park, Montana.

A study of the vegetation of an area is a necessary prerequisite for knowledgeable land use planning and management. With the construction of an ecologically based vegetation classification, systematic inventories can be conducted. Vegetation units important for wildlife habitats can be identified and mapped, and questions concerning carrying capacity and population control answered more readily. Unique vegetation and vegetation units especially sensitive to human impact can be identified, aiding in trail and wilderness camp planning. The classification of vegetation also forms a base for further research projects in many disciplines. Mapping of the units is, or should be, a major result of the vegetation classification for from this,the user can readily locate units in the field and become personally familiar with the vegetation. Vegetation cartography has been facilitated recently by remote sensing techniques and the increasing availability of products other than the conventional black-and-white photographs.

The aims of the present study are: (1) To define and describe the vegetation units of an alpine area on Teresa Island in northwestern British Columbia; (2) to relate these units to the major environmental factors acting in the alpine zone; (3) to further refine a currently used hierarchical classification suitable for the multi-scale cartographic representation of alpine and forest vegetation; (4) to show the value of remotely sensed data for multi-scale vegetation mapping; and (5) to produce multi-scale maps of the alpine study area suitable for the requirements of land planners and managers.

The study area, Teresa Island, is located in the southern end of Atlin Lake in northwestern British Columbia at approximately 59° 25' N latitude and 133° 45' W longitude (Figure 1). Birch Mountain (elevation

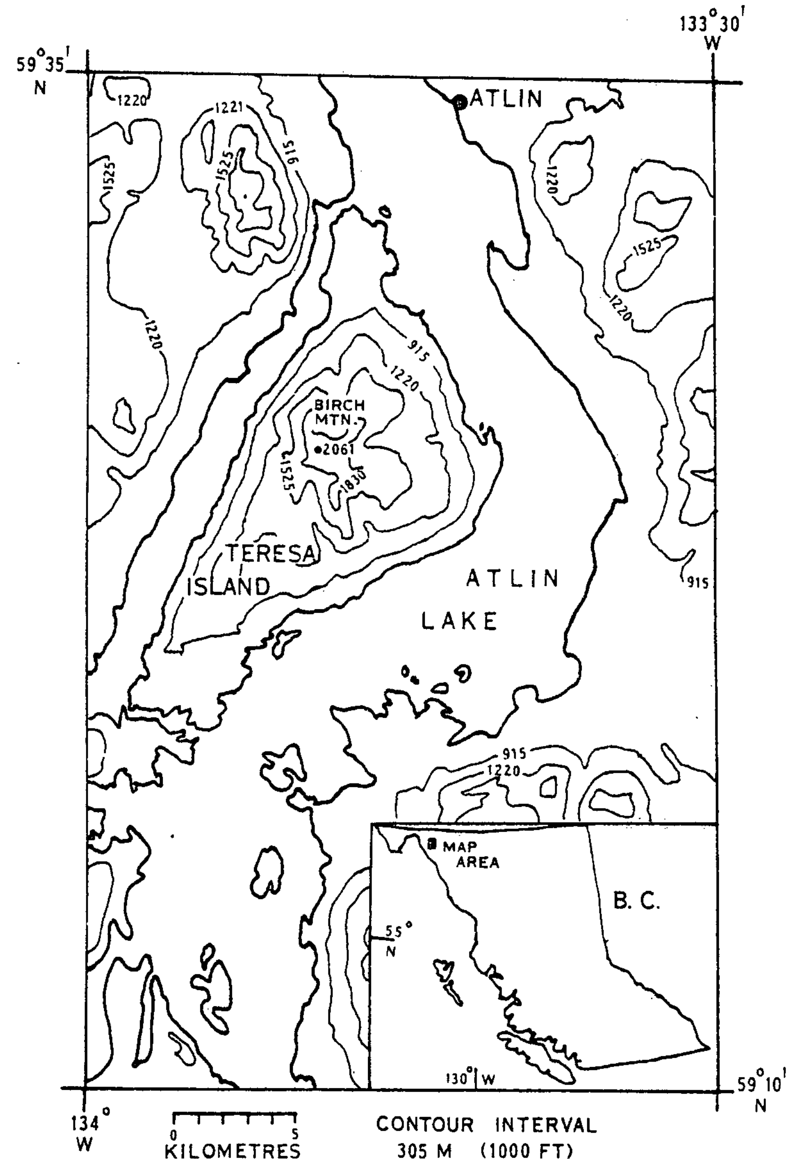

Figure 1: Location and map of study area in northwestern British Columbia. Work was restricted to elevations above 1500 m on Teresa Island.

2061 m) has an extensive alpine zone occupying over 51 km^2 of this 25-km-long, 11-km-wide island. All work was restricted to the alpine zone which is defined here as the area above the elevational limit of trees.

Teresa Island was chosen as the study area for a number of reasons. Accessibility is an important consideration. The town of Atlin is easily reached by road from the Alaska Highway and Teresa Island can then be reached by boat or helicopter. Logistics were handled primarily through the Foundation for Glacier and Environmental Research based in Atlin. By having the mountain isolated on an island, the study area was well defined. Teresa Island is included in the large, recently established Atlin Provincial Park; hence, the study could well provide base and detailed information that can be extrapolated easily to other alpine areas within the park, and used by the B. C. Parks Branch as a base for park planning and management policies.

A.2 Physiography and Geology

Teresa Island and the entire south end of Atlin Lake lie within the Tagish Highland physiographic unit of Holland (1964). The following description of the Tagish Highland is taken primarily from Holland's publication. The Tagish Highland and the Taktlan Highland to the south form a mountainous belt transitional between the 1524 m upland surfaces of the Yukon and Stikine Plateaus to the east and high granitic Alaska-Canada Boundary Range to the west. In the Tagish Highland, the Tertiary erosion surface, which makes up the upland plateaus, has been warped upward to the west. Dissection of this surface has resulted in relatively smooth, gently rolling upland surfaces lying,in general, at elevations between 1524 and 2134 meters. Rivers and glaciers have incised the area to an elevation of about 671 m. The elevation of Atlin Lake, part of the

Yukon River drainage system, is 644 m. Valleys within the Tagish Highland are U-shaped and often occupied by lakes. Relief ranges from about 1067 m to 1524 m.

The Tagish Highland is underlain largely by folded and faulted sedimentary and volcanic rocks of Palaeozoic and Mesozoic age (Holland, 1964). The geology of the Atlin area has been described in detail by Aitken (1959). Most of the southern end of Teresa Island, including the steep south slopes of Birch Mt., is composed of sedimentary rocks of the Jurassic Laberge Group. Volcanic greywackes are dominant in this group, with lesser amounts of siltstone, mudstone, shale, conglomerate, and sandy limestone. The more gentle and extensive northern slopes of Birch Mt. are composed of quartz monzonite, possibly Tertiary in origin (Aitken, 1959). The shore of the island consists of recent glacial drift and alluvium, containing pockets of peridotite and rocks of the Carboniferous-Permian Cache Creek Group, including chert, argillite, greenstone, volcanic greywacke and limestone.

A.3 Glacial History and Geomorphology

Topography has been modified primarily by the continental and alpine glaciations of the area. Many of the physical features described in this section, and place names used throughout this thesis, are shown in Figure 2, a 1:80,000 scale map of Birch Mt. and much of Teresa Island made from an aerial photograph, cf. Figure 74. According to Anderson (1970), most of the glacial action responsible for creating the existing landforms in the Atlin area took place during the Wisconsin and early Holocene. The glacial history during this interval for the Boundary Range - Atlin region has been described by Miller and Anderson (1974a, b), who attribute climatic fluctuations and resultant glacial movements to shifts in the position of storm tracks of the Arctic Front back and forth across the Canada-Alaska Boundary

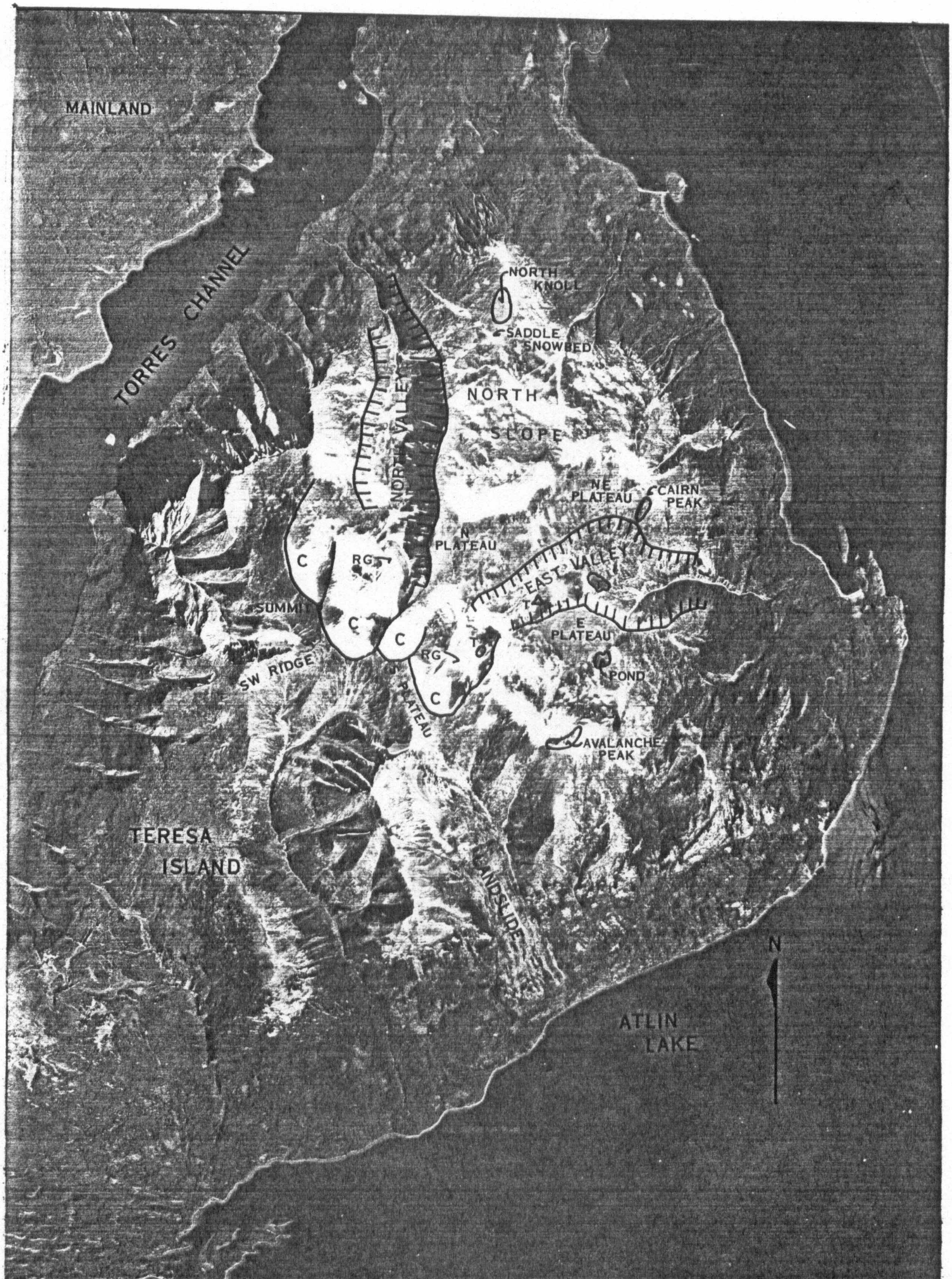

Figure 2: Teresa Island showing physical features and place names used in this study. Scale is 1:80,000. C = cirque; T = tarn; RG = rock glacier.

Range. The Arctic Front is the "line of demarcation between the high pressure anti-cyclonic continental weather conditions and the low pressure cyclonic maritime conditions on the coast" (Miller and Anderson, 1974a). When the storm paths are more continental, i.e., to the east of the Boundary Range, freezing levels in the Atlin valley are lower, storms and precipitation decrease, and low névé glaciers advance. If the storm paths are centered to the west of the Boundary Range, freezing levels in the Atlin area are higher, storm and precipitation increase, and low névé glaciers recede. At the present time this latter situation exists. A full discussion of the glacial history of the area can be found in Miller and Anderson (1974b). A summary diagram of the late Wisconsin - Holocene glaciobotanical chronology in the Atlin area is given in Figure 3.

The Atlin lake channel was probably formed during Time Interval IX (Figure 3) or a little earlier (Miller, 1964). Also at this time, the Atlin valley glacier established its outermost moraine complex at the northern end of what is now Little Atlin Lake in the Yukon Territory. Since the end of Time Interval IX (10,500 B.P.), there has been a general downwastage and retreat of the Atlin valley glacier with occasional readvances. The Atlin valley glacier is now solely represented by the Wilson and large Llewellyn glaciers, originating in the Boundary Range, with their termini at the south end of Atlin Lake.

Aitken (1959) believes that no peak within the Atlin area escaped glaciation during the maximum late Wisconsin Glaciation set at about 18,000 years ago (Flint, 1971). Holland (1964) states that the maximum elevation of ice in the Tagish Highlands during the Wisconsin glaciation was probably 1829 to 1981 m. It is very probable, however, that the summit of Birch Mt. (el. 2016 m) was above the glacial ice at Time Interval IX and has remained above since. Whether overriden or not, the higher elevations of the mountain

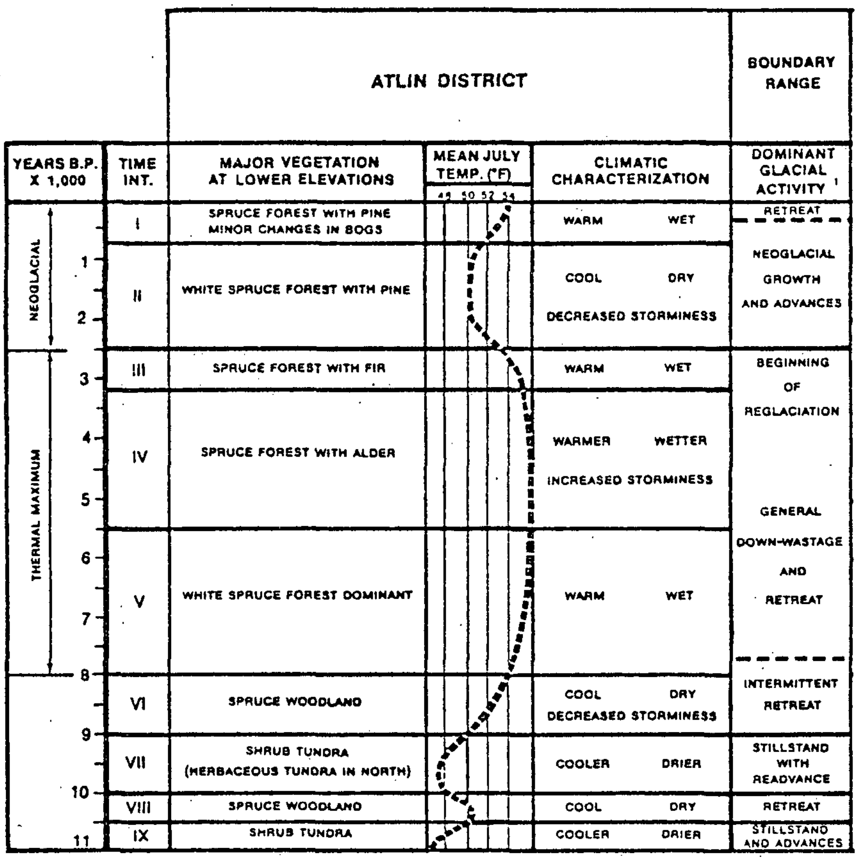

Figure 3: Summary diagram of the late Wisconsin and Holocene glacio-botanical chronology in the Atlin District. (From Miller and Anderson, 1974b)

could probably not have supported vascular vegetation due to severe frost shattering at this elevation.

Alpine glaciers occurred on Birch Mountain and many other peaks in the area. These alpine glaciers developed in old pre- or early-Wisconsin cirques (Anderson, 1970; Holland, 1969) and probably reached their maximum extent during Time Intervals VI and VII (Figure 3). Alpine glaciers probably disappeared entirely during the Thermal Maximum, but with the advent of cooler and wetter conditions in Time Interval II of the Neoglacial, perennial snow patches and small glacierets redeveloped (Anderson, 1970).

Alpine glacial activity on Teresa Island was restricted to the north and east sides of the mountain. Most peaks in the area have cirques only on their northern or eastern sides (Holland, 1964). This pattern can be accounted for by the prevailing south-southwesterly winds which deposit much of the winter snow on the northern and eastern lee slopes. The effect of this is compounded by the lower incidence of solar radiation on the northern slopes. The alpine glaciers are no longer present, but large permanent snowbeds occupy the old cirques and form extensive bands across the north slope (Figure 2).

Approximately four cirques occupy the north and northeast slopes of Birch Mountain. Two of these occur above 1829 m with their upper edges reaching 1940 m. The other two occur between 1676 m and 1829 m. The glacier flow from these cirques formed two hanging glacial troughs or valleys, characterized by steep walls, relatively straight courses and by the same U-shape of their transverse profiles. The lips of these hanging valleys are at 1372 m. A runoff stream flows down each valley and drops rapidly from the lip to the lake through a V-shaped notch. The larger of the two valleys runs directly north and empties into Torres Channel. The smaller valley runs ENE, emptying into the main body of the lake. This valley holds three ponds or tarns; one at the base of the lowest cirque (ca. 1676 m), one at the valley lip (ca. 1372 m), and one between the others (Figure 2).

Two abandoned cirques, one at the head of each valley, have given rise to tongues of blocks which have been interpreted as possible rock glaciers by Dr. W. H. Mathews (personal communication*). Morainal material is difficult to identify or interpret and should be studied more fully by a geomorphologist. Most of the glacial valley floors are covered with rock rubble. Rubble near the valley walls is not lichen-covered and thus is interpreted as fresh. This material can probably be considered talus. Other rubble within the valley is lichen-covered which indicates stability. Interspersed among the rocks are areas relatively free of lichens, indicating long snow duration. This surficial material within the valleys could be morainal or may be the result of collapsed rock glaciers (Dr. W. H. Mathews, personal communication). No classical moraine complexes were observed on the island. The present topography of Teresa Island, and especially Birch Mt., is related to the bedrock pattern. The resistant quartz monzonite erodes slowly, resulting in an extensive, gently sloping north slope system. The quartz monzonite slowly weathers to sand deposits which occur at the base of large permanent snowbeds where nivation tends to increase the rock erosion.

On the southern side of the mountain, the sedimentary rocks of the Laberge Group are more readily eroded. This erosion may be responsible for the steep, 30^{o} slopes and steep V-shaped valleys leading south and west (W. H. Mathews, personal communication). These valleys do not originate as cirques and are formed by water erosion. The sedimentary rocks of the Laberge Group erode quickly to large angular blocks which form talus piles along the walls of the southern valleys. The less stable condition of this

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bedrock is also illustrated by a massive landslide which almost reaches the shore of the island (Figure 2). Because of the nature of the bedrock and the steepness of terrain, the south side of the mountain is much less accessible than the northern slopes.

A.4 Periglacial Features

The frost action in a periglacial environment has also been instrumental in shaping the alpine area of Teresa Island. "Periglacial" has long been a confusing term (Washburn, 1973). Originally, it was used to describe the climate and climatically controlled features adjacent to the Pleistocene ice sheets (Lozinski, 1909), but a more accepted definition today is "the environment of cold regions in which frost action is important; the features resulting from frost action" (Brown and Kupsch, 1974). Frost action is an active process on the high elevations of the island at the present time, but there is evidence of a period of much greater frost action and thus, of a more severe periglacial environment in the past.

All of the peaks on Birch Mt. and most of the ridges above 1676 m exhibit frost wedging. This process, also called frost shattering, frost splitting and congelifraction, is the prying apart of materials, usually rock, by the freezing and expansion of water (Washburn, 1973). Frost wedging played a major role in the sculpturing of the mountain, and bedrock is only occasionally visible. Wedging contributes to the differential erosion of the north and south sides of the mountain, probably because sedimentary rocks, such as those of the Laberge Group, are much more susceptible to wedging than igneous rocks (Washburn, 1973).

Active frost wedging probably occurred during the late Wisconsin and early Holocene, and may have become more active again during Holocene Time Interval II. At present, however, the heavy blanket of lichens such as

Umbilicaria, Alectoria and Cornicularia on the frost riven rocks of the peaks and high ridges suggest current stable conditions with a much decreased incidence of shattering.

Extensive frost activity depends on an abundance of short-term freeze-thaw cycles, especially in the spring when melting snow provides the necessary moisture. Climatic data for the island are unavailable except for July and August, so the number of freeze-thaw cycles is not known. It is important to remember, however, that freeze-thaw temperature fluctuations of the air do not necessarily represent freeze-thaw cycles within rock (Washburn, 1973).

Washburn (1973) believes that frost wedging occurs in response to an annual freeze-thaw cycle as well as to short-term cycles. Accumulations of rock on the snow at the bases of steep, north-facing cliffs and cirques where the snow is permanent or lies long into the summer, indicates that some active frost wedging probably does occur. It is also likely that talus slopes at the bottom of the glacial troughs and south valleys are partially derived through frost shattering, although talus formation is by no means a strictly periglacial phenomenon.

Relict and active patterned ground features occur in the alpine and high subalpine areas of Teresa Island. Brown and Kupsch (1974) describe patterned ground as "a general term for any ground surface of surficial soil materials exhibiting a discernible, more or less ordered and symmetrical, micro-physiographic pattern." Detailed discussions of these features, their classification and possible origins are given by Davies (1969), Price (1972a) and Washburn (1956, 1973). The following is a short description of the patterned ground features occurring in the alpine areas of Teresa Island.

The most extensive and active periglacial process on the mountain is solifluction, "the process of slow, gravitational, downslope movement of saturated, non-frozen earth material behaving apparently as a viscous mass over a surface of frozen material" (Brown and Kupsch, 1974). Actually, a "surface of frozen material" is not necessary. Shallow bedrock or other subsurfaces that impede the downward flow of water, can produce the same results (Davies, 1969; Washburn, 1973). The primary prerequisite for solifluction is a constant supply of water throughout the summer (Washburn, 1973). This prerequisite is met on the gentle north slope of Birch Mt. where runoff from a permanent snowbed keeps downslope subsurfaces saturated throughout the summer season. Solifluction benches result from the differential horizontal flow of the surface material. These benches are step-like features with almost horizontal tops (1^{o}-2^{o}), and at times, nearly vertical fronts which can be over two meters high. Differential vertical flow results in the organic surface being overrun by the advancing bench front. Active solifluction also occurs to a lesser extent on the southern side of the East Plateau. Here the ground remains saturated by runoff from the southern ridges. Solifluction benches that appear to be inactive occur on the central and northern parts of the East Plateau. Here snowmelt is rapid, and the only added moisture is precipitation. Large snowbeds commonly form at the base of bench fronts. Well developed solifluction lobes occur at elevations as low as 1372 m on the north slope of the mountain. As is shown later, solifluction terrain is important in the distribution of vegetation on these slopes.

Other patterned ground features common in periglacial environments, and found in the alpine areas of Teresa Island, include stone nets, sorted and nonsorted circles, and rock stripes. These features are all produced by frost action but the exact method is difficult to ascertain. Washburn (1956) considers frost action a complex of processes and feels that the origin of frost features is polygenetic.

Stone nets are patterned ground intermediate in outline between polygons and circles, and characterized by rims of coarse-grained, rocky material and centers of fine-grained soils. Most of the stone nets on the mountain are relicts of a more severe climate of the past. Their earlier origin is evidenced by the complete covering of lichens on the rock rims, and usually a dense cover of vascular plants and the lichen, Cetraria nivalis, in the centers. These nets occur on horizontal, raised, well-drained sites. What appear to be active stone nets or polygons occur beneath the surface of the East Plateau Pond. These are visible in Figure 72 with the aid of a 10X hand lens.

On some of the dry, well-drained slopes, the stone nets are elongated to form relict stone stripes, oriented downslope. These are also well covered with lichens. Both the stone nets and the stripes just described are characteristic of fellfields usually over 1676 m in elevation.

Rock stripes also occur beneath some snowbeds where the snow remains until early or mid-July. These stripes consist of narrow (ca. 1 m) stripes of rocks oriented downslope which often disappear upslope into the snowbed. The stone stripes are triangular in cross section with large 10-to-12 cm diameter rocks above, tapering below to small pebbles. They probably originated by frost action but since they occur only at the base of snowbeds, they might be maintained by runoff. Water can usually be heard running through the stripes. Between the stripes are soil patches of varying width. Due to the long snow duration, these soil stripes are poorly vegetated.

Circles, both sorted and nonsorted, are common and active at the present time. A nonsorted circle is a barren circular area of fine material with a border of vegetation. A sorted circle is usually a barren area of fine material with a border of stones. However, the few sorted circles encountered on the mountain had a central core of stones surrounded by a ring of fine, sandy material bordered by vegetation. The barren centers of these circles are actively maintained by seasonal frost-heaving which prevents plant establishment (Johnson and Billings, 1962; Price, 1972a). Inactive circles are identified by the amount of vegetation in the centers, and by lichen-covered stones in the case of sorted circles (Washburn, 1973). These circles have developed on horizontal surfaces. Where the surface is slightly sloping, solifluction within the circles occurs resulting in a step formation. This phenomenon has been well documented (Bryant and Scheinberg, 1970; Johnson and Billings, 1962; Washburn, 1973). Circles have developed primarily on flat surfaces of lee slopes, such as the tops of solifluction benches, where moisture is available from snowbeds above. Often in late June, the circles will be covered by a film of water. The water-holding capacity must be high for even in early August the barren centers of the circles will be moist.

Activity of these circles due to frost action requires a supply of moisture and subsurface freeze-thaw cycles. From July 10 to August 17, 1974, continual temperature measurements were taken at a depth of 5 cm in two nonsorted circles at ca. 1698 m elevation with a Tempscribe temperature recording device. Results showed a total of 12 freeze-thaw cycles at each circle during the 38 days of investigation. This, combined with the fact that most of them are devoid of rooted vegetation, indicates active frost action. Activity is probably at its maximum during May and June when freeze-thaw cycles are more common and there is a ready supply of moisture from melting snow.

Some nonsorted circles occur at lower elevations (1524 m - 1615 m) in fellfields and dwarf birch and willow dominated areas. Because of the exposed position of the fellfields, there is very little snow to provide the moisture for the frost heaving. However, a lack of snow with its insulating effects could result in greater freezing fluctuations in the spring. Most extensive development occurs in the shrub dominated sites on west and northwest facing slopes (cf. Figure 68). On sloping surfaces, these circles elongate to form steps as described in Washburn (1973). These frost features can be found in all stages of revegetation, and thus appear to form cyclically. Where they occur snow cover is continuous but probably thin. It is possible that in winters of low snowfall, high spots are exposed and then eroded by the blowing snow. The bare soil thus exposed would be very susceptible to frost action. Bare circles are often colonized first by Sedum rosea, whose root system seems best able to withstand the constant strains associated with frost heaving. Salix polaris, Trisetum spicatum and Hierochloe alpina are also early colonizers. As the soil becomes stabilized by these plants, Festuca altaica invades the circles and eventually forms a thick turf allowing the reestablishment of Betula glandulosa and Salix planifolia.

On the steep, boulder-covered slopes of the high south ridge and peaks, there are debris islands. According to Washburn (1973), debris islands are "sorted circles amid blocks or boulders." They are commonly on slopes as steep as 30°. "Such slope forms tend to have central areas that are considerably less steep than the general gradient but can be as high as 25°" (Washburn, 1973). Most debris islands on Birch Mt. are inactive.

A general statement can be made that frost features on ridges and summits of Birch Mt. are currently inactive while features occurring on lee slopes are active. A similar situation was encountered by Johnson and Billings (1963) on the Beartooth Plateau. This is probably because of the lack of an adequate supply of moisture on the ridges and summits, and a consistently colder temperature with fewer subsurface freeze-thaw fluctuations.

A.5 Soils

There are five factors which influence the development of soil: (1) parent material; (2) climate; (3) living organisms; (4) topography; and (5) time (Jenny, 1951). The action of these factors on soil development in alpine areas of western United States has been discussed by Retzer (1965, 1974), who makes a number of generalizations concerning the characteristics of alpine soils and the processes of soil development in alpine areas. The parent materials common in alpine areas are low in basic compounds and produce very acidic soils. Chemical weathering of the parent material is low primarily because of the low temperatures at these high elevations, and the frequently low precipitation. For the most part, alpine soils have low inherent fertility. They are medium-to-coarse textured with large amounts of stone, cobble and gravel. The coarse soils and steep topography result in excessive drainage. There tends to be a slow net accumulation of organic matter in the topsoil. This is probably a result of the low temperatures and short period of soil thaw, resulting in low microbial activity (Floate, 1965).

The organic matter input of the vegetation, especially from the characteristically extensive root systems, results in a thick turf layer in many alpine soils that is important in the control of erosion (Nimlos and McConnell, 1962; Retzer, 1956). The soils of alpine areas in western North America are immature. In fact, many soils have not yet reached a stable equilibrium position (K. W. G. Valentine, personal communication*).

The major factor preventing the development of mature soil profiles is frost action such as the mixing of horizons and profiles by cryoturbation and solifluction, and the shattering of particles by frost. In the

*Canada Department of Agriculture, Vancouver, B. C., Canada.

alpine environment, these physical processes appear to overshadow the chemical and biological processes which are slowed down due to the low temperatures (K. W. G. Valentine, personal communication). Solifluction often results in buried A horizons and with cryoturbation also causes mixing of the A horizon with the parent material to form an AC horizon (Young and Alley, in press).

Very few soil studies have been carried out in the alpine areas of British Columbia, and practically no published information is available for the extensive alpine areas of northern B. C. (K. W. G. Valentine, personal communication). Alpine soils described in B. C. are usually regosols, brunisols, gleysols and occasional podzols* (Lord and Green, 1974; Lord and Luckhurst, 1974; Sneddon et al., 1972a + b; Valentine, personal communication; van Ryswyk, 1969; Young and Alley, in press). Podzols are most common in the subalpine and in alpine areas with accumulated volcanic ash (K. W. G. Valentine, personal communication). Valentine considers the general pattern of alpine soils in northern B. C. to consist of various forms of brunisols in the mid- and low-alpine areas, and turbic and cryic regosols in the high alpine tundra zone where low temperatures, slow chemical weathering, and frost action disrupt the soil. Young and Alley (in press) describe alpine soils in northern B. C. as primarily regosols and brunisols. Regosols are at high elevations where cryoturbation is active. "Regosols with disrupted horizons are the most common soils resulting from this strong periglacial activity" (Young and Alley, in press). Regosols also commonly occur in snowbeds and nivation hollows with a poor vegetation cover. Melanic, eutric and dystric brunisols are common in the meadows and solifluction slopes.

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*Soil nomenclature follows The System of Soil Classification for Canada, Publication 1455, Canada Department of Agriculture, 1974.

A survey of the alpine soils of Teresa Island was not attempted as part of the present study. A few soil pits were excavated in typical alpine habitats such as snowbeds, meadows and fellfields, and were visually described in the field. From these soil pits, a few generalizations can be made, but for better understanding of the ecology in this alpine area and for better management, a detailed survey should be conducted to supplement this vegetation study.

The distribution of soils on Birch Mt. seems to follow closely that described by Young and Alley (in press) above. Very little soil development occurs in the areas blown free of snow during the winter. Organic matter production is low in these sites and litter is frequently blown away. This, combined with the severe temperatures and frost action, results in coarse, well-drained regosols with A and C horizons or no noticeable horizons at all. Regosols blanket the knolls, peaks and ridges of Birch Mt. but are not restricted to these areas. In snowbeds where vegetation is poorly developed similar soils occur. In the meadows and on vegetated solifluction terrain, B horizons are fairly distinct and soils are probably brunisols. pH readings in these soils average about 5.0. The geological description of the area by Aitken (1959) indicates the possible occurrence of small pockets of more basic parent materials, and the scattered occurrence of species such as <u>Cetraria telisii</u>, <u>Dryas integrifolia</u>, <u>Saxifraga oppositifolia</u> and <u>S. cespitosa</u> on the south side of the mountain seems to indicate more basic soils. It is quite possible that soils developing on these rocks were not sampled for the highest pH reading was 5.6. In poorly drained areas, gleying frequently occurs resulting in gleyed brunisols or gleysols. Water tables as close to the surface as 30 cm were detected in August. The peaty topsoil with its insulative properties, and the perched water table, indicate the probable presence of permafrost. Permafrost also might be present under the later melting snowbeds.

A.6 Climate

Atlin lies in the Southwest Climatic Division of Kendrew and Kerr (1955), making it climatically similar to Teslin, Carcross and Whitehorse in the Yukon Territory. Lying in the rain shadow of the Northern Boundary Range, the Atlin area receives between 280 and 300 mm of precipitation per year and can be considered semiarid. Coastal mountains on the western side of the Boundary Range receive precipitation in excess of 2540 mm per year. At the southern end of Atlin Lake where Teresa Island is located, maritime influences from the southwest result in a moderation of the temperature extremes common in the Yukon and the interior of Northern British Columbia. Department of Transport records show that in Atlin, June is the warmest month of the year with an average temperature of 10°C and January, the coldest, averaging -17°C. Mean annual temperature is 0°C. According to the Thornthwaite system, the climate of the Atlin valley is $C_1C'_1db'_1$, a cold, microthermal, subhumid climate with little or no water surplus (Sanderson, 1948). In terms of moisture, the Atlin valley can also be compared with the Mackenzie Valley and Canadian prairies (Anderson, 1970). The tundra areas are somewhat more humid with seasonal distributions of precipitation and temperature parallel to those of the valley (Anderson, 1970). Throughout the year, wind comes primarily from the south and southeast (Anderson, 1970).

Microclimatic data were collected from Birch Mountain, Teresa Island, during July and August, 1974, 1975 and 1976. Four weather stations were established during this time period. Weather station #1 was located at 1280 m on a northeast-facing slope below Camp #1 in the subalpine zone where the vegetation is dominated by *Abies lasiocarpa* krummholz. Station #2 was located in the alpine zone at 1540 m at Camp #1 on the north slope. Station #3 was at approximately 1829 m on the north slope. Weather station #4 was situated at Camp #2 on the East Plateau at 1540 m. Locations of weather stations and camps are shown in Figure 4. At each station, a Stevenson shelter enclosing a Fuess hygrothermograph and Taylor Sixe maximum-minimum thermometer was placed directly on the ground. Precipitation data were collected with simple collecting-type Canadian pattern rain gauges (diameter 8.4 cm. cross-sectional area 65 cm^2).

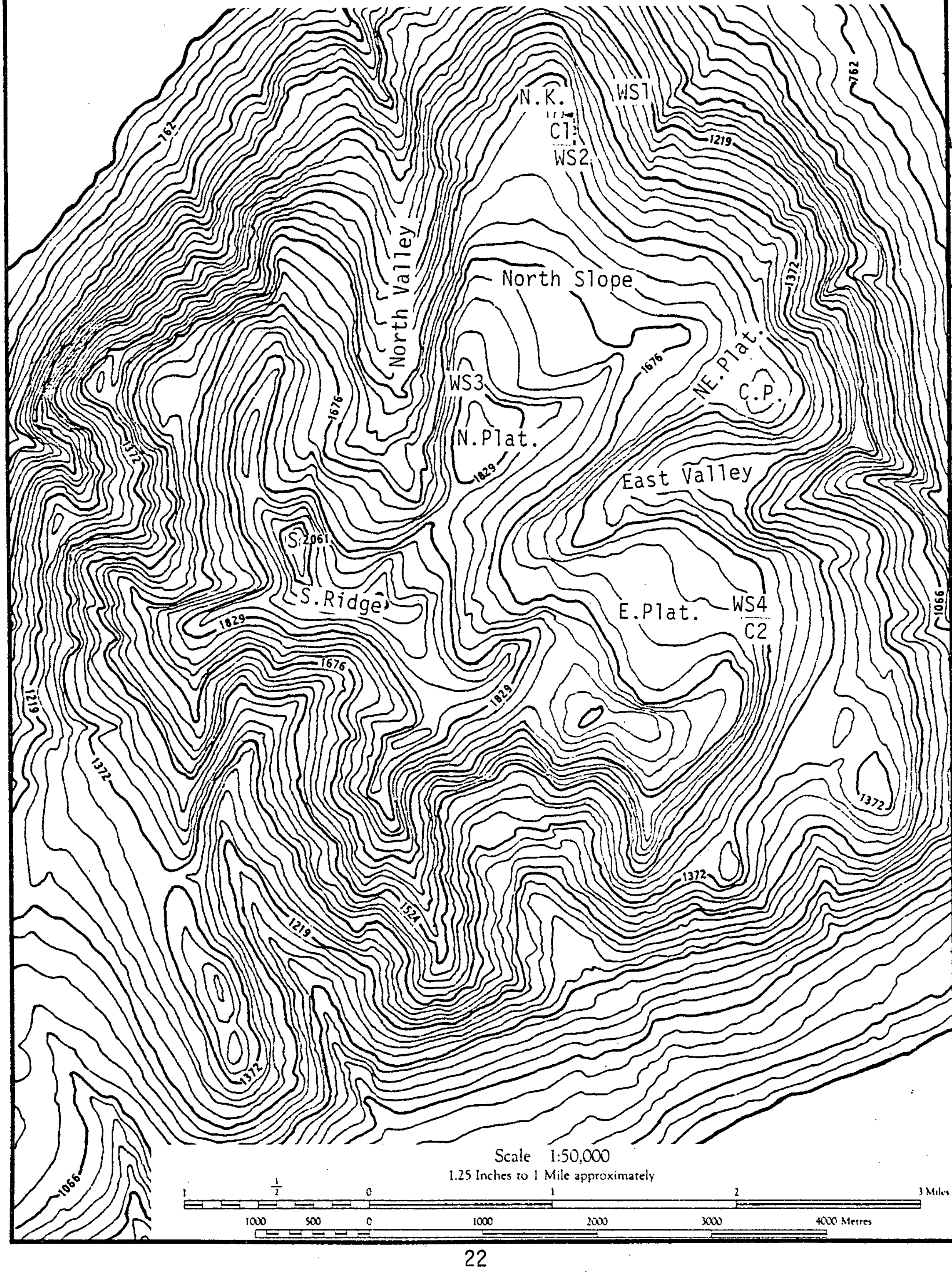
Microclimate varies greatly in areas of such strong relief. The data collected from these weather stations only serve to show the general alpine precipitation and temperature patterns and how they are affected by an increase in elevation. Measurements were made at ground level since this is the environment in which the plants live. Temperatures change with distance from the ground surface. To document this temperature difference, two Stevenson shelters were set up at weather station #2 during 1974, one at ground level and one at 1.2 m. Results are shown in Table 1. Although temperature differences were not great between the two shelters, the number of freeze-thaw cycles was much greater at ground level than at 1.2 m.

Temperature and precipitation results for all four weather stations

TABLE 1. Comparison of 1974 temperature data collected at the standard 1.2m height and at ground level at weather station #2 (el. 1556m).

Weather Station #2 1556m	Temperature, °C							
	July				August			
	Avg.	Max. (absolute)	Min. (absolute)	Freeze-Thaw Cycles	Avg.	Max. (absolute)	Min. (absolute)	Freeze-Thaw Cycles
Standard (1.2m)	4.6	12.4 (16)	-.6 (-.6)	5	7.4	15.4 (18.3)	1.1 (0)	2
Ground	5.0	13.3 (16.1)	-.6 (-.6)	6	7.1	15.4 (17.2)	-.2 (-1.1)	5.5

Figure 4: 1:50,000 scale topographic map of Birch Mt. WS1=Weather Station 1; WS2=Weather Station 2; WS3=Weather Station 3; WS4=Weather Station 4; C1=Camp 1; C2=Camp 2; N.K.=North Knoll; C.P.=Cairn Peak; S=Summit; Plat.=Plateau. Contour interval approximately 30.5 m.



are given in Table II. Temperature and precipitation data from Atlin (el. 659 m) are given for comparison. Three generalizations can be made: (1) Temperature decreases greatly with an increase in elevation, up to 8°C in this case. (2) With an increase in elevation the number of freeze-thaw cycles increases. (3) Precipitation increases with increased elevation. Of interest is the temperature and precipitation difference between the north slope (weather station #2) and the East Plateau on the southeastern side of the mountain (weather station #4). Temperatures on the East Plateau are consistently higher than on the north slope. The East Plateau is more perpendicular to the sun's rays and thus receives more radiation than the north slope. Precipitation is also greater on the East Plateau. The prevailing southerly wind brings storms from that direction which reach the East Plateau first. The difference in precipitation could be the result of a rain shadow effect of Birch Mt. itself.

A.7 Vegetation

On his map of the biogeoclimate zones of British Columbia, Krajina (1973) shows three zones occurring in the Atlin area. According to the current zonal nomenclature (Beil et al., 1976), these three zones are the Boreal White and Black Spruce Zone, the Spruce - Willow - Birch Zone and the Alpine Tundra Zone. These three zones are climatically defined (primarily on the basis of temperature) and thus occur in an elevational sequence.

The Boreal White and Black Spruce Zone, more common in the northeastern part of British Columbia, is restricted to the bottoms of the glacial valleys in the northwest. A brief climatic description of this zone is given as follows by Biel et al. (1976); "The mean annual temperature is -3 to 3°C. The average temperature is below 0°C for 5 to 7 months of the year, and above 10° for only 3 to 4 months (but is quite high during the peak of the

TABLE II: Birch Mt., Teresa Island, microclimatological data for 1974, 1975 and 1976. All data collected at ground level.

Weather Station		Temperature, °C								Precipitation, mm		
		July				August				July	August	
#	Elevation,m	Avg.	Max. (absolute)	Min. (absolute)	Avg. Freeze-Thaw Cycles	Avg.	Max. (absolute)	Min. (absolute)	Avg. Freeze-Thaw Cycles	Avg.	Avg.	Total Pcpt.
1	1280	8.9	18.1 (24.4)	.9 (0)	1.5	9.1	16.2 (21.6)	1.9 (0)	.5	40.2	28.6	68.4
2	1540	6	14.6 (23)	-.7 (-2.8)	6.5	6	15.1 (16)	1.1 (-1.7)	2	48	32	80
3	1829	4	12.2 (18)	-1.5 (-3.8)	13	5.2	13.6 (16.7)	.8 (-2.2)	9	50.8	32.4	84.3
4	1540	6.9	16.6 (21.6)	1.0 (-2.8)	6	7.9	17.4 (23.3)	1.8 (-1.1)	1	62.1	36	98
Atlin*	659	12	- (-)	- (-)	-	12	- (-)	- (-)	-	30	23	53

*Data for 1905-1946 from Anderson (1970).

summer)." Absolute minimum temperatures have been recorded between -59 to -42°C and absolute maximum between 30 to 41°C. The number of frost-free days is 20 to 150 (Biel et al., 1976). In the Atlin valley and on Teresa Island, the Boreal White and Black Spruce Zone appears to occur at elevations up to 800 to 900 m. Where this zone occurs in the Atlin valley, the dominant trees are *Picea glauca*, *Pinus contorta*, and *Populus tremuloides*. No black spruce (*Picea mariana*) has been found in this area (Anderson, 1970). An extensive survey of the vegetation of the Atlin valley was carried out by Anderson (1970) in conjunction with a palynological investigation. A mixed forest association, a white spruce association, an aspen association and a lodgepole pine association were the major vegetation types. The boreal forest has a typical low species diversity. Common species include *Salix glauca*, *Shepherdia canadensis*, *Rosa acicularis*, *Linnaea borealis*, *Hedysarum alpinum*, *Mertensia paniculata*, *Solidago multiradiata* and *Epilobium angustifolium*.

The Spruce - Willow - Birch Zone is a subalpine zone and develops between the upper limits of the Boreal White and Black Spruce Zone and the lower limits of the Alpine Tundra Zone (Krajina, 1975). In the Atlin area and on Teresa Island it ranges from 800 - 900 m to 1400 - 1500 m. This zone has not been well studied and its climatic characterization comes from only one station. Beil et al. (1976) report that the mean monthly temperature is below 0°C for seven months of the year and above 10°C for only one. The average number of frost-free days is 100. On Teresa Island the dominant species in this zone are *Abies lasiocarpa*, *Betula glandulosa*, *Salix* spp. and *Alnus* spp. Two subzones can be distinguished. The lower one is a subalpine forest dominated, on Teresa Island, by *Abies*. The upper subzone is an open parkland dominated by *Abies lasiocarpa* krummholz, *Betula glandulosa* and a number of *Salix* species, particularly *S. planifolia* and

S. arctica. Heath vegetation dominates between the clumps of krummholz and tall shrubs. The most common species here are Cassiope mertensiana, C. stelleriana, Empetrum nigrum and Vaccinium uliginosum. As in coastal subalpine areas (Brooke et al., 1970; Archer, 1963), the distrubution of heath vegetation and high shrub and krummholz vegetation is controlled by snow persistence. Heaths are usually restricted to basins and depressions with long snow duration.

The Alpine Tundra Zone develops above the subalpine zones at elevations above 900 m to 2250 m depending on the location of the mountain within the province. The growing season is very short in this zone, characterized by harsh climatic conditions. Beil et al. (1976) report that the mean annual temperature is between -.4 and -1.5^{o} C and the mean monthly temperature is below 0^{o} C for seven to eleven months of the year. No month has an average temperature over 10^{o} C and frost or snow can occur at any time of the year.

On Teresa Island the alpine zone begins between 900 m and 1500 m, depending on the slope angle and exposure, and extends to the summit. Because a climatic definition of alpine tundra is, in practice, difficult to use, I am using here the commonly accepted convention of defining alpine as the area above the climatic limit of trees, including the common occurrence of krummholz (Love, 1970).

The vegetation is composed almost entirely of herbs, bryophytes, lichens and dwarf shrubs. The distribution of the alpine vegetation on Teresa Island and the Atlin area suggests the division of the alpine zone into three subzones. The low alpine subzone is characterized by dwarf shrubs, particularly Betula glandulosa, Salix planifolia and species of Cassiope, and extends from the upper limit of the subalpine zone to approximately 1575 m. The mid-alpine subzone is characterized by more herbaceous meadow vegetation dominated by graminoids, especially species of Festuca, Poa and

Carex. This subzone extends to approximately 1700 m. High winds and resultant discontinuous snow cover result in a decrease in vascular vegetation in the high alpine subzone. Species here are mostly lichens. The alpine vegetation is discussed in great detail in the following section.

B. VEGETATION ECOLOGY

B.1 Introduction

The many ecological studies that have been made in alpine areas of the United States and Europe provide an excellent base for the principles of alpine ecology. Since they have been extensively reviewed many times in other publications, these studies are not reviewed here, but are cited, where appropriate, throughout the text. A good literature review is available in Eady (1971) and excellent review papers have been written by Billings (1974), Billings and Mooney (1968), and Bliss (1971).

Unfortunately, there is a general lack of information on the natural vegetation of alpine areas in British Columbia. This is indeed a paradox since much of the land surface of British Columbia is above treeline (Krajina, 1973).

In 1965, Dr. V. J. Krajina classified the land area of the province into eleven biogeoclimatic zones, defined by climate, soils and vegetation. The Alpine Biogeoclimatic Zone (AT) was environmentally characterized by Krajina (1965 and 1969) although very few climatic data were available. Except for the cold temperatures (no months have a mean temperature above 10°C and seven to nine months have mean temperatures below 0°C), the climatic data are variable, especially precipitation which tends to decrease from west to east. On the basis of this precipitation difference, Krajina (1965 and 1969) subdivided the Alpine Zone into two subzones: a Coastal subzone (ATa), characterized by a heavy snow cover of long duration and thus good water availability and short vegetative season, and an Interior subzone (ATb), with a lighter and more brief cover of snow with possible water shortage and longer growing season. The climax vegetation was thought to be dominated by *Phyllodoce empetriformis* and *Cassiope mertensiana* in the south and *Cassiope tetragona* in the north.

The first intensive alpine vegetation study in British Columbia was carried out by Archer (1963) in Garibaldi Park in the southwestern corner of the province. Here, Archer described the Phyllodoceto - Cassiopetum mertensianae association as the zonal or climatic climax vegetation, and stated that the distribution of vegetation in this high snowfall alpine area is influenced by snow cover and its duration. However, many of his plots were not located in the alpine but in recently deglaciated subalpine areas, and his results should be considered in this context.

In 1971 Eady described the alpine and timberline vegetation of Big White Mountain in the Okanagan Highland of southern British Columbia. In this study, soil moisture was considered to be the most important environmental factor influencing community patterns. The vegetation of this low precipitation area greatly differed from the Coastal Mountains but no zonal vegetation was hypothesised. Eady concluded that the alpine vegetation was not well developed here and much more alpine work needed to be done.

The alpine vegetation of the Gladys Lake Ecological Reserve and surrounding Spatsizi Plateau Wilderness Park in north central B. C. was studied by Pojar (1977). Fourteen plant communities were described, almost all of which were different from those described by Archer (1963) and Eady (1971). The mosaic of communities was due, in large part, to snow duration. Most of the fourteen communities were considered climax.

Luckhurst (1973), and Lord and Luckhurst (1974), described the alpine vegetation of Nevis Mountain and vicinity in northeastern B. C. in relation to stone sheep habitat.

Other vegetation studies of alpine areas outside the province, but near the Atlin Lake study site, were done in conjunction with the Icefield Ranges Research Project of the Arctic Institute of North America at Kluane National Park (southwestern Yukon Territory) and vicinity. An extensive vegetation study was done of Sheep Mountain in relation to Dall sheep habitat

(Hoefs, Cowan and Krajina, 1975). This mountain, because of its calcareous soils and low precipitation, supports vegetation very different, at least in floristic composition, from alpine areas studied in British Columbia.

Further alpine vegetation studies were done in southwestern Yukon Territory in the Ruby Range by Price (1972b), near the Klutlan Glacier in the St. Elias Mountains by Birks (1977), and in the southeast Wrangell Mountains of Alaska by Scott (1974a, b, c) and Detwyler (1974).

As can be seen, our knowledge of the extensive alpine regions of British Columbia is poor. The work which has been done shows a remarkable vegetation diversity correlated with geographical location, substrate and precipitation. The importance of the alpine zone in British Columbia for recreation and wildlife habitat and its diversity warrants much further study.

This section of the thesis seeks to expand our knowledge of the alpine vegetation in British Columbia. Objectives are: (1) to detect and define alpine vegetation units on Teresa Island; (2) to relate these units to the major environmental factors acting in the alpine zone; and (3) to form a foundation for the multi-scale mappable classification to be developed in the next section. If vegetation units can be related to environmental factors each can be used to predict the other. As a result, vegetation changes can be predicted when the environment is disturbed or manipulated.

B.2 Methods

B.2.1 Approach

Environment is a major factor controlling the distribution of taxa. A specific assemblage of species is characteristic of a specific habitat, with similar habitats supporting similar species assemblages or units of vegetation. On the ground these vegetation units form a mosaic coinciding with a mosaic of environmentally defined habitats. Between these relatively homogeneous units are areas of transition, the size of which are controlled by those environmental gradients influencing the distribution of taxa. If the environmental gradient is steep, the transitional zone is small, and the vegetation appears discontinuous. If, on the other hand, the gradient is gentle, the shift in species composition is gradual and the vegetation appears to represent a continuum. The delineation of units then becomes a question of the relative magnitude of the environmental gradients (Bliss, 1969). Gradients in mountainous regions are characteristically steep and usually simplify the identification and delineation of the units. Units which are similar according to predetermined criteria such as presence or absence of diagnostic species, dominance, or physiognomy can be joined into higher abstract units or noda (sensu Poore, 1955, 1956, and 1964).

Throughout the thesis, I shall call the basic units "sites", and similar sites will be combined into communities or community types. The characteristics of these community types are derived from the characteristics of the sites which make them up.

Sites were subjectively chosen for sampling, and were chosen on the basis of: (1) uniform appearance, influenced mainly by the uniform distribution of the dominant species; (2) uniform environmental conditions such as moisture and snow duration; and (3) homogeneity, or the uniform distribution of species within the sites.

The random or systematic locating of sites requires a great number of sample sites in order to adequately represent all the communities. The actual locating of sample sites can prove a problem and greatly increase sampling time. Subjective site selection adequately covers all communities, even the infrequent ones, and the speed permits a much larger area to be sampled in much less time. This is very important, especially in an area of difficult accessibility and short growing season. At the same time, subjective site selection allows the above site criteria to be maintained, and thus emphasizes the vegetation units rather than the transitional areas. This provides a clearly defined ecological framework of plant communities within which transitional areas can be placed.

The criteria for combining sites into communities is influenced by the purpose and ultimate use of the classification. Since the aim here is to produce a classification which can be detected by remote sensing devices and mapped, the major criterion of a community is that it must be distinguishable from a distance. Because the dominant species or group of species gives a site its characteristic appearance or physiognomy, dominance is considered here to be important in combining sites into communities. Total floristic composition and characteristic species combinations are also important. In regions of low species diversity, such as boreal and alpine, species are seldom restricted in distribution to one community, and thus fidelity (sensu Braun-Blanquet, 1964) is of little or no importance in characterizing communities. Of greater importance is species constancy and cover within a community, and the total floristic complement or characteristic combination of species. Poore (1955) and Dahl (1956) have similarly recommended the use of these criteria, especially dominance, to characterize communities in areas of low species diversity. To strengthen the ecological base, communities should be composed of sites with similar environmental parameters.

Many of the environmental factors discussed in conjunction with the communities have been assessed by critical observation and inferred from topographic relationships. In a study such as this, it is impractical and indeed often impossible to measure and quantify the complex of factors making up the environment. The factors most often affecting the distribution of alpine vegetation are those which are easily observed or inferred such as snow duration, moisture and slope.

B.2.2 Logistics

The fieldwork extended through three summers; 1974, 1975 and 1976. The field seasons extended from late June until late August, and were spent camped above treeline on Teresa Island. In 1974, one camp was established at an elevation of approximately 1540 m on the north slope. In 1975 and 1976, an additional camp was established on the East Plateau which greatly increased the accessibility of this alpine area (Figure 4). The initial set-up and final break-down of camps each year was accomplished by a helicopter based in Atlin. Other logistic support such as lodging when in Atlin, boat transport to Teresa Island, and daily radio communication was provided by the Foundation for Glacier and Environmental Research based in Atlin.

B.2.3 Flora

During the three field seasons, extensive collections of vascular plants, bryophytes and macrolichens from above treeline were made (Buttrick, 1977). Identification of vascular species was facilitated by reference to Welsh (1974), Hultén (1968), Viereck and Little (1972), Hubbard (1969) and Brayshaw (1976). Nomenclature of vascular taxa is according to Taylor and MacBryde (1977). Assistance in identifying mosses and hepatics was given by Dr. W. Schofield, Mr. A. Banner and Dr. J. Godfrey. Lichen collections were identified with the assistance of Hale (1969), Thomson (1967), and Dahl and Krog (1973). Lichen identifications were checked, and difficult specimens identified by Dr. J. Thomson, Ms. W. Noble and Mr. G. Otto. All species identified are listed in Appendix A.

B.2.4 Vegetation

A total of 151 sites were sampled in the course of the three field seasons. Seventeen of these sites were sampled in 1974 using fifteen randomly placed .5 x .2 m quadrats for a total sample area of 1.5 m^2. This quadrat size has previously proven satisfactory (Bliss, 1963; Billings and Bliss, 1959; Johnson and Billings, 1962; and Price, 1973), but the method proved to be too time-consuming considering the limited time available and extent of area to be covered. Since mapping was a major objective in the study, it was realized that a more rapid reconnaissance-type technique was needed, thus the sampling scheme was modified in 1975. The remainder of the sites were sampled in 1975 and 1976 using two 1 m^2 quadrats: this not only decreased sampling time, but also increased the sample area. An attempt was made to randomize quadrat position within the site by tossing the 1 m^2 frame in. Obvious disturbances within a site were avoided.

Within each quadrat all identifiable species of vascular plants, bryophytes and macrolichens were recorded. Unknown individuals were collected. If species could not be identified, as in the case of some grasses and sedges in their vegetative state, they were recorded by genus. Crustose lichens were recorded by color and substrate.

Average cover was estimated for each taxon using a simple nine-class cover scale which is a very slight modification of the Domin scale (Shimwell, 1972). Both scales are shown in Table III. Total cover was also calculated for shrub, herb, lichen and bryophyte strata. Cover estimates were made for water, rock, bare ground, and litter. Due to the frequent difficulty in alpine areas of determining what constitutes an individual, density data was not collected. For each site, quantitative and qualitative data were obtained on the physiographic factors of slope angle, exposure, elevation, and topographic position.

Domin Scale	Class	Range	Class mid-point
+ - a single individual			
1 - 1-2 individuals			
2 - less than 1% cover	+	<1%	.5
3 - 1-4%	1	1-5%	3
4 - 5-10%	2	6-10%	8
5 - 11-25%	3	11-25%	18
6 - 26-33%	4	26-33%	29.5
7 - 34-50%	5	34-50%	42
8 - 51-75%	6	51-75%	63
9 - 76-90%	7	76-90%	83
10 - 91-100%	8	91-100%	95.5

(Class, Range and Class mid-point are headed "Cover Scale Used In This Study")

TABLE III: Nine class modified Domin Scale used in this study for estimating percent cover of taxa. Domin cover/abundance scale is included for comparison.

Cover values from the pairs of quadrats were averaged and entered onto a floristic table. Using a tabular comparison synthesis method similar to the process of successive approximation described by Poore (1962), the sites were carefully compared to each other to detect floristic and environmental similarities and differences according to the criteria outlined on page 31. Sites which were shown to be environmentally and floristically similar were grouped together in the table and formed the basis for the community classification. The communities thus formed were named according to dominant (high constancy and cover) and characteristic species. Constancy is the percentage of sites of a particular community in which a species occurs, and thus is an expression of presence. The constancy percentages were expressed on the following five-class scale.

Class	Percentage
I	0 - 20
II	21 - 40
III	41 - 60
IV	61 - 80
V	81 - 100

Separate tables were made for each community. Average cover for each taxa was calculated using cover class midpoints. Constancy was calculated for each taxa except when the number of quadrats was fewer than five. In these cases a simple presence value, the number of quadrats in which a taxa occurred over the total number of sites sampled, was used in defining the community type.

B.2.5 Transects

Three line transects and one belt transect were sampled during the field program to document changes in species distribution along environmental gradients.

Transect #1 was set up and sampled in 1974. A base line 78 m long was made from the edge of a snowbed to a fellfield on top of the North Knoll. Total elevation gain along the transect is approximately 15 m. The vegetation was sampled in .5 x .2 m quadrats laid perpendicular to the base line. Two quadrats were sampled and averaged at two-meter intervals.

Transect #2 was set up and sampled in 1976. A 46 m long base line was positioned so that it crossed a solifluction lobe and runoff area on the north slope. The sampling scheme was the same as in Transect #1 except that 1 x .5 m quadrats were used.

Transect #3 was established and sampled in 1975. A permanent 59 m long base line was laid across a solifluction lobe and snowbed on the north slope. The sampling scheme was the same as in Transect #2 but position of quadrats was marked for relocation in 1976. During the 1976 field season, the snowmelt pattern of this snowbed was recorded. Each week the upper and lower edges of the snowbed were marked with paint.

Transect #4 was a belt transect established in 1975 which crossed a snowbed and was designed to document vegetation change with increase in duration of snow. The snowmelt was recorded by outlining the upper and lower snowbed edges each week with paint. Each week, three 1 x .5 m permanent quadrats were set up and sampled along the upper and lower edges of the snowbed. Cover was estimated using the nine-class cover scale and tabulated by averaging all three quadrats. One quadrat from each time-line was resampled each week to examine the increase in cover of a species over the summer.

B.3 Results

B.3.1 Community types

Careful floristic and environmental comparison of the sites indicate the presence of sixteen community types. A summary of these community types showing their characteristic species is given in Table IV.

The following is a list of the communities. For each community, an abbreviation of the name is also given. These abbreviations will be used in later tables and figures.

1.	*Umbilicaria* blockfield	(U bf)
2.	*Cetraria nivalis* - *Vaccinium uliginosum* fellfield	(Cn-Vu ff)
3.	*Cetraria nivalis* - *Carex microchaeta* fellfield	(Cn-Cm ff)
4.	*Carex microchaeta* meadow	(Cm m)
5.	*Festuca altaica* - *Cladina* dry meadow	(Fa-C dm)
6.	*Festuca altaica* - *Potentilla diversifolia* rich meadow	(Fa-Pd rm)
7.	*Betula glandulosa* - *Cetraria cucullata* shrubfield	(Bg-Cc sf)
8.	*Cassiope tetragona* - *Cladina mitis* heath	(Ct-Cm h)
9.	*Cassiope stelleriana* - *Phyllodoce empetriformis* snowbed	(Cs-Pe sb)
10.	*Sibbaldia procumbens* - *Polytrichum piliferum* snowbed	(Sp-Pp sb)
11.	*Anthelia juratzkana* - *Luzula arcuata* late snowbed	(Aj-La sb)
12.	*Carex pyrenaica* - *Luetkea pectinata* - *Juncus drummondii* snowbed	(Cp-Lp-Jd sb)
13.	*Salix planifolia* - *Empetrum nigrum* - *Sphagnum* runoff	(Sp-En-S ro)
14.	*Calamagrostis canadensis* - *Plagiomnium rostratum* runoff	(Cc-Pr ro)

TABLE IV: Summary floristic table showing characteristic species combinations for the sixteen community types. Values represent average cover class and constancy or presence. Values are recorded only when a species occurs in 40% or more of the sites making up the community type.

	U bf	Cn-Vu ff	Cn-Cm ff	Cm m	Fa-C dm	Fa-Pd rm	Bg-Cc sf	Ct-Cm h	Cs-Pe sb	Sp-Pp sb	Aj-La sb	Cp-Lp-Jd sb	Sp-En-S ro	Cc-Pr ro	Ap-Sp-Cs-Cm ro	R-Cp-Sn ro
Cetraria nivalis	2-3/3	4V	5V	1IV	2V	1III	+III	2IV								
Alectoria miniscula	2-3/3	2V	1V													
Umbilicaria proboscoidea	3-3/3	1V	1V													
Alectoria ochroleuca	2-2/3	1V	1V													
Cetraria commixta	1-3/3	1IV	1IV													
Vaccinium uliginosum		3V					1IV						1III			
Dryas octopetala		2V	1III													
Saxifraga tricuspidata		1V														
Saxifraga bronchialis			1V					1III		+III						
Carex microchaeta			3V	3V				1III		1III					3V	1III
Dactylina arctica	+-2/3		1IV	1V	1V	1IV	1IV	1V		+III			+III	+-2/3	+III	
Potentilla hyparctica			1III	1IV												
Pedicularis langsdorfii			+III	+IV												
Ptilidium ciliare				+III												
Tritomaria quinquedentata				+III												
Cladina rangiferina				1III	2V		1III	1III								
Cladina arbuscula		1III		+III	3V	1III	1III									
Festuca altaica		1III			5V	4V	+III	2IV						2-2/3		
Potentilla diversifolia						1V										
Hylocomium alaskanum				2III		1IV							1III	1-2/3	1III	
Aconitum delphinifolium						1IV							1III	1-2/3	1IV	
Betula glandulosa							5V									
Empetrum nigrum							3IV						3IV			
Cetraria cucullata			2III	1III			1V									
Cassiope tetragona								3V	1IV				1III			
Cladina mitis								1V								
Solorina crocea								1III	1IV	1V	1V	1-4/4				
Cassiope stelleriana									4V							
Phyllodoce empetriformis									1IV			+-3/4				
Sibbaldia procumbens									1V	2V	1III	+-2/4				1III
Polytrichum piliferum								1III		1IV						
Brachythecium albicans										1III						
Luzula arcuata			1III	1III						1V	1V	2-3/4				+III
Anthelia juratzkana								1III			2V	2-4/4				
Carex pyrenaica										1III		4-4/4				
Luetkea pectinata									1III			3-3/4				
Juncus drummondii												1-3/4				
Aulacomnium palustre				2IV		1III							3V	1-3/3	3V	2III
Sphagnum sp.													2III		3IV	
Salix planifolia							3IV						5V			
Salix reticulata													1III			
Vaccinium vitis-idaea							1III						1IV			
Calamagrostis canadensis														6-3/3		
Plagiomnium rostratum														2-3/3		
Claytonia sarmentosa															1IV	
Senecio yukonensis															+III	
Bistorta vivipara				+III					+III				+III		1V	+IV
Saxifraga nelsoniana															1III	1III
Carex podocarpa														1-2/3		2III

15. *Aulacomnium palustre* - *Salix polaris* - *Claytonia sarmentosa* - *Carex microchaeta* runoff (Ap-Sp-Cs-Cm ro)

16. *Ranunculus* - *Carex podocarpa* - *Saxifraga nelsoniana* - moss runoff (R-Cp-Sn ro)

B.3.1.1 *Umbilicaria* blockfield (Table V)

The *Umbilicaria* blockfield community type is characterized by a substratum composed entirely of angular blocks ranging from .1 to well over 1 meter in diameter. The blocks in turn have a complete cover of black lichens dominated by *Umbilicaria proboscoidea* (Figure 5). The rocks with their uniform cover of black lichens make this community the easiest to recognize in the field.

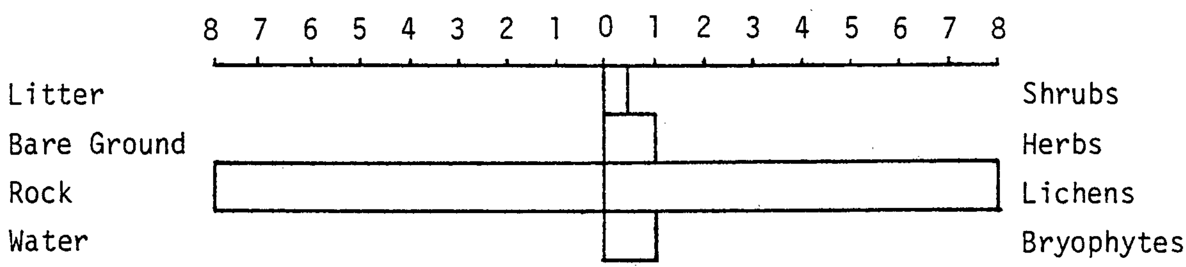


Figure 5: Cover relations in *Umbilicaria* blockfield community type.

This community type attains its best development at elevations above 1676 m where it covers the ridges, peaks, and steep southern slopes, thus forming the largest continuous community type on Birch Mt. Large patches of *Umbilicaria* blockfield also occur as low as 1372 m in the glacial valleys.

The lichen-covered rocky substrate within the glacial valleys is derived from morainal and talus material, and possibly from collapsed rock glaciers. At higher elevations, the substrate has been derived from frost shattering during colder climatic conditions. The complete lichen

TABLE V: Floristic table for the *Umbilicaria* blockfield showing species composition and cover.

Community Type: *Umbilicaria* blockfield

Site Number	113	92	145		
Elevation (m)	1676	1829	1615		
Position/Relief#	⌒	\	\		
Slope (°)	0-2	25	5		
Exposure	W	SE	NW		
Hygrotope¢	1	1	1		
	Cover Classes			Presence /3	Avg. Cover %
Rocks	8	8	8		95
LICHENS					
Crustose rock	3	4	5	3/3	30
Umbilicaria hyperborea	3	6	2	3/3	30
Umbilicaria proboscoidea	4	1	4	3/3	21
Alectoria miniscula	2	3	1	3/3	10
Rhizocarpon geographicum	2	1	3	3/3	10
Cetraria nivalis	3	1	+	3/3	7
Cetraria commixta	1	1	2	3/3	5
Alectoria ochroleuca	1	1		2/3	2
Dactylina arctica	1		+	2/3	1
Parmelia stygia	3			1/3	6
Hypogymnia oroarctica		1		1/3	1
Parmelia centrifuga		1		1/3	1
Stereocaulon botryosum			1	1/3	1
BRYOPHYTES					
Rhacomitrium lanuginosum	+	+		2/3	+*
Total Shrubs		+			+
Total Herbs		1			+
Total Lichens	8	8	7		91
Total Bryophytes	+	+	1		1

Other species occurring in only one site with their average cover: *Dryas octopetala* +, *Carex microchaeta* +, *Luzula arcuata* +, *Saxifraga bronchialis* +, *Cetraria islandica* +, *Cladonia gracilis* +, *C. rangiferina* 1, *Cladonia* sp. +, *Thamnolia vermicularis* 1, *Andreaea rupestris* 1, *Dicranoweisia crispula* +.

#/ — =horizontal; \=slope; ⌒=knoll or ridge; ◡=basin or depression; ⌝=convexity on slope; ∟=concavity on slope; ∿∿=hummocky.

¢/ 1=xeric; 2=submesic; 3=mesic; 4=hygric; 5=hydric.

*/ +=Less than 1% cover.

cover on the rocks indicates that this frost action is no longer of great importance.

The vegetation here is composed almost entirely of lichens. In addition to Umbilicaria proboscoidea, other common macro-lichens are: Alectoria minuscula, Alectoria ochroleuca, Cetraria commixta, and Parmelia stygia. All of these species are attached to the rocks and are black in color, giving the community its characteristic appearance (Figure 6). Other lichens characteristic of the Umbilicaria blockfield include Stereocaulon botryosum and Hypogymnia oroarctica, both attached to rocks, and Cetraria nivalis, Thamnolia vermicularis and Dactylina arctica which are commonly found loose between the rocks and are thus protected from the wind.

Soil development is poor, resulting in regosols with little or no horizonation. Few vascular plant species occur in this community type. The little soil that does accumulate supports isolated individuals of Luzula arcuata, Carex microchaeta, Dryas octopetala and Saxifraga bronchialis. The latter species attains the highest elevation, ca. 2050 m, of any vascular plant on the mountain. The relatively recent cessation of extensive frost shattering, and the very exposed nature of the sites, which results in discontinuous winter snow cover and the blowing away of organic material, probably account for the lack of soil development. Steep slopes aggravate the situation. Without fines to retain moisture, this community represents the most xeric habitat on the mountain.

B.3.1.2 Cetraria nivalis - Vaccinium uliginosum fellfield (Table VI)

The Cetraria nivalis - Vaccinium uliginosum fellfield community type is a common unit found on raised convex terrain with slopes

Figure 6: False-color infrared photograph of Umbilicaria blockfield. Note black Umbilicaria covered rocks and small tufts of vascular vegetation (pink).

TABLE VI: Floristic table for the Cetraria nivalis - Vaccinium uliginosum fellfield showing species composition and cover.

Community Type: Cetraria nivalis - Vaccinium uliginosum fellfield

Site Number	121	135	147	114	43	8	41	31	80	74	47	46	27	18	1		
Elevation (m)	1570	1554	1600	1554	1859	1631	1753	1585	1783	1570	1600	1722	1707	1591	1594		
Position /Relief	)	⌒	⌒	⌒	)	)	⌒	⌒	⌒	)	)	⌒	⌒	)	⌒		
Slope (°)	5	0	2	2	7	8	0	0	4	8	13	1	4	26	0		
Exposure	SSW	ENE	ENE	WNW	S	NNW	S	E	N	WNW	NE	W	N	ENE	N		
Hygrotope	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1		
	Cover Classes															Constancy	Avg. Cover %
Litter		1	1	1	1	1	1	1	1	+		1	1	3	2		4
Ground	1		+	1			1	1	1	+		+	1	2	3		3
Rocks	6	3	3	3	3	2	3	3	3	6	5	3	3	2	2		24
SHRUBS																	
Vaccinium uliginosum	4	3	4	5	2	2	3	3	1	5	3	3	1	4	3	V	20
Dryas octopetala	2		1	1	4	1	3	2	3	1	1	3	2	3	2	V	10
Salix polaris		2	1	1	1	1	1	1	1		1	+	1			IV	2
Empetrum nigrum		2		+		+	+				1					II	+
Betula glandulosa				1	1	+								1		II	+
Salix reticulata					1	1						1	1			II	+
HERBS																	
Saxifraga tricuspidata	+	1	1	+	1	+	1	1	1	+		1		+	1	V	2
Stellaria longipes		1	+	+	+	+	+	+	+	+	+	+	+		+	V	+
Carex sp.					+	+	+	+			1	+	3			III	2
Festuca altaica		1	1	+	1	+		+	1					1		III	1
Carex microchaeta		1	1			1			1	1					+	III	1
Festuca brachyphylla		+	+	+					+	+	+	1		+		III	+
Trisetum spicatum				+	+	+		+			+	+		+	+	III	+
Antennaria monocephala		1	1	+	+	+	+				+					III	+
Pedicularis capitata				1		+	+		1		+		+		+	III	+
Lupinus arcticus					1	+	2					2		1		II	2
Artemisia arctica		1		+	+	+			+				+			II	+
Saxifraga bronchialis		1				1			+		+				+	II	+
Campanula lasiocarpa		+	+		+	+			+							II	+
Luzula spicata		1				+			+		1					II	+
Hierochloe alpina				+	+	+					+					II	+
Draba nivalis						+							+		+	I	+
LICHENS																	
Cetraria nivalis	1	4	3	4	3	5	5	3	5	3	6	3	5	1	3	V	27
Alectoria minuscula	5	1	1	1	1	1	1	1	1	3	2	1	1	1	3	V	8
Crustose - rock	1	1	1	2	1	1	1	1	1	3		1	1	1	1	V	4
Alectoria nigricans		1	+	1	+	2	1	1	1	1	1	1	1	1	3	V	4
Umbilicaria proboscoides	1	1	1		1	1		1	1	3	2	1	1	1	1	V	4
Thamnolia vermicularis	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	V	3
Rhizocarpon geographicum	1	1	1	1	1	1	1	1	1	1	+	1	+	1	2	V	3
Stereocaulon tomentosum	1	1	3	+		+		+	1		1		1	1		IV	3
Alectoria ochroleuca		1		+	1	+	+	1	1	1	1	1	1		+	IV	2
Umbilicaria hyperborea		1	+	1	1	2	1	1			1	1	+		1	IV	2
Cetraria commixta	1		1	+		1	1	+	1	1	+	1				IV	2
Cladina arbuscula		1	1	+		1		1	1		2		1		+	III	2
Cetraria islandica		1	2	+	1	1			+				+	1		III	1
Pertusaria dactylina		1		1		+	+	+			+		+		1	III	+
Cornicularia muricata					1		1				1	2			1	II	1
Parmelia stygia		1					1				2			+	1	II	1
Cladina rangiferina		1	1			1			+		+		1			II	+
Cladonia gracilis		1	1	+		1			+		1					II	+
Dactylina ramulosa				+	+	1	+		+			+				II	+
Cladonia amourocraea		+		+		1			+							II	+
Cladonia sp.				1	1	+						1	1			II	+
BRYOPHYTES																	
Polytrichum piliferum		1	1	1										+	1	II	1
Dicranum elongatum				1		1			1				2			II	1
Dicranum sp.		1					1	1			2					II	1
Bryum sp.		1	+			1	1	+					+			II	+
Polytrichum alpestre		1	1					1				1				II	+
Total Shrubs	4	5	5	5	5	3	5	3	4	5	4	6	3	5	3		35
Total Herbs	1	3	2	1	3	2	2	1	3	1	1	3	3	2	1		9
Total Lichens	6	6	6	7	5	6	6	6	7	7	8	6	6	3	6		65
Total Bryophytes		1	1	2	1	1	1	1	1	1	2	1	3	+	1		4

Other species occurring in less than 20% of the sites with their average cover: Cassiope tetragona +, Dryas integrifolia +, Vaccinium vitis-idaea +, Antennaria alpina +, Bistorta vivipara +, Carex bipartita +, C. nardina +, Lupinus kuschei +, Myosotis alpestris +, Oxytropis huddelsonii +, Pedicularis langsdorfii +, Pedicularis sp. +, Poa arctica +, P. leptocoma +, Poa sp. +, Potentilla hyparctica +, Sedum lanceolatum +, Silene acaulis +, Cetraria cucullata +, C. hepatozon +, C. telisii +, Cladina mitis +, Cladonia coccifera +, C. fimbriata +, C. gonecha +, C. pocillum +, C. pyxidata +, C. verticillata +, Crustose-Ground-black 1, Crustose-Ground-gray 2, Dactylina arctica +, Dermatocarpon rivulorum +, Hypogymnia oroarctica +, Nephroma expallidum +, Parmelia centrifuga +, Peltigera canina +, Umbilicaria deusta +, Anastrophyllum minutum +, Aulacomnium turgidum +, Barbilophozia sp. +, Bartramia ithyphylla +, Desmatodon latifolium +, Dicranoweisia crispula +, Encalyptra rhabdocarpa +, Polytrichum alpinum +, Rhacomitrium lanuginosum +.

between 0^{o} and 10^{o} on all aspects, and attains best development on northern and eastern exposures. The raised topography, along with the coarse-textured, poorly developed soils (regosols), result in strong drainage and xeric-to-subxeric conditions. Snow cover is probably light and discontinuous on the more exposed sites.

Best development of the community occurs between 1555 and 1700 m, but on southern slopes it can extend up to 1800 m. At higher elevations, the Cetraria nivalis - Vaccinium uliginosum fellfield is replaced by the Cetraria nivalis - Carex microchaeta fellfield.

All sites are characterized by extensive bare ground and exposed rock (25-33%), a high lichen cover (up to 75%), and a dwarf shrub cover (50-90%) (Figure 7). The characteristic dwarf shrub species are Vaccinium uliginosum and Dryas octopetala. The most characteristic herb is Saxifraga tricuspidata which occurs in 90% of the sites. Oxytropis huddelsonii, a relatively uncommon species in British Columbia (Buttrick, 1977), is restricted to this community type and found only on the North Knoll where it is common.

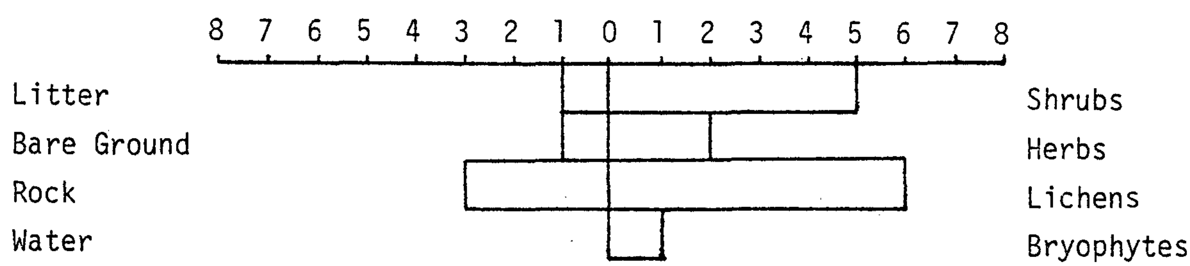


Figure 7: Cover relations in Cetraria nivalis - Vaccinium uliginosum fellfield community type.

The community type is easy to identify even at a distance by its distinctive yellow and black color. The yellow color comes from Cetraria nivalis and Cetraria cucullata and the black tones are from Umbilicarias and Alectorias (Figure 8).

Figure 8. Cetraria nivalis - Vaccinium uliginosum fellfield looking northwest down the North Slope. Yellow is mostly Cetraria nivalis, light green areas are Dryas octopetala and Vaccinium uliginosum. Dark green patches in center right are Empetrum nigrum. Note black Umbilicaria covered rocks.

On slopes between 5^{0} and 10^{0} relict stone stripes occur. Where the slope approaches 0^{0}, old stone circles can be found as well as active nonsorted circles. Although moisture is not readily available in these sites, the light, discontinuous snow cover would result in deep freezing of the soils. Micro-patterning of vegetation is obvious in these sites. These patterns are often the result of frost activity which, by altering the surface microtopography, results in differential snow accumulation and other microenvironmental factors. The effect of frost activity on the micro-patterning of fellfield vegetation has been described by Bryant and Scheinberg (1970). Betula glandulosa and Salix planifolia are common in small snow pocket depressions within the fellfield. Festuca altaica, a characteristic species of the mesic alpine meadows, also is in these depressions.

B.3.1.3 Cetraria nivalis - Carex microchaeta fellfield (Table VII)

On peaks, ridges and well-drained slopes and plateaus above 1676 m, the Cetraria nivalis - Vaccinium uliginosum fellfield gives way to the Cetraria nivalis - Carex microchaeta fellfield community type. At these elevations, Dryas octopetala decreases in abundance, Vaccinium uliginosum completely disappears, the cover of Salix polaris increases, Saxifraga tricuspidata is replaced by S. bronchialis and Carex microchaeta greatly increases in prominence.

This fellfield, as in the Cetraria nivalis - Vaccinium uliginosum fellfield, has a characteristic black and yellow appearance. The amount of bare ground and rock increases with elevation with an accompanying increase in lichen cover (ca. 80%) (Figure 9). The concurrent decrease in vascular vegetation emphasizes the black and yellow color

TABLE VII: Floristic table for the Cetraria nivalis - Carex microchaeta fellfield showing species composition and cover.

Community Type: Cetraria nivalis - Carex microchaeta fellfield

Site Number	10	67	72	73	89	109	112	134	133		
Elevation (m)	1905	1890	1859	1890	1859	1859	1676	1798	1798		
Position/Relief	⌒	⌒	⌒	⌝	⌝	⌒	⌝	⌝	⌝		
Slope (°)	0	0-10	0-5	5-10	1-10	0-3	5	15	10		
Exposure	0	SSE	WSW	S	SSE	N	W	SE	SE		
Hygrotope	1	1	1	1	1	1	1	1	2		Avg.
	Cover Classes									Constancy	Cover %
Litter	1	+	1	1	1	1	1				2
Ground	1		+						6		7
Rocks	2	6	1	5	1	1	1	5	3		21
SHRUBS											
Salix polaris	1	1	2	2	1	1	1	2	1	V	5
Dryas octopetala					1	+	3	1	+	III	3
HERBS											
Carex microchaeta	2	+	3	1	2	2	2	1	2	V	7
Stellaria longipes	+	+	1	1	1	+	1	+	+	V	2
Antennaria monocephala	1		1	1	+	1	1	1	1	V	2
Saxifraga bronchialis	+	1	1	1		+	+	+	1	V	2
Campanula lasiocarpa		+		+	+		1	+	+	IV	+
Luzula arcuata			1		+	1		1	1	III	1
Silene acaulis	+				1		1	1	1	III	1
Potentilla hyparctica		1	1	1	+				1	III	1
Pedicularis langsdorfii	+		1	1	+	+				III	+
Poa sp.		+	1	1		+		+		III	+
Hierochloe alpina				1	+		1	+		III	+
Festuca brachyphylla					+	+		+	+	III	+
Lupinus arcticus							1	1	1	II	1
Festuca altaica					1		1	1		II	1
Draba nivalis				+		+			+	II	+
Luzula spicata							1		1	II	+
Artemisia arctica							1		+	II	+
Bistorta vivipara					1		+			II	+
Saxifraga tricuspidata	+							+		II	+
LICHENS											
Cetraria nivalis	5	5	6	6	5	6	5	6	1	V	47
Crustose rock	3	3	+	3	1	1	1	3	3	V	11
Rhizocarpon geographicum	1	2	+	1	1	1	+	2	1	V	4
Alectoria minuscula	1	1	1	3		1	+	1	1	V	4
Thamnolia vermicularis	1	1	1	1	1	1	1	2	+	V	3
Alectoria ochroleuca	1	1	1	1	1	1	1	1	+	V	3
Alectoria nigricans	1	1	1	2	1	1	1	1		V	3
Umbilicaria proboscoidea		3	1	3		+		1	+	IV	5
Umbilicaria hyperborea		3			1	1	+	2	1	IV	4
Cetraria commixta	2	1		+		+		+	1	IV	2
Dactylina arctica	1		1			+	1	+	+	IV	1
Stereocaulon tomentosum	+	+			+	1	1		1	IV	1
Cetraria cucullata			1	1	3	3	3			III	7
Pertusaria dactylina	1				+	1	1	1		III	1
Cetraria islandica	1		1	+			1	1		III	1
Cladonia sp.	1		1	1		1	+			III	1
Cladonia amaurocraea	+		+			+	1			III	+
Crustose Ground-gray			1	1	1					II	1
Cladina arbuscula	1		1				1			II	1
Cladina rangiferina	1		+				1			II	+
Cladonia gracilis	1					+	1			II	+
Dactylina ramulosa	1	+			+					II	+
Peltigera aphthosa	1						1			II	+
Crustose Ground-black	+	1								II	+
Cladonia coccifera	1	+								II	+
BRYOPHYTES											
Polytrichum piliferum	2	1				5		+		III	6
Dicranum elongatum					1	1	3			II	3
Rhacomitrium lanuginosum			1	+			2			II	1
Dicranum sp.	1		1				1			II	1
Bryum sp.		1						+		II	+
Dicranoweisia crispula		1							+	II	+
Desmatodon latifolius	+								+	II	+
Total Shrubs	1	1	2	2	2	1	3	3	1		8
Total Herbs	3	1	5	3	3	3	3	2	3		18
Total Lichens	7	8	7	7	7	8	8	7	5		82
Total Bryophytes	3	1	2	2	3	6	5	2	1		19

Other species occurring in less than 20% of the sites with their average cover: Cassiope tetragona +, Dryas integrifolia +, Salix reticulata +, Vaccinium uliginosum +, Cardamine bellidifolia +, Cerastium beeringianum +, Draba incerta +, Pedicularis capitata +, Pedicularis sp. +, Poa arctica +, Saxifraga nelsoniana +, Trisetum spicatum +, Cetraria telisii +, Cladonia pocillum +, Cornicularia muricata +, Parmelia stygia +, Anastrophyllum minutum +, Barbilophozia sp. +, Grimmia sp. +, Pohlia sp. +, Polytrichum alpestre +, P. alpinum +.

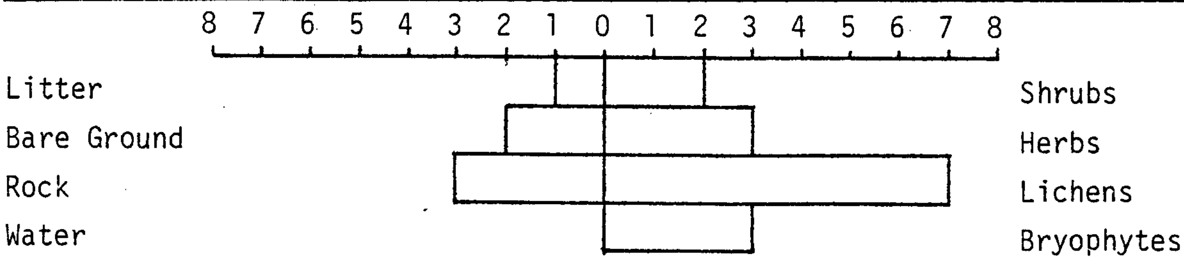


Figure 9: Cover relations in Cetraria nivalis - Carex microchaeta fellfield community type.

(Figure 10).

The increase in herb cover is attributed mostly to the increase in Carex microchaeta, but significant increases also occur in Luzula arcuata, Potentilla hyparctica and Silene acaulis.

The Cetraria nivalis - Carex microchaeta fellfield is truly intermediate between the Umbilicaria blockfield and the Cetraria nivalis - Vaccinium uliginosum fellfield in both floristic composition and elevation. This community type occurs on all aspects, but reaches its best development on the regosolic soils of the southern slopes and ridges above the glacial cirques. This vegetation, which is quick to colonize debris islands that frequently develop on the boulder slopes of the southern ridges and peaks, will, given time, probably form the climax community at these high elevations.

B.3.1.4 Carex microchaeta meadow (Table VIII)

The Carex microchaeta meadow community type is best developed on north and south slopes from 1676 m to over 1890 m. At the lower elevation end of its distribution, this type occurs on horizontal to gently sloping (10^{o}) terrain, and is the major vegetation of the upper surface of solifluction lobes on the north slope. At high elevations, 1829 - 1890 m, the Carex microchaeta meadow is confined to shallow depressional areas where

Figure 10: Cetraria nivalis - Carex microchaeta fellfield, looking northeast toward summit. Black tones on steep southwestern slope of summit and scattered black patches in foreground represent Umbilicaria blockfield.

TABLE VIII: Floristic table for the Carex microchaeta meadow showing species composition and cover.

Community Type: Carex microchaeta meadow

Site Number	12	16	17	70	71	90	108		
Elevation (m)	1890	1713	1713	1890	1890	1859	1691		
Position/Relief									
Slope (°)	1	2	2	5	5	5	0-2		
Exposure	S	NNE	NNE	SSE	SSE	SSE	NE		
Hygrotope	2/3	3/4	3	3	3	3/4	3/4		Avg. Cover
	Cover Classes							Constancy	%
Litter	2	3	3	2	1	3	1		11
Ground	1	+							+
Rocks	1	1	1	+					1
SHRUBS									
Salix polaris	2	3	3	1	3	+	1	V	10
Salix reticulata			+				7	II	12
HERBS									
Carex microchaeta	3	2	3	4	6	3	3	V	25
Antennaria monocephala	1	1	+	1		1	+	V	2
Poa sp.		1	+	1	1	1	+	V	2
Stellaria longipes	+	+	+	+	+	1	+	V	+
Artemisia arctica	+	2	1			1	+	IV	2
Potentilla hyparctica	+		+	1	1	1		IV	1
Pedicularis langsdorfii		+	+	1	1		+	IV	1
Luzula arcuata			+	2			+	III	1
Claytonia sarmentosa		1	1				+	III	+
Bistorta vivipara		+	+				1	III	+
Taraxacum lyratum	+	+				+		III	+
Luzula spicata	+					+	+	III	+
Cardamine bellidifolia					1	+		II	+
Trisetum spicatum		+				1		II	+
Festuca altaica		+	+					II	+
Ranunculus eschscholtzii		+	+					II	+
Gentiana glauca		+	+					II	+
LICHENS									
Cetraria islandica	1	1	1	1	1	1		V	3
Dactylina arctica	1	+	1	1	1	1		V	2
Stereocaulon tomentosum	3	1		3	2	1		IV	7
Cetraria nivalis	1		+	1	1		+	IV	1
Cladina rangiferina	1	+	3	1				III	4
Cladonia gracilis	2	1	1	1				III	2
Thamnolia vermicularis	1			1	1	1		III	2
Cetraria cucullata			1		1	1		III	1
Rhizocarpon geographicum	1	1	1					III	1
Peltigera canina	1	1	1					III	1
Peltigera aphthosa				+	1	1		III	+
Cladina arbuscula		+	1		1			III	+
Cladonia pyxidata		+	1				+	III	+
Umbilicaria hyperborea		1	1					II	+
Crustose rock		1	1					II	+
Cladina mitis	1			1				II	+
Pertusaria dactylina	1	+						II	+
Cladonia amourocraea	+		1					II	+
Crustose Ground-gray	1	+						II	+
Cladonia verticillata	+			1				II	+
BRYOPHYTES									
Dicranum sp.	1		+		3	5	3	IV	12
Aulacomnium palustre		3	3		3	1	1	IV	9
Hylocomium alaskanum	1			1	3		3	III	6
Barbilophozia sp.	1		1	+		+		III	1
Tritomaria quinquedentata	1		1	+		+		III	1
Ptilidium ciliare			1	+	1	+		III	1
Drepanocladus uncinatus	+	1				1		III	+
Anastrophyllum minutum		+	1		1			III	+
Polytrichum alpestre	2	2						II	2
Dicranum elongatum			1	2				II	2
Aulacomnium turgidum					1		2	II	2
Sphagnum sp.			2				1	II	2
Bartramia ithyphylla		1	1					II	+
Anthelia juratzkana		+	1					II	+
Bryum sp.		1	+					II	+
Lophozia sp.		1				+		II	+
Blepharostoma trichophyllum		+	+					II	+
Total Shrubs	2	3	3	1	3	+	7		21
Total Herbs	3	4	3	6	6	3	3		33
Total Lichens	6	2	4	5	3	2	1		25
Total Bryophytes	4	6	5	2	6	6	5		44

Other species occurring in less than 20% of the sites with their average cover: Dryas octopetala +, Vaccinium vitis-idaea +, Aconitum delphinifolium +, Campanula lasiocarpa +, Carex bipartita +, Draba incerta +, Erigeron humilis +, Eriophorum scheuchzeri +, Festuca brachyphylla +, Luzula sp. +, Pedicularis capitata +, Ranunculus nivalis +, Saxifraga bronchialis +, Senecio yukonensis +, Silene acaulis +, Cetraria delisei +, Cladonia cenotea +, C. coccifera +, C. ecmocyna +, C. pocillum +, Cladonia sp. +, Cornicularia muricata +, Crustose Ground-black +, Dactylina ramulosa +, Solorina crocea +, Umbilicaria cylindrica +, Andreaea rupestris +, Brachythecium sp. +, Cephalozia sp. +, Orthocaulis floerkii +, Paraleucobryum inerve +, Polytrichum alpinum +, Rhacomitrium canescens +, Tomenthypum nitens +.

snow cover probably persists throughout the winter.

On the north slopes, this community is influenced by seepage from upper snowbeds. Drainage is imperfect because of impermeable discontinuous permafrost layers which occur here. The water table in the moister sites is as shallow as 55 cm in early August. Hygrotope is mesic to hygric. Of all the meadow communities, this is the most moist and occurs at the highest elevations. Soil horizons are better developed than in the previous communities, and brunisols probably predominate. Gleying occurs in the wetter areas.

Seepage, horizontal surfaces with imperfect drainage, and the presence of permafrost have possibly been responsible for the large number of nonsorted and sorted circles that occur in this community type.

The vegetation is characterized by high herb cover (50%) dominated by Carex microchaeta (Figure 11), and an equally high bryophyte cover dominated by Aulacomnium palustre, Drepanocladus uncinatus and Dicranum sp. The first two are characteristic of hygric sites. The moist nature of the terrain is also demonstrated by the scattered occurrence of Claytonia sarmentosa and Senecio yukonensis, both usually occurring in mossy runoff areas. Other herbs characteristic of the Carex microchaeta meadow are Potentilla hyparctica, Pedicularis langsdorfii and Luzula arcuata, the latter also being characteristic of snowbeds. The liverworts, Tritomaria quinquedentata and Ptilidium ciliare, have their highest occurrence here. The lichen stratum is not as well developed as in the fellfields but is still well represented by Cetraria nivalis, C. cucullata, Thamnolia vermicularis and Dactylina arctica. The 25% shrub cover is composed entirely of Salix polaris (Figure 12).

Figure 11: Carex microchaeta meadow. Note low growth form of the Carex. Salix planifolia shrubs can be seen in the distance.

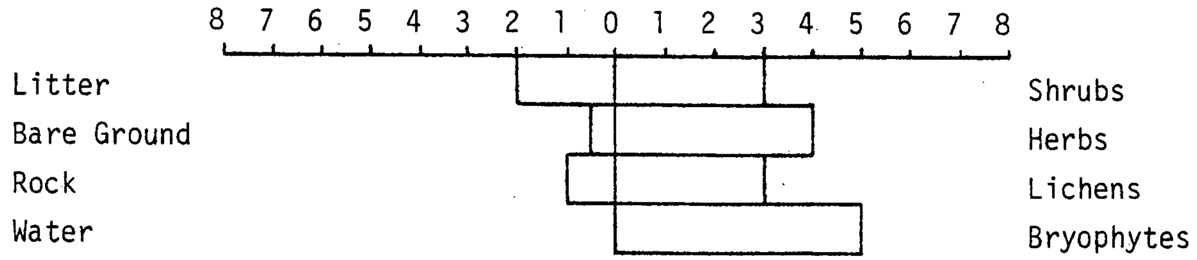


Figure 12: Cover relations in *Carex microchaeta* meadow community type.

B.3.1.5 *Festuca altaica* - *Cladina* dry meadow (Table IX)

The *Festuca altaica* - *Cladina* dry meadow community type is found on horizontal, slightly convex to gently sloping (10^{0}) sites on all exposures between 1494 m and 1753 m, but reaches its best development at elevations above 1615 m. This subxeric to mesic community probably has a light, continuous winter snow cover and is free of snow at least by early June. The dry meadow occupies slightly better protected areas than the *Cetraria nivalis* - *Vaccinium uliginosum* fellfield with which it frequently merges. Small patches of this community often occupy shallow depressions within fellfields (Figure 13).

The vegetation is characterized by a 50% herb cover dominated by the clump fescue, *Festuca altaica*, and by a high (50%) cover of lichens. Important lichen species characteristic of this community are *Cladina rangiferina* and *C. arbuscula*. *Cetraria nivalis* and *Thamnolia vermicularis* are still important species, and show the close relationship with the fell-field community types. Shrub cover in these sites is low and can be attributed to *Salix polaris* (Figure 14).

The *Festuca altaica* - *Cladina* dry meadow frequently occurs in mosaics with the *Festuca altaica* - *Potentilla diversifolia* rich meadow, the *Cassiope tetragona* meadow and the *Cetraria nivalis* - *Vaccinium uliginosum*

TABLE IX: Floristic table for the Festuca altaica - Cladina dry meadow showing species composition and cover.

Community Type: Festuca altaica - Cladina dry meadow

Site Number	42	50	35	61	40	81	45	150	62	24		
Elevation (m)	1707	1600	1631	1600	1585	1707	1707	1494	1608	1753		
Position /Relief	╲	╲	—	⌒	╲	◡	◡	⌒	╲	╲		
Slope (°)	0-4	0-4	0	0-6	0-4	2	1	5	8	0-4		
Exposure	E	NE	W	NNW	E	S	SW	SSW	WNW	N		
Hygrotope	2	2	2	2	2	2	2	2	2	3	Con-stancy	Avg. Cover %
	Cover Classes											
Litter	1	1	2	2	1	3	3		2	3		9
Ground							+					+
Rocks	2	3	2	2	1	1	1	+		1		5
SHRUBS												
Salix polaris	1	3	2	3		1	1	1	3	2	V	7
HERBS												
Festuca altaica	5	4	3	3	3	3	5	4	6	3	V	30
Artemisia arctica	1	3	1	3	2	2	1	2	2	1	V	8
Antennaria monocephala	1	1	+	1		+	1	+	1		IV	2
Stellaria longipes	+	+	+	+		1		1	+	+	IV	+
Carex sp.			1	2	1		1		1	2	III	3
Hierochloe alpina	+			1				1		1	II	+
Bistorta vivipara	+		+		+					+	II	+
Luzula arcuata	+		+	+						+	II	+
Silene acaulis			1	1			1				II	+
Luzula spicata		1				+	1				II	+
Carex microchaeta		1				+		1			II	+
Potentilla hyparctica	1	+								+	II	+
LICHENS												
Cladina arbuscula	1		+	1	1	3	1	3	4	1	V	8
Cladina rangiferina	1	1	+	+	+	2	1	3	3	2	V	6
Cetraria nivalis	1	2	3	1	1	1	1	1		2	V	5
Dactylina arctica	1	1	1	1	+	1	+	1	1	1	V	3
Cetraria islandica	1	1	1	1	1	1	3	1		1	V	3
Cladonia gracilis	+	1	1	1	+	1		1	1	1	V	2
Thamnolia vermicularis	+	1	1	+	+	1	+	+	+		V	1
Stereocaulon tomentosum	1	2	1	1	3	2	2	3			IV	9
Crustose rock	1	1	1	2	1	1					III	2
Rhizocarpon geographicum	+	1	1	1	1	1					III	2
Umbilicaria hyperborea	1	1		1	1	1					III	2
Cladonia amourocraea	+	1	1			1				1	III	1
Umbilicaria proboscoidia	1	1	1	1							II	1
Cladonia coccifera	+	1	1								II	+
Cladonia pocillum												
BRYOPHYTES												
Dicranum sp.	1	1				1	1	3		3	III	5
Polytrichum alpestre	1			1				1	1	1	III	2
Hylocomium alaskanum	2					+		1	3		II	3
Total Shrubs	1	3	3	3	1	1	1	1	3	2		10
Total Herbs	6	6	3	5	4	5	6	5	6	5		47
Total Lichens	3	6	6	6	4	6	4	6	5	5		48
Total Bryophytes	3	2	+	1	3	1	1	3	3	4		12

Other species occurring in less than 20% of the sites with their average cover: Cassiope tetragona +, Dryas octopetala +, Salix planifolia +, S. reticulata +, Vaccinium uliginosum +, Aconitum delphinifolium +, Carex bipartita +, C. nardina +, Campanula lasiocarpa +, Gentiana glauca +, Luzula confusa +, Minuartia obtusiloba +, Pedicularis capitata +, P. langsdorfii +, Poa arctica +, P. leptocoma +, Poa sp. +, Potentilla diversifolia +, Saxifraga bronchialis +, S. tricuspidata +, Senecio yukonensis +, Alectoria minuscula +, A. nigricans +, A. ochroleuca +, Cetraria commixta +, C. cucullata 2, Cladina mitis +, Cladonia macrophylla +, C. uncialis +, C. verticillata +, Cladonia sp. 2, Crustose Ground-gray 5, Dactylina ramulosa +, Peltigera apthosa +, P. canina +, Pertusaria dactylina +, Solorina crocea +, Anastrophyllum minutum +, Aulacomnium palustre +, A. turgidum +, Barbilophozia sp., Brachythecium sp. +, Bryum sp. +, Drepanocladus exannulatus +, D. uncinatus +, Lophozia sp. +, Polytrichum alpinum +, P. piliferum +, Ptilidium ciliare +.

Figure 13: Festuca altaica - Cladina dry meadow occupying a shallow depression in a Cetraria nivalis - Vaccinium uliginosum community.

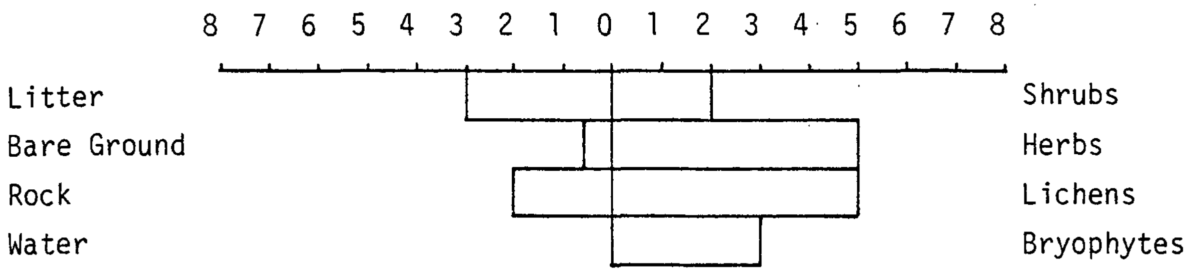


Figure 14: Cover relations in Festuca altaica - Cladina dry meadow community type.

fellfield. Soils grade between the regosols of the fellfields and the well developed brunisols of the rich meadows.

B.3.1.6 Festuca altaica - Potentilla diversifolia rich meadow (Table X)

The Festuca altaica - Potentilla diversifolia rich meadow community type forms the zonal vegetation at elevations below 1737 m. It develops on shallow depressional, horizontal or sloping topography on all aspects with best development on the southern slopes above the East Valley (see Figure 72). On this southern exposure, it can occur on slopes as steep as 30^{o} while on northern aspects slopes this steep collect snow and develop snowbed vegetation.

Winter snow cover is probably moderate and continuous. On south slopes the snow probably melts out in May while on horizontal and north slopes it can remain until late June. The sites are mesic to subhygric as compared to the subxeric sites of the dry Festuca meadow previously described, and are occasionally influenced by seepage which prevents them from drying out. Some of the south slope sites above the East Valley are the richest and most productive sites on the mountain. Here the snow melts early. The steep, almost 30^{o} slopes have good drainage, but constant seepage through July. The greater cover of herbs and decreased

TABLE X : Floristic table for the Festuca altaica - Potentilla diversifolia rich meadow showing species composition and cover.

Community Type: Festuca altaica - Potentilla diversifolia rich meadow

Site Number	32	5	107	130	82	38	56	21	137	125	76	116	44		
Elevation (m)	1585	1615	1676	1600	1737	1615	1676	1570	1539	1585	1554	1585	1539		
Position/Relief	~	\	—	\	(	\	~	(	~	—	∪	~	\		
Slope (°)	1	3	2	4	20	3	2	13	2	2	2	2	30		
Exposure	NNE	NW	NE	ESE	S	E	SE	W	ENE	ESE	SE	SE	S		
Hygrotope	3	3	2-3	3	3	3	3	3	4	2-3	3	4	3-4		Avg. Cover
	Cover Classes													Constancy	%
Litter	1	4	2		3	1	2	3	1	1	3	1	1		9
Ground	+	+					1	1		+			1		+
Rocks		+					1	1	+	1	1		1		1
SHRUBS															
Salix polaris	3	1	1	1	2	1	1		1		1	1		IV	4
HERBS															
Festuca altaica	5	3	4	6	3	4	6	4	6	3	2	5	3	V	29
Artemisia arctica	2	3	3	3	3	3	3	3	3	3	3	3	3	V	17
Potentilla diversifolia	+	1	+	1	1	1	2	1	2	3	1	+	1	V	5
Stellaria longipes	+	+	+	1	+	+	+	+	+			+	+	V	+
Antennaria monocephala	1	+	1	2		1		1	+	+	1	+		IV	2
Aconitum delphinifolium	1	1	1	1	1	+			1			1	1	IV	2
Campanula lasiocarpa				+	1	+	+		1	1	1		1	IV	1
Gentiana glauca	1	+	1	1	+	+								III	+
Carex microchaeta		2	1		1			1		2				II	2
Myosotis alpestris									2			1	1	II	1
Carex podocarpa			1	1							1	2		II	1
Festuca brachyphylla				1				+		1	1		+	II	+
Luzula spicata				1	+		+			1	+			II	+
Bistorta vivipara	+	+	1	+	+									II	+
Sedum rosea	+			+	+		+		1					II	+
Carex capitata				1				1		1	1			II	+
Carex sp.	1					1	1						1	II	+
Poa sp.			+	+			+						1	II	+
Solidago multiradiata					1				1				1	II	+
Hierochloe alpina		+		1		1								II	+
Silene acaulis				+					+		1			II	+
LICHENS															
Cetraria islandica	1	1	1	1	1	+	1	1	1	1	1			V	2
Stereocaulon tomentosum	1	+	1	3	+	+	2	1	1	1				IV	3
Dactylina arctica	+	1	1	1	1	+	+	1		1	+			IV	2
Cladonia gracilis	1	1	1	1	1		1			1				III	2
Cladonia coccifera	+	+			1		+	1		2	1			III	1
Cladina arbuscula	1		1	1		1		+			1			III	1
Cetraria nivalis		1	1	+	+			1		1				III	1
Peltigera aphthosa	1	1	+	+				+	1					III	+
Cladina mitis		2					1			2				II	1
Crustose rock							1	1	+	1	1			II	+
Cladina rangiferina		+	1	+				+		1				II	+
Cladonia ecmocyna				+		1	1			1				II	+
Rhizocarpon geographicum		+						+		1	1			II	+
Cladonia sp.		+	1									+	1	II	+
Cladonia verticillata						+	1				1			II	+
Umbilicaria hyperborea							1		+		1			II	+
Cladonia amaurocraea			+	+	1									II	+
BRYOPHYTES															
Hylocomium alaskanum	1	1	1	1	1		3		3			1		IV	4
Dicranum sp.	1		+	1	1	+	1	1	1					IV	1
Aulacomnium palustre	4	1	2	1	1							3		III	5
Polytrichum alpestre			1	2	1	1				1			1	III	2
Barbilophozia sp.	+	+	+	+	1	+	+							III	+
Bryum sp.		+		+	+							3		II	2
Drepanocladus uncinatus		+					+		2			2		II	1
Polytrichum piliferum				+		1					1			II	+
Tomenthypnum nitens		+	1									+		II	+
Total Shrubs	3	1	2	1	2	1	1	1	1		1	1	3		6
Total Herbs	6	5	6	7	6	6	6	6	7	6	6	7	6		66
Total Lichens	3	3	3	3	2	3	3	3	1	4	3	+	1		14
Total Bryophytes	5	3	3	3	3	1	3	2	1	1	1	5	1		15

Other species occurring in less than 20% of the sites with their average cover: Cassiope tetragona +, Empetrum nigrum +, Phyllodoce empetriformis +, Salix arctica +, S. planifolia +, S. reticulata +, Vaccinium vitis-idaea +, Anemone richardsonii +, Antennaria alpina +, Arnica latifolia +, Calamagrostis canadensis 3, Carex bipartita +, C. phaeocephala +, Castilleja unalaskensis +, Claytonia sarmentosa +, Draba crassifolia +, Draba densifolia +, D. incerta +, Epilobium angustifolium +, Equisetum palustre +, Geranium erianthum +, Luzula confusa +, Luzula sp. +, Minuartia obtusiloba +, Oxyria dygina +, Pedicularis capitata +, P. langsdorfii +, Pedicularis sp. +, Poa arctica +, Polemonium pulcherrimum +, Potentilla hyparctica +, Pyrola grandiflora +, Sanguisorba canadensis +, Saxifraga bronchialis +, S. tricuspidata +, Selaginella sibirica +, Senecio lugens 1, Sibbaldia procumbens +, Trisetum spicatum +, Valeriana sitchensis +, Veronica wormsjkoldii +, Cetraria cucullata +, C. richardsonii +, Cladonia carneola +, C. fimbriata +, C. pocillum +, C. pyxidata +, C. uncialis +, Crustose ground-black +, Crustose ground-gray 1, Nephroma expallidum +, Thamnolia vermicularis +, Umbilicaria proboscoidea +, Anastrophyllum minutum +, Brachythecium sp. +, Cephalozia sp. +, Desmatodon latifolius +, Grimmia sp. +, Lophozia sp. +, Plagiomnium rostratum +, Polytrichum alpinum +, Rhacomitrium canescens +, Sphagnum sp. +, Tritomaria quinquedentata +.

litter in the rich meadow indicate better nutrient cycling and production than in the dry Festuca community. Species such as Arnica latifolia, Valeriana sitchensis, Polemonium pulcherrimum and Geranium erianthum are restricted to these habitats.

The vegetation of this community type is dominated, as is the drier Festuca-lichen community, by Festuca altaica, which forms dense clumps and covers 50% of the sites. Although Festuca altaica is ubiquitous, occurring almost everywhere on the mountain except in the latest snowbeds and most exposed blockfields, it never attains elsewhere the high cover it does in the two Festuca community types. The Festuca altaica - Potentilla diversifolia rich meadow can be easily distinguished from the Festuca altaica - Cladina dry meadow by its floristic makeup. The rich meadow is characterized by the presence of Potentilla diversifolia and by Aconitum delphinifolium (Figure 15). It is further differentiated from the dry meadow by a 50% decrease in lichen cover, particularly Cladina rangiferina, C. arbuscula, Cetraria nivalis and Thamnolia vermicularis. A decrease in rock cover contributes to this decrease in lichens as well as indicating better soil development (Figure 16).

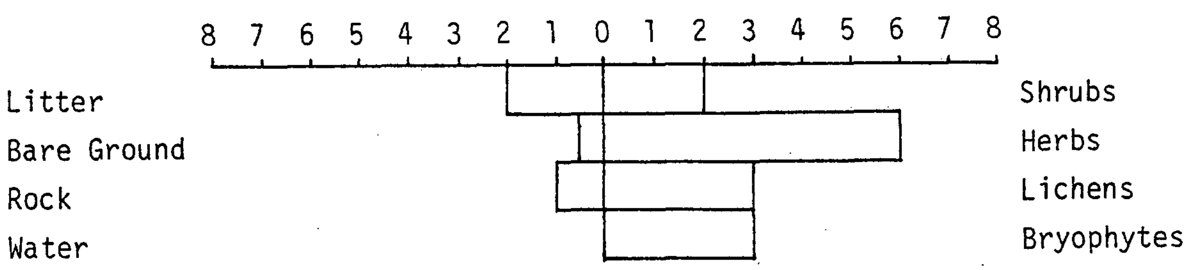


Figure 16: Cover relations in Festuca altaica - Potentilla diversifolia rich meadow community type.

Arctic ground squirrels (Spermophila parryii) seem to prefer this community for their burrows. Their presence contributes to the richness and floristic diversity of these sites. The dense vegetation serves to

Figure 15: Photograph of a Festuca altaica - Potentilla diversifolia rich meadow looking east across the Northeast Plateau toward Cairn Peak. Vegetation on Cairn Peak is composed of Cetraria nivalis - Vaccinium uliginosum fellfield (light green and gray tones) and Betula glandulosa - Cetraria cucullata shrubfield (dark green).

insulate the soil from freeze-thaw cycles. Consequently, these sites do not reflect frost action.

At elevations around 1555 m, Festuca meadows are invaded by tall shrub communities which displace the Festuca. In areas where snow persists a little too long for shrub development (late June), but not long enough to promote snowbed vegetation, Festuca dominates.

B.3.1.7 Betula glandulosa - Cetraria cucullata shrubfield (Table XI)

The Betula glandulosa - Cetraria cucullata shrubfield community type develops on mesic to subxeric sites where moderate and continuous winter snow cover remains no longer than mid-June. Best development is between 1524 m and 1600 m, marking this community as one of the community types forming the lower limit of alpine vegetation. This vegetation might be considered an alpine extension of the subalpine tall shrub communities where Betula glandulosa is prominent on acidic well-drained slopes. Pinus contorta and Abies lasiocarpa reach their altitudinal limits in the protection of the Betula community.

The vegetation is characterized by a scant herb cover consisting of scattered individuals of Festuca altaica, Hierochloe alpina, Stellaria longipes, and Aconitum delphinifolium. Alpine populations of Pedicularis laboradorica are restricted to this community. Low herb cover is attributed to shading out by the dense shrub canopy. Lichens are common, the most characteristic species being Cetraria cucullata. Cetraria richardsonii, an uncommon species on the mountain, is frequently found around the North Knoll in this community type. Cladonia gracilis, Cladina rangiferina, C. arbuscula, Cetraria nivalis and Thamnolia vermicularis also contribute significantly to the lichen cover. Mosses dominated by Hylocomium alaskanum frequently form spongy mats around the bases of the

TABLE XI: Floristic table for the Betula glandulosa - Cetraria cucullata shrubfield showing species composition and cover.

Community Type: Betula glandulosa - Cetraria cucullata shrubfield

Site Number	2	14	19	15	123	119	30	75	77	20	124		
Elevation (m)	1570	1554	1570	1539	1585	1585	1600	1554	1570	1570	1554		
Position/Relief	—	~	~	⌒	—	\	⌣	—	⌣	—	—		
Slope (°)	3	12	13	11	1	18	7	1	6	0	0		
Exposure	SSW	ENE	W	ENE	NNW	E	ESE	S	SE	W	NNW		
Hygrotope	3	3	3	3	3	3	2	3	3	2	2		
	Cover Classes											Constancy	Avg. Cover %
Litter	3	3		4		1	1	2	2	1			8
Ground	1								1	6	1		7
Rocks				+	1		+		+	2	7		9
SHRUBS													
Betula glandulosa	4	3	5	7	5	7	7	7	1		1	V	43
Empetrum nigrum	+	3			3	5	1		7	1		IV	15
Salix planifolia	2	6	5	1	2					1	1	IV	12
Vaccinium uliginosum	+	1	1	2	1					1	2	IV	3
Vaccinium vitis-idaea	1	1	+		1			1			+	III	1
Ledum palustre					3					+	+	II	2
Salix reticulata	+				1					1		II	+
Salix polaris	+									1	+	II	+
HERBS													
Artemisia arctica	1	3	1	1	+	+	1		+			IV	7
Stelleria longipes	+	+	+	+		+	+	+				IV	+
Antennaria monocephala	+		+			1	+	+	+			III	+
Festuca altaica	+				+	1	1		1			III	+
Poa sp.	+			+	+			1				II	+
Carex sp.	+			+	+				+			II	+
LICHENS													
Cetraria cucullata	1	+	1	2	1	1	2	1			1	V	3
Cladonia gracilis	+	1	+	1	1	1	1	1	1			V	2
Stereocaulon tomentosum	2			1		1	1	3		1	1	IV	4
Dactylina arctica	+	+	1	1	1		1	1	1			IV	2
Cladina arbuscula			2	1	1	3		3		+		III	5
Cladina rangiferina			1	1	1	1	1	3				III	3
Cetraria islandica	2			1	1	+		1	1			III	2
Cetraria nivalis	1			1		1	1	+			+	III	1
Thamnolia vermicularis	+			+		+				+	+	III	+
Peltigera aphthosa		2	2	1						+		II	2
Cladina mitis	2						1		1			II	1
Cetraria pinastri		+	1	1				1				II	+
Cetraria richardsonii	1		1	+			1					II	+
Cladonia amaurocraea	+				1		1	1				II	+
Cladonia sp.	+	+						+			1	II	+
Crustose ground-gray	1								1		1	II	+
Cladonia coccifera					1			+	1			II	+
Crustose rock	1								+		1	II	+
Rhizocarpon geographicum	+			+						+		II	+
BRYOPHYTES													
Dicranum sp.	2	+	+	1	2		1	1			1	IV	3
Bryum sp.					1	1		1	+		+	III	+
Hylacomium alaskanum		4	1	2	+							II	4
Polytrichum alpestre				2	4						1	II	4
Aulacomnium palustre		3			3						+	II	3
Barbilophozia sp.					1			1			+	II	+
Lophozia sp.		+			1						+	II	+
Total Shrubs	4	7	8	7	6	7	7	7	7	3	2		65
Total Herbs	3	3	2	1	1	1	1	1	1	1	2		7
Total Lichens	5	2	3	3	3	4	3	6	3	1	2		22
Total Bryophytes	2	5	1	3	6	1	1	2	+		1		14

Other species occurring in less than 20% of the sites with their average cover: Cassiope tetragona +, Dryas octopetala +, Loiseleuria procumbens +, Aconitum delphinifolium +, Antennaria alpina +, Bistorta vivipara +, Carex microchaeta +, Cerastium beeringianum +, Festuca brachyphylla +, Gentiana glauca +, Hierochloe alpina +, Luzula spicata +, Minuartia obtusiloba +, M. rubella +, Pedicularis capitata +, P. laboradorica +, Poa arctica +, Potentilla hyparctica +, Saxifraga tricuspidata +, Sedum rosea +, Senecio lugens +, Trisetum spicatum +, Alectoria minuscula +, Cladonia bellidiflora +, C. carneola +, C. ecmocyna +, C. fimbriata +, C. gonecha +, C. macrophylla +, C. pocillum +, C. uncialis +, C. verticillata +, Crustose ground-black +, Nephroma arctica +, N. expallidum +, Umbilicaria hyperborea +, Aulacomnium turgidum +, Ceratodon purpureus +, Drepanocladus uncinatus +, Polytrichum alpinum +, Ptilidium ciliare +, Rhacomitrium canescens +, Sphagnum sp. +.

tall shrubs. Shrub species are in two strata and contribute the greatest cover to this community (Figure 17). The upper stratum is composed entirely of Betula glandulosa and Salix planifolia. The former occurs in homogeneous patches where the ground is raised and well-drained. In shallow depressions where there is some seepage influence from snowbeds, the Betula occurs mixed with and often beneath Salix planifolia. The herbs tend to be concentrated in these richer locations, whereas the lichens are more conspicuous in the drier sites. The low stratum shrubs are Empetrum nigrum, Vaccinium uliginosum, and V. vitis-idaea.

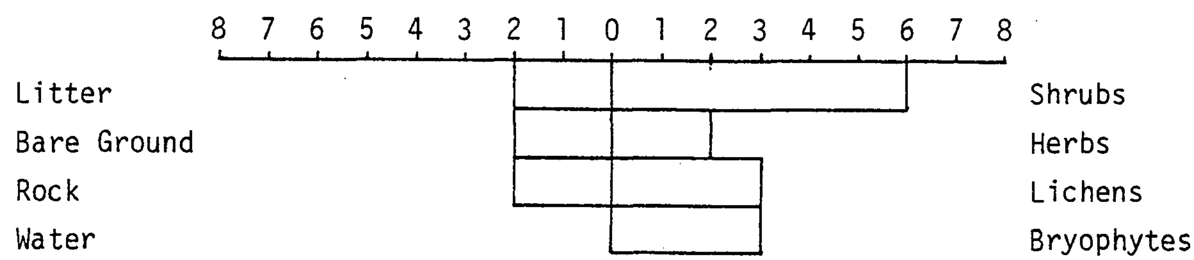


Figure 17: Cover relations in Betula glandulosa - Cetraria cucullata shrubfield community type.

Shrub height is controlled by snow depth. Any twigs of Betula or Salix extending above the snow during the winter months are killed by snow abrasion and extreme cold. This gives the community a very flat-topped appearance during the snow-free months (Figure 18). Depending on the microtopography, Betula attains heights of .08 to .3 m and Salix planifolia, .3 to .6 m. Changes in surface topography can be detected from a distance by color differences between birch, which has a very dark green appearance, and willow, with a much lighter tone. These differences are enhanced in late August when the birch leaves turn red and the willow turn yellow.

The Betula glandulosa - Cetraria cucullata shrubfield is usually found in association with the Festuca meadows and the Cetraria

Figure 18: The Betula glandulosa - Cetraria cucullata shrubfield looking west down the west slope of the North Knoll. Shrub in the foreground is Salix planifolia and shrubs beyond are mostly Betula glandulosa. Note flat-topped appearance due to winter wind pruning.

nivalis - Vaccinium uliginosum fellfield, where it occupies a position intermediate in exposure between the two. Where the Festuca communities come in contact with the birch, the Festuca altaica is displaced to areas where snow lasts until late June. This snow duration is too long for the establishment of Betula and Salix planifolia; however, Empetrum nigrum often extends into these areas, forming mats and further displacing the Festuca. Small patches of the birch community develop in concavities within fellfields. This is best seen on the north side of the North Knoll where Betula glandulosa forms bands across the slope in the lee of shallow lobes, probably of solifluction origin. In the lee of these lobes and in shallow depressions, wind abrasion keeps the birch trimmed down to the level of the surrounding topography.

Very common features within the Betula community are non-sorted circles, stripes and pockets of Festuca altaica. These seem to be genetically related and are discussed in the section on periglacial features. Brunisols probably predominate here.

B.3.1.8 Cassiope tetragona - Cladina mitis heath (Table XII)

The Cassiope tetragona - Cladina mitis heath community type develops on gentle northern and eastern slopes where snow cover is continuous, moderate and remains until early-to-late June. The soils, especially those on the north slope, are influenced by seepage and are mesic to subhygric. Vascular vegetation does not form a continuous carpet and is frequently interrupted by sorted and nonsorted circles and solifluction steps. The concentration of rocks at the soil surface could also indicate strong frost heaving (Figure 19). Vegetation has invaded most of the circles and the rocks are lichen-covered, implying that frost activity was probably more intense in the past. The circles have a tendency to creep

TABLE XII: Floristic table for the Cassiope tetragona - Cladina mitis heath community and the Cassiope tetragona - Solorina crocea subcommunity showing species composition and cover.

Community Type:	Cassiope tetragona - Cladina mitis heath											
				Cassiope tetragona-Solorina crocea subcommunity								
Site Number	36	128	129	4	37	55	22	79	49	3		
Elevation (m)	1631	1631	1631	1570	1615	1676	1585	1768	1600	1554		
Position/Relief	—	—	—	⌣	⌣	⌣	⌣	⌣	⌣	◟		
Slope (°)	1	4	3	4	3	5	10	4	5	5		
Exposure	E	ESE	ESE	W	E	SE	NNW	N	NE	W		
Hygrotope	2	2	2	3	3	3	3	3	3	3	Con-stancy	Avg. Cover %
	Cover Classes			Cover Classes								
Litter	2			1	1	1	1	1	1	2		3
Ground				3	+	1	1	2		1		4
Rocks	3	1	2	2	3	3	1	4	4	1		14
Water				+			+					+
SHRUBS												
Cassiope tetragona	3	4	1	2	4	3	6	3	5	3	V	25
Salix polaris	1	2	3	3	1	1	+	1	1	1	V	6
Empetrum nigrum	+			+						1	II	+
Dryas octopetala	+			+						+	II	+
HERBS												
Artemisia arctica	+	1	3	1	1	1		1	1	1	V	4
Antennaria monocephala	1	1	1	1	1	1	+	1	1	1	V	3
Carex microchaeta	+	1	1	1	+	+	1	1	+	1	V	2
Festuca altaica	2	3	4	+	1	1	1	1			IV	7
Saxifraga bronchialis	+	+	+	+	+				3		III	2
Bistorta vivipara	+	1	1		+	1				+	III	1
Silene acaulis				1	+	1	1		+	+	III	1
Stellaria longipes	+	1	1		+	+				+	III	+
Minuartia obtusiloba	+	1	+		+	1				+	III	+
Potentilla diversifolia		1	1	+					+		II	+
Pedicularis capitata				+		1				+	II	+
Gentiana glauca				+			1			+	II	+
Campanula lasiocarpa		+	1			+					II	+
Pedicularis langsdorfii	+			+				+			II	+
LICHENS												
Stereocaulon tomentosum	1	1	3	3	+	1	1	+		3	V	7
Cetraria islandica	1	1	1	1	1	2	1	1	1	1	V	4
Rhizocarpon geographicum	1	1	1	2	1	2		2	1	1	V	4
Cladina mitis	1	1	1	1	1	+	1	1		+	V	2
Crustose ground-gray	1			1	4	5		3	3	2	IV	12
Crustose rock	1	1	2		2	2		3	3		IV	7
Cetraria nivalis	1	3	3	1	2			1	1	1	IV	6
Cladonia gracilis	1	1	1	+			1	+	2	1	IV	2
Dactylina arctica	1			+	1	+	+	1	1	1	IV	2
Cladonia coccifera	1			1	1	+	1	1	1		IV	2
Umbilicaria hyperborea	1	1		1	2			1	1		III	2
Solorina crocea				2	1	1	1	1	+		III	2
Dactylina ramulosa		1	1	+	1				+	1	III	1
Cladonia pyxidata		3	1	1							II	2
Cladonia sp.								1	3	1	II	2
Cladonia ecmocyna		1	1		1	+					II	+
Cladonia verticillata			+		1	+				1	II	+
Cladina rangiferina	1						+		+	1	II	+
Cladonia pocillum	+						1			1	II	+
Pertusaria dactylina				1	+					+	II	+
Peltigera aphthosa					+			+		1	II	+
BRYOPHYTES												
Polytrichum alpestre	+	1	1	1			1		1	2	IV	2
Anthelia juratzkana				1	3	+	3	1			III	4
Dicranum sp.	+				1			+	1	1	III	1
Barbilophozia sp.	+				1				1	+	II	+
Bryum sp.				1		+			+	+	II	+
Polytrichum piliferum				+				1		1	II	+
Total Shrubs	3	4	3	3	5	4	6	4	5	5		33
Total Herbs	3	5	5	2	2	2	2	2	3	2		17
Total Lichens	4	4	6	5	6	6	3	5	6	6		48
Total Bryophytes	+	1	1	2	3	1	3	1	2	3		8

Other species occurring in less than 20% of the sites with their average cover: Abies lasiocarpa +, Betula glandulosa +, Ledum palustre +, Salix planifolia +, S. reticulata +, Vaccinium uliginosum +, V. vitis-idaea +, Antennaria alpina +, Cardamine bellidifolia +, Festuca brachyphylla +, Hierochloe alpina +, Luzula arcuata +, L. spicata +, Lycopodium alpinum +, Oxyria dygina +, Poa arctica +, Poa sp. +, Pyrola grandiflora +, Saxifraga nelsoniana +, S. rivularis +, Sedum rosea +, Sibbladia procumbens +, Trisetum spicatum +, Alectoria minuscula +, A. nigricans +, Cetraria cucullata +, C. delisei +, C. richardsonii +, Cladonia amaurocraea +, C. carneola +, C. macrophylla +, C. uncialis +, Cladina arbuscula +, Cornicularia muricata +, Nephroma expallidum +, Peltigera canina +, Thamnolia vermicularis +, Umbilicaria proboscoidea 2, Anastrophyllum minutum +, Andreaea rupestris +, Dicranoweisea crispula +, Drepanocladus uncinatus +, Lophozia sp. +, Rhacomitrium canescens +.

Figure 19: The *Cassiope tetragona* - *Cladina mitis* heath on north slope. Note the clumped appearance of the *Cassiope* and the large number of exposed rocks.

down the 2 - 5^{o} slope. Two soil pits, dug so as to bisect the circles, show a buried organic horizon, illustrating the overriding effect of this solifluction action.

Shrubs, dominated by Cassiope tetragona, are the dominant vascular vegetation (Figure 20). Salix polaris is constantly present in these sites. The Cassiope tends to be concentrated around the rocky perimeters of the sorted circles, imparting a clumped appearance from a distance and from the air (Figure 66). The most prominent herb is Festuca altaica. Other common herbs are Carex microchaeta, Saxifraga bronchialis, and Potentilla diversifolia. Cetraria nivalis and Cladina mitis commonly form a major part of the vegetation. Luzula arcuata, Solorina crocea and Anthelia juratzkana, all characteristic snowbed and late snowbed species, are early colonizers of the barren frost-formed circles on the north slope.

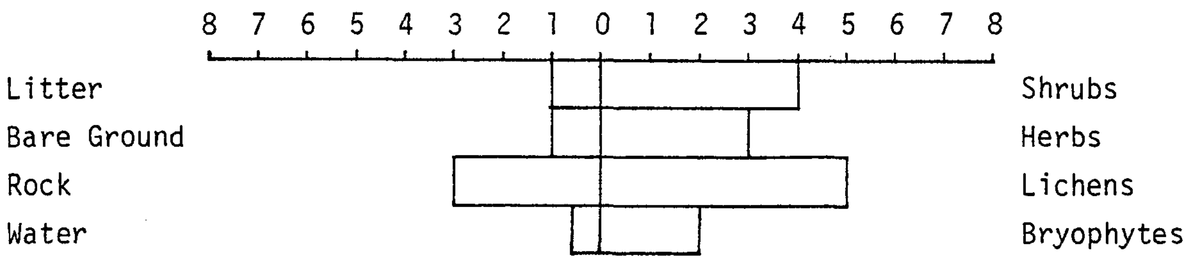


Figure 20: Cover relations in Cassiope tetragona - Cladina mitis heath community type.

The Cassiope community is frequently associated with the Festuca altaica meadows. Differences can be attributed mostly to snow duration. Differences in snow duration can be hypothesized by the phenology of the Cassiope. Where the heath and meadow communities occur on the same slope, the Cassiope tetragona within the Cassiope community will be, at any one time during the growing season, phenologically behind the scattered individuals of Cassiope occurring within the Festuca meadows. Cladina rangiferina prefers well-drained sites that become free of snow earlier in the growing season (Scott, 1974). The replacement of Cladina rangiferina by Cladina mitis is also indicative of the prolonged snow duration within the Cassiope community.

The Cassiope tetragona - Cladina mitis heath community type is a major vegetation type of the East Plateau. The East Plateau lies in the lee of the high ridges and peaks on the south side of the mountain resulting in a greater accumulation of snow. At the same time, this plateau is slightly domed which hinders the development of long-lying snowbeds. Aerial photographs show these sites to be snow-free by at least the first week in June.

At alpine elevations below 1600 m on depressional topography, a variant of the Cassiope community occurs which I do not consider sufficiently different to warrant community status. This variant, which I have named the Cassiope tetragona - Solorina crocea subcommunity, does not form large patches but is confined to the outer lower edge of late-lying snowbeds where snowmelt occurs between late June and early July. The Cassiope subcommunity is usually flanked by a snowbed community type on one side and the Festuca altaica - Potentilla diversifolia meadow community on the other.

B.3.1.9 Cassiope stelleriana - Phyllodoce empetriformis snowbed (Table XIII)

The Cassiope stelleriana - Phyllodoce empetriformis snowbed community type occurs on eastern and northern slopes in depressional topography and in the lee of solifluction lobes where snow tends to accumulate during the winter months. It attains its best development below 1676 m and extends well into the subalpine zone. The sandy soils are irrigated throughout the growing season by seepage from upper snowbeds and rarely dry out. On the average, snow remains until the first week in July. Soils

TABLE XIII: Floristic table for the Cassiope stelleriana - Phyllodoce empetriformis snowbed showing species composition and cover.

Community Type: Cassiope stelleriana - Phyllodoce empetriformis snowbed

Site Number	34	28	29	66	39	60	11	142		
Elevation (m)	1554	1570	1570	1585	1600	1600	1554	1570		
Position/Relief	〰	◡	◡	◡	◡	〰	◡	◡		
Slope (°)	1	7	13	2	1	1	8	1		
Exposure	E	ENE	ENE	E	E	NE	NE	NNE		
Hygrotope	3	3	3	3	3	3-4	3-4	4		Avg. Cover
	Cover Classes								Constancy	%
Litter	1	4	3	1		2	3			10
Ground	+	+	+	1		+		1		1
Rocks	+	+		4	1	1		1		5
Water			1			+		1		+
SHRUBS										
Cassiope stelleriana	5	2		3	3	6	5	3	V	26
Salix polaris			+	3	1	3	2	3	IV	8
Phyllodoce empetriformis	1	1	2	1			3	1	IV	5
Cassiope tetragona		1		1	+	+		1	IV	1
HERBS										
Sibbaldia procumbens	1	1	+	+	1	+	1	1	V	2
Artemisia arctica	+	+	1	+	1	+	1	1	V	2
Antennaria monocephala		+	+	+	+	+	+	+	V	+
Carex sp.	+		+	2	+	1	1		IV	2
Gentiana glauca	+	+	+			+	+	1	IV	+
Luetkea pectinata	1	1	1				3		III	3
Antennaria alpina		1	+	1			+		III	+
Bistorta vivipara					+	1	+	1	III	+
Lycopodium alpinum			3				+		II	2
Pedicularis sp.		+			1	+			II	+
Luzula arcuata				1				+	II	+
Epilobium anagallidifolium							+	+	II	+
Ranunculus eschscholtzii						+	+		II	+
Equisetum scirpoides						+		+	II	+
Luzula sp.					+		+		II	+
Huperzia selago						+	+		II	+
LICHENS										
Rhizocarpon geographicum		+	+	3	1			1	IV	3
Solorina crocea	1	1	1	2	1				IV	3
Cladonia sp.	1		1	1	1		1		IV	2
Cetraria islandica	+	1	+	1	+		1		IV	1
Crustose ground-gray		1	1	3	2				III	4
Cladonia ecmocyna		1	1	+	1				III	1
Crustose rock				3	1			1	II	3
Peltigera canina		1					2		II	1
Stereocaulon tomentosum		+		+	1				II	+
Peltigera aphthosa			1		1				II	+
Cladonia coccifera		1			+				II	+
BRYOPHYTES										
Dicranum sp.	3	1	1		1	2	1	1	V	5
Lophozia sp.	1	1	1				1	2	IV	3
Drepanocladus uncinatus	1	1				1		3	III	3
Aulacomnium palustre						3	+	2	II	3
Anthelia juratzkana				1	1	1			II	1
Polytrichum piliferum		1		1	1				II	1
Polytrichum alpinum	1	1						1	II	1
Cephalozia sp.						2		1	II	1
Sphagnum sp.						2		+	II	1
Bartramia ithyphylla					1			1	II	+
Barbilophozia sp.		+			1			1	II	+
Total Shrubs	5	3	2	5	4	6	6	5		38
Total Herbs	2	3	3	3	3	2	2	3		14
Total Lichens	1	3	1	4	5		2	1		13
Total Bryophytes	4	1	2	2	3	6	2	7		28

Other species occurring in less than 20% of the sites with their average cover: Abies lasiocarpa +, Salix planifolia 1, S. reticulata +, Kalmia microphylla +, Aconitum delphinifolium +, Castilleja unalaskensis +, Carex bipartita +, Carex microchaeta +, C. pyrenaica +, Festuca altaica +, Hierochloe alpina +, Minuartia obtusiloba +, Pedicularis capitata +, P. langsdorfii +, Petasites frigidus +, Poa sp. +, Potentilla diversifolia +, Pyrola grandiflora +, Ranunculus nivalis +, Sedum rosea +, Veronica wormskjoldii +, Cladina mitis +, Cladonia verticillata 1, Lobaria linita +, Umbilicaria hyperborea +, Anastrophyllum minutum 1, Blepharostoma trichophyllum Brachythecium sp. 2, Hygrohypnum styriacum +, Paludella squarrosa +, Pleuroclada albescens +, Rhacomitrium canescens +, Tomenthypnum nitens 1, Tritomaria quinquedentata +.

probably range from gleyed brunisols to regosols.

These sites are well vegetated with very few bare areas and exposed rocks (Figure 21). The combination of snow duration and uniform vegetative mat tends to decrease the thaw rate of the soil. On August 9, 1974 the soil at one site was still frozen at a depth of 55 cm indicating the probable occurrence of permafrost.

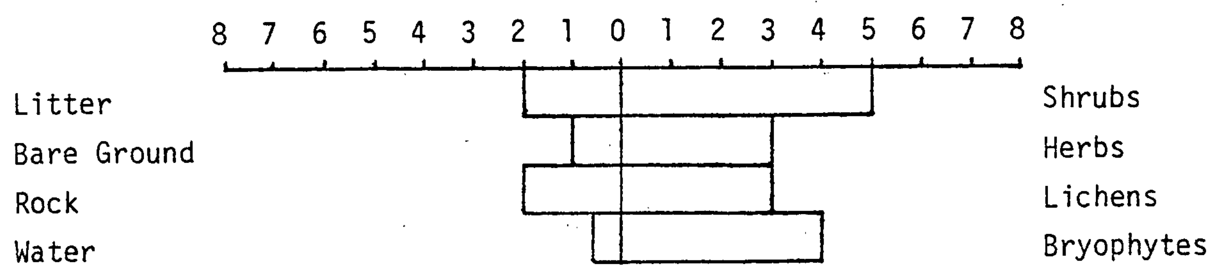


Figure 21: Cover relations in Cassiope stelleriana - Phyllodoce empetriformis snowbed community type.

Dwarf shrubs, dominated by Cassiope stelleriana, contribute most of the vegetation cover (Figure 22). Phyllodoce empetriformis is a characteristic associate whose prominence increases with a decrease in elevation and attains a maximum cover in the subalpine. Cassiope mertensiana is rare on Teresa Island above treeline and reaches its highest elevation within this community type.

The most prominent and constant herb is Sibbaldia procumbens. Luetkea pectinata is another characteristic herb whose prominence increases in the subalpine. Important associates are Antennaria alpina, Lycopodium alpinum and Bistorta vivipara. The Lycopodium attains its best development in these sites, especially in the low alpine and subalpine.

The scarcity of macrolichens helps to characterize this and all other snowbed communities. The most diagnostic macrolichen here and in other snowbeds is Solorina crocea. Anthelia juratzkana, a liverwort commonly associated with snowbeds, is frequently found in the Cassiope snowbed.

Figure 22: Cassiope stelleriana - Phyllodoce empetriformis snowbed community beside runoff stream from the East Plateau Pond near Camp #2. Scene is looking north across East Valley to the Northeast Plateau.

Drepanocladus uncinatus and Bistorta vivipara are both promoted by the constant seepage through the site.

B.3.1.10 Sibbaldia procumbens - Polytrichum piliferum snowbed (Table XIV)

The Sibbaldia procumbens - Polytrichum piliferum snowbed community type develops in areas of snow accumulation on northern and eastern slopes from 1707 m to below treeline. This community lacks seepage and its sandy, well-drained, poorly developed soils dry out early in the growing season. Within a long-lasting snowbed, this dry community usually occurs on the upper edge. The lower edges of most snowbeds are constantly irrigated by the melting snow. In early melting snowbeds, which are not subject to much seepage from melting snow above them, the Sibbaldia community can occur on the top or bottom and if the entire snowbed melts out early in July, this community can occur in the center.

Vascular vegetation only covers between 40 and 60% of the sites. The herb layer is the best developed, dominated by Sibbaldia procumbens. Important associates are Luzula arcuata, Carex pyrenaica and Carex microchaeta. The shrub layer is represented almost entirely by Salix polaris. The dominant bryophyte is Polytrichum piliferum, a species characteristic not of snowbeds, but of xeric sites. It is also found frequently in fellfields. Lichens form the major ground cover (Figure 23). Most of the lichen cover can be attributed to crustose species which cover the rocks and large areas of what would otherwise be bare ground. These crustose species give the community a distinctive whitish tone (Figure 24). The various species of crustose lichens were not identified. In the sampling they were grouped together according to color and substrate.

TABLE XIV: Floristic table for the *Sibbaldia procumbens* - *Polytrichum piliferum* snowbed showing species composition and cover.

Community Type: *Sibbaldia procumbens* - *Polytrichum piliferum* snowbed

Site Number	54	85	86	63	48	127	146		
Elevation (m)	1676	1707	1707	1585	1600	1783	1600		
Position/Relief	◡	◡	◡	◡	◡	◡	◡		
Slope (^{o})	3	5	1	4	7	8	5		
Exposure	SE	NE	NE	E	NE	ESE	ENE		
Hygrotope	3	3	2	2	2	2	2		Avg. Cover
	Cover Classes							Constancy	%
Litter	1	1	1	+	1		1		3
Ground		+	+	1	1				1
Rocks	1	+	4	3	6	5	4		27
SHRUBS									
Salix polaris	5	5	3	3	1	+	3	V	20
HERBS									
Artemisia arctica	1	1	1	2	3	1	2	V	7
Sibbaldia procumbens	2	3	2	1	1	+	1	V	6
Luzula arcuata	1	1	1	1	1	1	1	V	3
Antennaria monocephala		1	1	1	1	1	1	V	3
Trisetum spicatum		+	1			1	3	III	4
Carex microchaeta		1	1			2		III	2
Carex sp.	2			1	1			III	2
Carex pyrenaica		1	1	+			1	III	1
Campanula lasiocarpa		+	1			+	1	III	1
Poa sp.	+	+		+		1		III	+
Saxifraga bronchialis					+	1	+	III	+
Minuartia obtusiloba			+	+		+		III	+
Luzula spicata						2	+	II	1
Festuca brachyphylla					+	1		II	+
Festuca altaica			+	1				II	+
Veronica wormskjoldii		1	+					II	+
Silene acaulis					1	+		II	+
Cardamine bellidifolia			+			+		II	+
Ranunculus eschscholtzii	+	+						II	+
LICHENS									
Crustose rock	+	+	1	2	3	4	2	V	10
Rhizocarpon geographicum	+	+	1	1	3	2	1	V	5
Solorina crocea		+	1	1	1	1	1	V	2
Stereocaulon tomentosum	+	1	+	1	+	1		V	2
Crustose ground-gray		+	3	6	5	3		IV	20
Cetraria islandica			1	1	2	1		III	2
Cladonia coccifera				1	1	2		III	2
Dactylina arctica			+		1	+		III	+
Cladonia pocillum			1		2			II	2
Umbilicaria proboscoidea			1			1		II	+
Umbilicaria hyperborea				1	1			II	+
Cladonia macrophylla		1	1					II	+
Cladonia gracilis			+	1				II	+
Peltigera canina	1	+						II	+
Cladonia sp.		+	1					II	+
BRYOPHYTES									
Polytrichum piliferum			1	1	2	1	+	IV	3
Lophozia sp.	1	1	3					III	3
Bryum sp.	1	1					1	III	1
Brachythecium albicans	1	1					1	III	1
Barbilophozia sp.	1	1			+			III	+
Polytrichum alpestre			2			1		II	2
Polytrichum alpinum	1	1						II	+
Dicranum sp.	+		1					II	+
Cephalozia sp.	1				+			II	+
Drepanocladus uncinatus		+				+		II	+
Total Shrubs	5	5	3	3	1	+	3		20
Total Herbs	4	5	4	3	4	5	5		33
Total Lichens	1	2	6	7	6	7	4		44
Total Bryophytes	2	2	3	1	3	2	1		17

Other species occurring in less than 20% of the sites with their average cover: *Cassiope tetragona* +, *Empetrum nigrum* +, *Salix arctica* +, *S. planifolia* +, *Aconitum delphinifolium* +, *Antennaria alpina* +, *Bistorta vivipara* +, *Carex bipartita* +, *C. phaeocephala* +, *Draba crassifolia* +, *Epilobium anagadilifolium* +, *E. latifolium* 3, *Gentiana glauca* +, *Luetkea pectinata* 1, *Lycopodium alpinum* +, *Oxyria digyna* +, *Pedicularis* sp. +, *Poa arctica* +, *P. leptocoma* +,*Saxifraga nelsoniana* +, *Sedum rosea* +, *Solidago multiradiata* +, *Taraxacum lyratum* +, *Alectoria minuscula* +, *Cetraria nivalis* +, *Cladina mitis* +, *Cladonia ecmocyna* +, *Cornicularia muricata* +, *Lobaria linita* +, *Parmelia stygia* +, *Peltigera aphthosa* +, *Stereocaulon arcticum* +, *Anthelia juratzkana* +, *Aulacomnium palustre* +, *Bartramia ithyphylla* +, *Blepharostoma trichophylla* +, *Dicranoweisia crispula* +, *Grimmia* sp. +, *Hylocomium alaskanum* +, *Lophocolea minor* +, *Tritomaria quinquedentata* +.

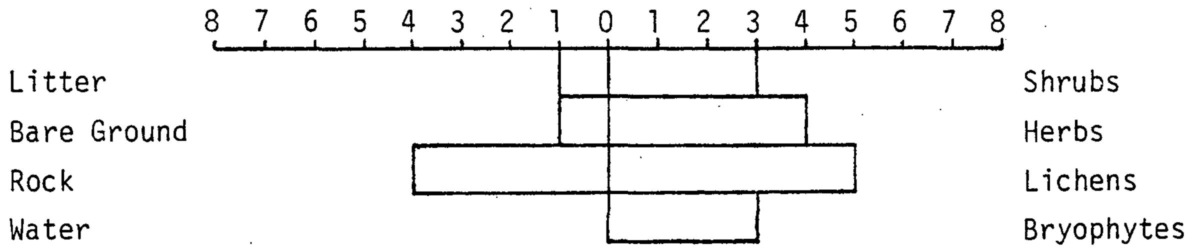


Figure 23: Cover relations in *Sibbaldia procumbens* - *Polytrichum piliferum* snowbed community type.

B.3.1.11 *Anthelia juratzkana* - *Luzula arcuata* late snowbed (Table XV)

The *Anthelia juratzkana* - *Luzula arcuata* late snowbed community type is the most widespread snowbed community on the mountain, occurring at all alpine elevations and down into the upper subalpine. The community is characterized by a meagre (25%) cover of vascular vegetation and by a high rock cover, usually 75 to 95% (Figure 25). Lichens have a high, 50%, cover and are represented almost exclusively by crustose species on the soil and rocks (Figure 26). These characteristics of the late snowbed community appear to develop because of three factors which are controlled or influenced by snow. 1) The extended duration of the snow results in a growing season which is normally too short to allow vascular taxa to complete their life cycles. Establishment of vascular plants in these long snow duration sites probably occurred during a period of mild winters and warm summers which lengthened the snow-free season. The critical period of snow duration varies with elevation. In the relatively mild environment of the subalpine, many vascular taxa can become established and reproduce (usually asexually) in areas free of snow as late as mid-August. At elevations above 1830 m, snowmelt occurring as early as mid-July can effectively inhibit plant colonization. 2) At mid- and high-alpine elevations, the

Figure 24: The Sibbaldia procumbens - Polytrichum piliferum snowbed community looking northeast to Atlin Lake. Note the white lichen-free rocks indicative of prolonged snow duration.

TABLE XV : Floristic table for the Anthelia juratzkana - Luzula arcuata snowbed showing species composition and cover.

Community Type: Anthelia juratzkana - Luzula arcuata snowbed

Site Number	53	65	110	138	140	131	132	83	139	122	126	91	68	69	88		
Elevation (m)	1676	1585	1753	1631	1631	1615	1615	1722	1631	1707	1737	1859	1877	1877	1707		
Position/Relief	◡	◡	◡	—	—	—	—	◡	—	—	—	—	◡	—	—		
Slope (°)	5	2	2	2	3	5	5	2	3	10	13	7	3	2	3		
Exposure	SE	E	ESE	NNE	NNE	ENE	ENE	NNE	NNE	NNW	NE	NNW	N-S	S	NE		
Hygrotope	3	3	3	2	2	3	3	3	3	3	2	1	1	2	2	Con-stancy	Avg. Cover %
	Cover Classes																
Litter	1	1	1	1		1	2	+				+	1	1	3		3
Ground	2	3	1	1	1	1	1	1	2	1	1	2	5	3	1		9
Rocks	6	6	4	4	5	4	6	7	6	5	6	6	3	6	2		48
Water															+		+
SHRUBS																	
Salix polaris	1		+	1	1	1		+	1	+			1	+		IV	1
Cassiope tetragona	1	+				+	1				1				1	II	+
HERBS																	
Luzula arcuata	3	1	1	2	1	3	1	1	3	1	1	+	1		3	V	7
Poa sp.	+	+						+				1	1	1	2	III	1
Sibbaldia procumbens	2	+	+	+	+	1	1									III	1
Antennaria monocephala	+			1		+			+			1	1		+	III	+
Silene acaulis		+		1					+	+	1	+		+		III	+
Carex pyrenaica		+	1	1	2	1	1									II	1
Cardamine bellidifolia	1					+		+	+				+		1	II	+
Artemisia arctica	1	+		+	1	+									+	II	+
Saxifraga bronchialis				1						1		+	1	1		II	+
Antennaria alpina	+	+	+	+	+											II	+
Carex microchaeta			1	1				+					1			II	+
Oxyria digyna		1	+						+			1				II	+
Saxifraga nelsoniana	+			+					1						1	II	+
Minuartia obtusiloba								+	+	+				+		II	+
LICHENS																	
Crustose rock	3	4	3	3	3	3	5	3	5	4	4	3	1	1	1	V	21
Crustose ground-gray	3	1	3	2		3	2	1		1	1	3		1		IV	7
Rhizocarpon geographicum	3	1	+		+	3	1	1		1	3	1	1	+		IV	5
Stereocaulon tomentosum		+	1	2	3	1		+	1	3	+		1	1	+	IV	4
Solorina crocea	1	2	3		1	1	1	1		1	1		1	1		IV	4
Cladonia sp.	1			4		1	1			+			1	1		III	3
Cetraria islandica	1			1	1	1		+		1	+	+	1			III	1
Umbilicaria hyperborea	1									1	1				+	II	+
Cetraria nivalis											+		1	1	+	II	+
Cladonia coccifera		1		+							1	+				II	+
BRYOPHYTES																	
Anthelia juratzkana	1	1	5	1		5	3	2	1	1	1	1		+	+	V	9
Bryum sp.	1			1	1	1	+	1	1	1	1	1	+		1	IV	2
Polytrichum alpestre			3	1					1	1	1			1	3	III	3
Polytrichum alpinum					1	1	1	1	+							II	+
Rhacomitrium sudeticum		1	+		+	1	1									II	+
Total Shrubs	1	+	+	1	1	1	1	+	1	+	1		1	+	1		2
Total Herbs	3	3	3	2	3	3	2	1	3	1	1	3	3	2	3		13
Total Lichens	6	5	5	6	6	4	6	5	5	5	6	5	3	3	1		38
Total Bryophytes	3	2	6	3	3	5	3	3	2	1	3	3	2	1	6		22

Other species occurring in less than 20% of the sites with their average cover: Cassiope stelleriana +, Empetrum nigrum +, Phyllodoce empetriformis +, Salix arctica +, Campanula lasiocarpa +, Carex bipartita +, C. capitata +, Carex sp. +, Draba incerta +, Epilobium latifolium +, Festuca brachyphylla +, Luzula sp. +, Lycopodium alpinum +, Papaver kluanense +, Potentilla hyparctica +, Ranunculus nivalis +, R. pygmaeus +, Saxifraga cernua +, S. ferruginaea +, S. oppositifolia +, S. rivularis +, S. tricuspidata +, Stelleria longipes +, Trisetum spicatum +, Alectoria miniscula +, A. nigricans +, Cetraria commixta +, C. cucullata +, C. delisei +, Cladonia carneola +, C. gracilis +, C. lepidota +, C. pocillum +, C. pyxidata +, Crustose ground-black +, Dactylina arctica +, Peltigera aphthosa +, Pertusaria dactylina +, Thamnolia vermicularis +, Umbilicaria cylindrica +, U. proboscoidea +, Andreaea rupestris +, Aulacomnium palustre 1, Barbilophozia sp. +, Brachythecium albicans +, Cephalozia sp. +, Ceratodon purpureus +, Dicranoweisia crispula 1, Dicranum sp. +, Drepanocladus uncinatus +, Grimmia sp. +, Lophozia sp. 1, Polytrichum piliferum +, Rhacomitrium canescens +, R. lanuginosum +, Scapania sp.

Figure 25: Anthelia juratzkana - Luzula arcuata late snowbed looking west across the north slope. A mat of Anthelia can be seen in the lower left-hand corner of the photograph.

effect of snow duration is often compounded by intense frost action which hinders plant establishment by disruption of the soil. Stone nets, sorted circles and stripes are common features within late snowbed habitats. The intense frost action of late snowbeds has been noted by Johnson and Billings (1962) and Scott (1974). 3) Melt-water erosion from permanent snowbeds is a factor on northern slopes of 10^{o} and over. This commonly results in late snowbed sites, below permanent snowbeds, with little or no soil present.

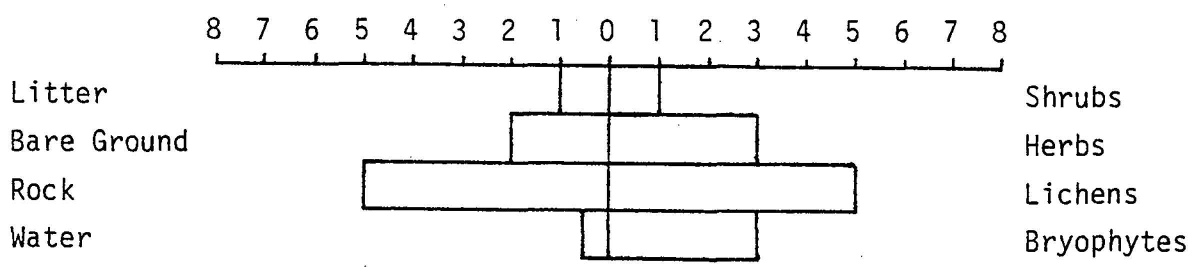


Figure 26: Cover relations in Anthelia juratzkana - Luzula arcuata late snowbed community type.

Soil development in all the sites is weak and regosols are the most common soil types.

Of all the vegetation, shrubs contribute the least cover. Salix polaris is a constant species, Cassiope tetragona is occasional, occurring in about 30% of the sites, and Cassiope stelleriana and Phyllodoce empetriformis are rare. The dominant herb is Luzula arcuata, which occurs in all sites. Important associates are Carex pyrenaica, Sibbaldia procumbens and Silene acaulis. Oxyria digyna, a common arctic and alpine species, has a restricted occurrence on Teresa Island and is most commonly found in the late snowbed communities. Papaver kluanense and Saxifraga oppositifolia are restricted to this community type and are found only on the high southern ridges. (The saxifrage is more indicative of pockets of alkaline soils than it is of late snowbeds.)

Anthelia juratzkana is an important diagnostic bryophyte.

It occurs in most sites and attains its best cover where the soil is kept moist by seepage. Dicranoweisia crispula and Rhacomitrium sudeticum are important associates, but do not occur on all sites. Lichens contribute to the vegetation cover. There are characteristically few macrolichens with the exception of Solorina crocea. Crustose species form the major cover and in dry sites gray crustose lichens dominate over the soil.

B.3.1.12 Carex pyrenaica - Luetkea pectinata - Juncus drummondii snowbed (Table XVI)

This snowbed community type is restricted to the East Plateau where it develops at elevations between 1585 m and 1646 m in small snow accumulation pockets on gradual slopes of all aspects except south. This is a very infrequent community and as such was sampled only four times. Snowmelt occurs between early and mid-July. Light seepage throughout the summer results in a mesic substrate with a vegetation mat dominated by herbs (Figure 27).

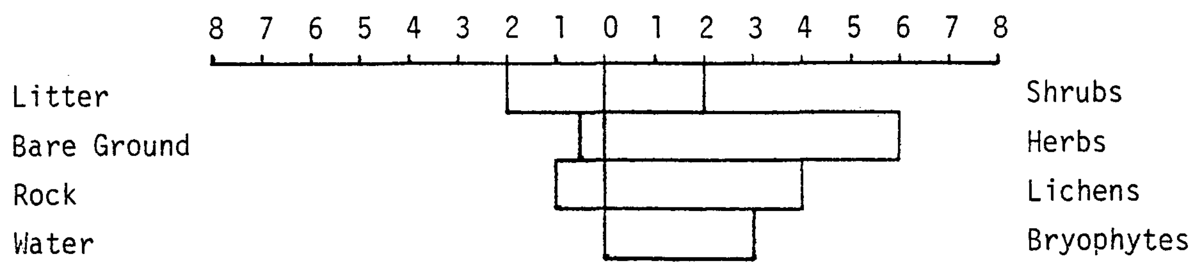


Figure 27: Cover relations in Carex pyrenaica - Luetkea pectinata - Juncus drummondii snowbed community type.

Carex pyrenaica with its narrow, wavy leaves, is the most characteristic species, occurring in all four sites and attaining an average cover of 35%. The distribution of this Carex on the mountain is restricted to areas of snow accumulation. An important herb associate is Luetkea pectinata with an average cover of 25%. This species has its major

TABLE XVI: Floristic table for the *Carex pyrenaica* - *Luetkea pectinata* - *Juncus drummondii* snowbed showing species composition and cover.

Community Type: *Carex pyrenaica* - *Luetkea pectinata* - *Juncus drummondii* snowbed

Site Number	48	102	64	115		
Elevation (m)	1646	1600	1585	1585		
Position /Relief	—	◡	—	◡		
Slope (^{o})	4	5	4	4		
Exposure	E	SE	E	NNW		
Hygrotope	3-4	3-4	3-4	3-4		
	Cover Classes				Presence /4	Avg. Cover %
Litter	3	2	1	2		9
Ground			1			+
Rocks	+	+	3	1		6
SHRUBS						
Salix polaris	3	+	+	1	4/4	6
Phyllodoce empetriformis	+	+		+	3/4	+
Cassiope stelleriana		+		+	2/4	+
HERBS						
Carex pyrenaica	3	5	3	5	4/4	30
Luzula arcuata	1	1	1	3	4/4	7
Sibbaldia procumbens	+	+	1	1	4/4	2
Artemisia arctica	+	+	+	+	4/4	+
Luetkea pectinata	3	5	3		3/4	20
Juncus drummondii	2	1	1		3/4	4
Antennaria alpina	+	+	+		3/4	+
Saxifraga ferruginea	+			1	2/4	+
Epilobium anagallidifolium	+		+		2/4	+
Veronica wormskjoldii	+	+			2/4	+
LICHENS						
Cetraria islandica	1	1	1	1	4/4	3
Crustose rock	+	+	1	1	4/4	2
Rhizocarpon geographicum	+	+	1	1	4/4	2
Solorina crocea	1		3	2	3/4	7
Cladonia sp.	1		1	3	3/4	6
Crustose ground-gray			4	1	2/4	8
Cladonia bellidifolia		1		1	2/4	2
BRYOPHYTES						
Dicranum sp.	1	2		3	3/4	7
Lophozia sp.	3	1			2/4	5
Drepanocladus uncinatus		1		3	2/4	5
Polytrichum alpinum	1	1			2/4	2
Total Shrubs	3	1	+	1		6
Total Herbs	6	7	3	6		57
Total Lichens	1	1	6	5		28
Total Bryophytes	4	5	1	4		20

Other species occurring in only one site with their average cover: *Cassiope tetragona* +, *Carex podocrapa* +, *Gentiana glauca* +, *Hieracium gracile* +, *Minuartia obtusiloba* +, *Poa* sp. +, *Pyrola grandiflora* +, *Cladonia carneola* +, *C. ecmocyna* +, *C. gracilis* +, *Stereocaulon tomentosum* +, *Bryum* sp. +, *Diplophyllum taxifolium* +, *Kiaeria falcata* +, *Orthocaulis kunzeana* +, *Polytrichum piliferum* +, *Scapania* sp. +.

distribution in the subalpine and its presence in this community reflects the protection provided by the snowbed. Other important herb associates are Juncus drummondii, the tallest species within this community, Luzula arcuata, Antennaria alpina and Epilobium anagallidifolium, all promoted by an extended snow duration.

Salix polaris contributes the most to the shrub cover. Phyllodoce empetriformis, Cassiope tetragona and Cassiope stelleriana are of scattered occurrence. Bryophyte cover is dominated by Anthelia juratzkana with Drepanocladus uncinatus and Polytrichum alpinum as important associates. These last two mosses are promoted by seepage. Gray crustose species form the lichen cover but very important is the constant occurrence of Solorina crocea.

The sites have a distinctive, light brown color from a distance due to the Juncus and the dead attached leaves of Carex pyrenaica. This community retains its brown appearance even on infrared film (Figure 28).

B.3.1.13 Salix planifolia - Empetrum nigrum - Sphagnum runoff (Table XVII)

This community type develops below 1676 m on snow accumulation slopes. The snow provides a constant summer runoff and affords protection during the winter for the Salix. Snow probably melts by late May or early June. This community is most extensive on the mountain in the small basin below the East Plateau Pond and on the north slope above the North Knoll (see Figures 68 and 69). On the north slope, these runoff sites occur frequently on the upper surface of solifluction benches (treads).

The vegetation varies physiognomically depending on slope and elevation. On well-drained runoff slopes between 5 and 15^{o} at alpine

Figure 28: Color-infrared photograph of Carex pyrenaica - Luetkea pectinata - Juncus drummondii snowbed on East Plateau. Brown tones are Carex pyrenaica and Juncus drummondii; the reddish brown in the foreground is Luetkea pectinata and the pink above the snowbed community is primarily Festuca.

TABLE XVII: Floristic table for the Salix planifolia - Empetrum nigrum - Sphagnum runoff community and the Cassiope tetragona - Empetrum nigrum subcommunity showing species composition and cover.

Community Type:	Salix planifolia - Empetrum nigrum - Sphagnum runoff								Cassiope tetragona - Empetrum nigrum sub-community			
Site Number	93	33	23	7	120	94	104	103	96	141		
Elevation (m)	5100	5100	5300	5450	5200	5100	5150	5200	5150	5100		
Position/Relief	~	~	~	~	~	~	∪	—	~	~		
Slope (°)	1	2	5	2	1	6	8	4	2	2		
Exposure	E	NE	NNW	NW	NWW	E	W	W	WSW	SSW		
Hygrotope	4	4-5	4	4	4	4-5	4	4	4-5	4-5	Con-	Avg. Cover
	Cover Classes								Cover Classes		stancy	%
Litter	1	1		2		1	3	2	3	1		6
Ground				+						+		+
Rocks		1							3	3		4
Water				2						1		1
SHRUBS												
Salix planifolia	3	6	5	4	6	8	8	7		+	V	49
Empetrum nigrum	4	6	3	1	4		+		3	3	IV	18
Vaccinium vitis-idaea	1		1	1	+	+		+		1	IV	1
Cassiope tetragona	1			+	1		+		3	3	III	4
Vaccinium uliginosum	1	1	1	2			+	1			III	2
Salix reticulata	+	1		2			+	1		1	III	2
Betula glandulosa			5		+			2			II	5
Salix polaris	+			1					2	1	II	1
HERBS												
Artemisia arctica	1	1	2	1	1	2	1	1	1	1	V	4
Stellaria longipes	+	+		+	+	1	1	1			IV	1
Aconitum delphinifolium	+			+	1	1		1			III	1
Bistorta vivipara	+			+				+	1	1	III	+
Pedicularis capitata	+			+				+	1	+	III	+
Carex sp.	1	+		+		+		+			III	+
Petasites frigidus			1	2		1			1		II	2
Gentiana glauca				+				+	+	1	II	+
Saxifraga nelsoniana						+	1	+			II	+
Poa sp.						+		+	+		II	+
LICHENS												
Peltigera aphthosa		2		1	1			+		1	III	2
Cladonia gracilis	1	+		1					1	1	III	1
Dactylina arctica	+			+	+				+	+	III	+
Cetraria nivalis	+								1	3	II	2
Cladonia coccifera	+								1	2	II	1
Cladina rangiferina	+			1					2	1	II	1
Crustose rock		1							1	2	II	1
Cetraria islandica		1		1					+	1	II	+
Cladina mitis		1			+				+	+	II	+
Cladina arbuscula	1			1						1	II	+
Cetraria cucullata		1	+	1							II	+
Rhizocarpon geographicum		+							1	1	II	+
Stereocaulon tomentosum					+			+	1		II	+
Cladonia gonecha				1					+	+		
BRYOPHYTES												
Aulacomnium palustre	3	1	2	2	5	3	1	+	1	1	V	11
Sphagnum sp.	2		3	3		1		2	+		III	6
Polytrichum alpestre	2			2	4				2	2	III	6
Hylacomium alaskanum	1	1			2	1		2	1		III	3
Dicranum sp.	+	1		1				1	1	3	III	3
Bryum sp.	1	+		1		1	1		1		III	2
Drepanocladus uncinatus				+		1	2	2			II	2
Lophozia sp.	1			1	1					1	II	1
Cephalozia sp.	1			1					1		II	+
Total Shrubs	6	7	8	5	7	8	8	7	5	5		72
Total Herbs	1	1	3	3	1	4	2	3	2	3		13
Total Lichens	1	3	+	2	1		+	1	3	6		12
Total Bryophytes	6	2	3	6	7	5	3	5	5	5		42

Other species occurring in less than 20% of the sites with their average cover: Ledum palustre +, Anemone richardsonii +, Antennaria monocephala +, Campanula lasiocarpa +, Carex microchaeta +, Epilobium angustifolium +, Equisetum palustre +, E. scirpoides +, Festuca altaica +, Hierochloe alpina +, Luzula spicata +, Lycopodium annotinum +, Mertensia paniculata 2, Pedicularis langsdorfii +, Pedicularis sp. +, Poa arctica +, Potentilla diversifolia +, Ranunculus eschscholtzii +, Saxifraga tricuspidata +, Sedum rosea +, Senecio sheldonensis +, Sibbaldia procumbens +, Veronica wormskjoldii +, Alectoria minuscula +, A. nigricans +, Cetraria pinastri +, Cladonia amourocraea +, C. cenotea +, C. fimbriata +, C. pyxidata +, C. uncialis +, Cladonia sp. +, Crustose ground-gray +, Parmelia stygia +, Stereocaulon arcticum +, Anastrophyllum minutum +, Aulacomnium turgidum +, Bartramia ithyphylla +, Blepharostoma trichophyllum +, Brachythecium sp. +, Calliergon stramineum +, Plagiomnium rostratum +, Polytrichum alpinum 2, P. piliferum +, Tritomaria quinquedentata +, T. scitula +.

elevations 1555 m and extending into the subalpine, there is a profuse growth of *Salix planifolia*, reaching over one meter in height and having a nearly 100% cover (Figure 29). Water moves quickly through these sites, at least during July, and often deposits mud on the ground beneath the shrubs. This deposition and the intense shade produced by the high shrub layer result in poor development of the vegetation of lower strata.

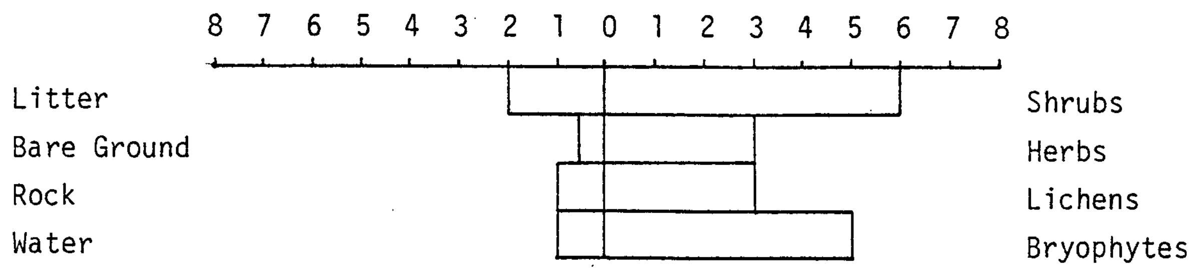


Figure 29: Cover relations in *Salix planifolia* - *Empetrum nigrum* - *Sphagnum* runoff community type.

As the slope decreases at higher elevations, drainage becomes impeded and moss hummocks increase while shrub cover decreases proportionately. The hummocks are up to .4 meters high and composed primarily of mosses, especially *Sphagnum* sp., *Dicranum* sp., *Aulacomnium palustre* and *Hylocomium alaskanum*. The troughs contain standing or slowly moving water throughout the season (Figure 30). The water table is very shallow; at one site only 35 cm by July 29, 1974. This poor drainage, combined with the thick moss cover, seems to indicate permafrost. Another possible indication of permafrost is the nonsorted, turf-edged circles which are common in this community on the north slope.

The acidic bog-like condition of these mossy, slowly drained sites promotes the occurrence of acidophiles such as *Empetrum nigrum*, which forms a major part of the ground cover on the hummocks, and *Ledum palustre*. In these poorly drained acidic conditions, *Salix planifolia* is restricted to the hummocks and grows to only .3 meters. Other shrubs that are

Figure 30: Salix planifolia - Empetrum nigrum - Sphagnum runoff on the north slope looking northeast toward Atlin Lake.

characteristically found in this community are Vaccinium vitis-idaea, Vaccinium uliginosum and Salix reticulata. The sites are further characterized by the lack of Salix polaris, so common in most of the community types.

Herb cover is only 25%. Aconitum delphinifolium is common here as well as in the rich Festuca meadow. Other important associates are Petasites frigidus and the ubiquitous Artemisia arctica.

Lichens play a minor role. Most of the cover can be attributed to Cladina sp.; Cetraria cucullata; and Cetraria pinastri, which is found growing on the Salix branches.

A variant of the Salix planifolia runoff community, which I have called the Cassiope tetragona - Empetrum nigrum subcommunity, forms the vegetation on the northern and eastern sides of the East Plateau Pond and is restricted to this location. The pond is part of the drainage system of the East Plateau and as such, has water constantly moving through it.

This variant is similarly characterized by moss hummocks covered with dwarf shrubs and water-filled troughs. Although all the mosses described for the community type are present here, Polytrichum spp. and Dicranum spp. are dominant. Salix planifolia is present in this site but is scattered. Its place is occupied by Cassiope tetragona which is co-dominant with Empetrum nigrum. Common herbs include Bistorta vivipara, Carex microchaeta, Gentiana glauca, Artemisia arctica, Hierochloe alpina and Pedicularis capitata, but the total herb cover is only 10 to 15%. Lichens are more important here than in the community type. The lichen stratum is composed primarily of Cladina rangiferina, Cladina arbuscula, Cladina mitis, Cetraria nivalis, Cetraria islandica and Solorina crocea.

The floristic differences between this site and the rest of the community type might be the result of both a longer snow duration as evidenced by the Solorina crocea and Cassiope tetragona, and water level fluctuation.

The moisture conditions of this subcommunity vary throughout the summer depending on water level of the pond. From late-June until late-July, water is a dominant feature in this community, occupying all the troughs to depths of over 30 cm. At this time of the year, most species, including Cassiope tetragona, are underwater. By late-August, the water level of the pond has dropped 30 to 50 cm and the troughs often dry up.

Upslope, the moss hummocks of this pond-side variant are slowly replaced by Festuca altaica hummocks, and the variant gradually grades into the Festuca altaica - Potentilla diversifolia rich meadow community type.

B.3.1.14 Calamagrostis canadensis - Plagiomnium rostratum runoff (Table XVIII)

The Calamagrostis canadensis - Plagiomnium rostratum runoff community type is not common on the mountain, but is physiognomically and floristically distinct enough to warrant community-type status. This community was found in only three areas, each of which was sampled. Two of these sites are on the East Plateau, one at the base of the South Saddle and one at Camp #2 within the stream draining the East Plateau Pond. The other site is on the east side of the north slope in the major drainage channel of the high snowbank. Total elevational range of these three sites is between 1550 and 1675 m. Soils are probably brunisols.

These well-drained sites all have rapidly moving water throughout the entire summer. The vegetation develops large hummock islands within the meltwater channels. All vascular vegetation and lichens are restricted to these hummocks. Snow cover is probably heavy during the winter, but when thawing begins in the spring, and the runoff channels become once

TABLE XVIII. Floristic table for the Calamagrostis canadensis - Plagiomnium rostratum runoff showing species composition and cover.

Community Type: Calamagrostis canadensis - Plagiomnium rostratum runoff

Site Number	100	97	105		
Elevation (m)	1631	1570	1676		
Position /Relief	~	~	~		
Slope (^{0})	5	0	2		
Exposure	SE	E	N		
Hygrotope	4	4	5		
	Cover Classes			Presence /3	Avg. Cover %
Litter	3	1	1		8
Rocks		1			1
Water			1		1
HERBS					
Calamagrostis canadensis	6	5	7	3/3	63
Festuca altaica	2	3		2/3	9
Artemesia arctica	+	3		2/3	6
Stellaria longipes	1	1		2/3	2
Aconitum delphinifolium	1	1		2/3	2
Carex podocarpa		1	+	2/3	1
LICHENS					
Dactylina arctica	+	+		2/3	+
BRYOPHYTES					
Plagiomnium rostratum	1	+	3	3/3	7
Aulacomnium palustre	1	2	+	3/3	4
Polytrichum alpinum	1		1	2/3	2
Hylocomium alaskanum	1	+		2/3	1
Drepanocladus uncinatus	+	+		2/3	+
Total Shrubs		1			1
Total Herbs	7	7	7		83
Total Lichens	+	1			1
Total Bryophytes	3	3	4		22

Other species occurring in only one site with their average cover: Cassiope tetragona +, Salix polaris 1, S. reticulata 1, Bistorta vivipara 1, Pedicularis capitata +, Petasites frigidus 1, Poa leptocoma 1, Poa sp. +, Potentilla diversifolia 1, Sanguisorba canadensis 1, Saxifraga ferruginea +, Sedum rosea 1, Senecio sheldonensis +, Cetraria islandica +, Crustose rock +, Peltigera aphthosa +, Rhizocarpon geographicum +, Brachythecium sp. 1, Bryum sp. 1, Diplophyllum taxifolium +, Pohlia sp. 1, Sphagnum sp. 1.

again active, snowmelt is rapid.

Herbs cover all the vegetated areas. Most of the herb cover can be attributed to the Bluejoint Grass, *Calamagrostis canadensis*, whose purple hue gives this community its characteristic appearance (Figure 31). The *Calamagrostis* is slow to develop. It does not come up until mid- or late July and flowers in mid- or late August. Important herb associates are *Carex podocarpa*, *Festuca altaica*, *Aconitum delphinifolium*, *Potentilla diversifloia* and *Petasites frigidus*.

Lichens and shrubs contribute very little to the vegetation but mosses average a 33% cover (Figure 32). *Plagiomnium rostratum* and *Aulacomnium palustre* are constant species with *Polytrichum alpinum*, *Drepanocladus uncinatus*, *Tomnethypnum nitens* and *Sphagnum* spp. frequently occurring with them.

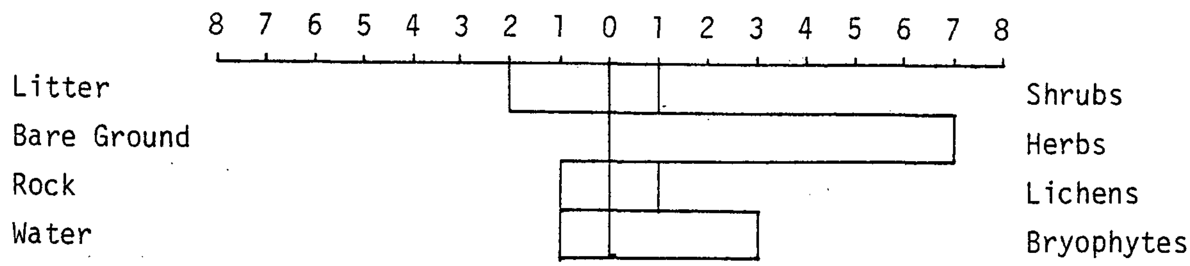


Figure 32: Cover relations in *Calamagrostis canadensis* - *Plagiomnium rostratum* runoff community type.

B.3.1.15 *Aulacomnium palustre* - *Salix polaris* - *Claytonia sarmentosa* - *Carex microchaeta* runoff (Table XIX)

The community type is found only on the north slope where it is common. Its occurrence seems to be restricted to the gradually sloping tops of the solifluction lobes. The slow drainage through these sites has resulted in an accumulation of mosses and the development of moss hummocks, which give these sites a characteristic appearance (Figure 33).

Figure 31: Calamagrostis canadensis - Plagiomnium rostratum runoff on the north slope. The purple tinged Calamagrostis makes this community easily recognizable from a distance.

TABLE XIX: Floristic table for the Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta runoff showing species composition and cover.

Community Type: Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta runoff

Site Number	9	84	26	13	51	52	78	87	25		
Elevation (m)	1631	1722	1707	1737	1600	1600	1676	1707	1753		
Position/Relief	~~~	—	_/~	~~~	◡	~~~	◡	◡	~_/~		
Slope (°)	2	1	7	1	3	2	10	2	4		
Exposure	NNW	NE	N	N	N	N	N	NE	N		
Hygrotope	5	4-5	5	5	4-5	5	4-5	4-5	4-5		Avg.
	Cover Classes									Constancy	Cover %
Litter	2	1	+	1	1		+	1	1		3
Ground	+			+			+		+		+
Rocks	+			1	1			1			1
Water	1		3	1		1					3
SHRUBS											
Salix polaris	1	2	3	3	1	4	2	5	5	V	19
Salix reticulata	2			1						II	1
Cassiope tetragona				+			+			II	+
HERBS											
Carex microchaeta	1	+	3	1	6	3	3	3	2	V	17
Artemisia arctica	1	1	3	1	3	3	1	2	2	V	9
Bistorta vivipara	+	1	1	1	1	1	1	+		V	2
Claytonia sarmentosa	3	1	2		1	1		1		IV	4
Stelleria longipes	1	1	1	+			1		1	IV	2
Aconitum delphinifolium	+	1	+				1	+	1	IV	1
Gentiana glauca	+	+	+	+			+		+	IV	+
Saxifraga nelsoniana	1				3	2		+		III	3
Antennaria monocephala		+		+			1	1	1	III	1
Senecio yukonensis	+	+		+			+		+	III	+
Campanula lasiocarpa	+		+				1	+		III	+
Ranunculus eschscholtzii	+					1		1		II	+
Luzula arcuata			+				1	+		II	+
Poa sp.			1				1			II	+
Poa arctica	1							1		II	+
Potentilla hyparctica			+				1			II	+
Sibbaldia procumbens					1			+		II	+
Pedicularis langsdorfii				+			1			II	+
LICHENS											
Cladonia gracilis		1		1			1	+	1	III	1
Cladonia amaurocraea		1		+			1		+	III	+
Dactylina arctica		1		+			+		+	III	+
Peltigera aphthosa	1		1				1			II	1
Cladonia coccifera				1			1	+		II	+
Cladina arbuscula		1					1		+	II	+
Cetraria islandica				+	+			1		II	+
Stereocaulon tomentosum							+	1	+	II	+
Cladina rangiferina		1					1			II	+
Rhizocarpon geographicum				+				1		II	+
Peltigera canina		1						+		II	+
Cladonia sp.		+					1			II	+
Cetraria cucullata				+			+			II	+
BRYOPHYTES											
Aulacomnium palustre	3	5	2	2	3	1	5	3	6	V	24
Sphagnum sp.	3	2	2	5	+	6	2		2	IV	16
Dicranum sp.	1			1		1	+	1	2	IV	2
Lophozia sp.	1	1	1	1					2	III	2
Hylocomium alaskanum	+		2	1			1	+		III	2
Bryum sp.	1		1	+	+			1		III	1
Tritomaria quinquedentata	2		1	1						II	2
Polytrichum alpinum			1	3						II	2
Anastrophyllum minutum				1			3			II	2
Drepanocladus uncinatus	+							3		II	2
Polytrichum alpestre	2							1		II	1
Brachythecium sp.				+	+					II	+
Aulacomnium turgidum	+	1								II	+
Hygrohypnum styriacum					5					I	5
Total Shrubs	3	2	3	3	1	4	2	5	5		21
Total Herbs	4	4	5	3	7	5	5	5	5		41
Total Lichens	1	3	1	1	1		3	1	1		6
Total Bryophytes	6	6	7	7	6	7	7	5	7		72

Other species occurring in less than 20% of the sites with their average cover: Cassiope stelleriana +, Dryas integrifolia +, Empetrum nigrum +, Ledum palustre +, Salix planifolia +, Vaccinium uliginosum +, V. vitis-idaea +, Calamagrostis canadensis 2, Cardamine bellidifolia +, Carex biparta +, C. phaeocephala +, Hierochloe alpina +, Petasites frigidus +, Potentilla diversifolia +, Sedum rosea +, Trisetum spicatum +, Alectoria ochroleuca +, Cetraria nivalis +, Cladonia carneola +, C. cenotea +, C. pocillum +, Crustose ground-gray +, Crustose rock +, Dermatocarpon rivulorum +, Blepharostoma trichophyllum +, Brachythecium campestre +, Calliergon stramineum +, Cephalozia sp. +, Paludella squarrosa +, Plagiomnium rostratum +, Pleuroclada albescens +, Pohlia sp. +, Tomenthypnum nitens +.

Figure 33: Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta runoff on the north slope.

Ponding and semi-stagnant conditions are common, especially in June and July when snowmelt is at a maximum. Water can be heard running beneath the moss carpet in August so active drainage does occur through these sites during the entire snow-free season.

Soils are peaty with organic material extending down to 15 cm overlying a sandy substrate. The water table in early August can be as high as 30 cm from the surface.

This mossy runoff community can occur at elevations between 1555 and 1768 m. Snow cover is probably moderate to light, and continuous. Sites between 1646 and 1768 m are probably free of snow by June. These sites are often mixed with Cetraria nivalis - Carex microchaeta fellfields and Carex microchaeta meadows, depending on drainage and topographic conditions. Below 1646 m, runoff areas free of snow before June are usually invaded by Salix planifolia and develop Salix planifolia - Empetrum nigrum - Sphagnum runoff community type vegetation. The Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta sites at these elevations, then, are confined to areas of greater snow duration (possibly until late June). These sites are often flanked downslope by the Salix planifolia runoff community and upslope by the snowbed variant of the Cassiope tetragona community or other snowbed community types.

The moss stratum forms the most conspicuous vegetation in this community (Figure 34). Aulacomnium palustre, with an average cover of 33%, is the dominant moss of this community in all micro-habitats except for the wettest. Sphagnum sp. are also characteristic of these runoff communities and develop best in the troughs and on the sides of the hummocks. Mosses frequently found on the tops of the hummocks are Dicranum spp., Bryum spp., Polytrichum alpestre, P. alpinum and Hylocomium alaskanum. Drepanocladus uncinatus, Bryum spp., Hygrohypnum styriacum and

Paludella squarrosa occur in the wet troughs.

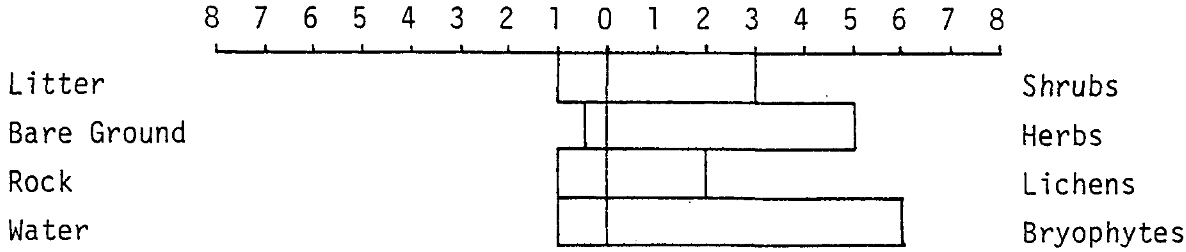


Figure 34: Cover relations in Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta runoff community type.

Shrub cover is formed entirely by the dwarf, procumbent Salix polaris. Herb cover averages 50%. Most of this cover can be attributed to Carex microchaeta and Artemisia arctica. Herbs more diagnostic of this community are Claytonia sarmentosa and Senecio yukonensis. Both of these species are restricted to the north slope of the mountain. Lichens are a minor part of the vegetation. The scattered species are mostly Cladonias and Cladinas. Cladonia gracilis is the most constant.

B.3.1.16 Ranunculus - Carex podocarpa - Saxifraga nelsoniana - moss runoff (Table XX)

The Ranunculus - Carex podocarpa - Saxifraga nelsoniana - moss runoff community type is the most heterogeneous community on the mountain. The individual sites of this mixed forb community are united more on their physiognomic and environmental similarities than on their floristic homogeneity. Intensive sampling within this community type might result in its being subdivided into more floristically homogeneous units. If this were done, these units would be small, physiognomically similar, and form mosaics within the community type described here. Since environmental differences among these units would probably not be significant in relation

TABLE XX : Floristic table for the Ranunculus - Carex podocarpa - Saxifraga nelsoniana - moss runoff showing species composition and cover.

Community Type: Ranunculus - Carex podocarpa - Saxifraga nelsoniana - moss runoff

Site Number	101	95	59	117	136	57	6	144	143	111	151	106	58	99		
Elevation (m)	1631	1554	1600	1554	1539	1585	1615	1615	1570	1753	1494	1676	1585	1646		
Position / Relief	—	—	~	~	—	~	—	—	◡	◡	—	~	—	—		
Slope (°)	1	2	1	0	0	1	5	0	1	2	1	2	1	1		
Exposure	SSE	E	E	ENE	ENE	E	NW	N	NE	ESE	SW	N	E	SE		
Hygrotope	5	4-5	4-5	5	4-5	5	4-5	4-5	5	4-5	4-5	4-5	5	5		Avg.
	Cover Classes														Constancy	Cover %
Litter	1	+	1	1	1	1	3	1		1	+	+				3
Ground			+			+	+			2						+
Rocks		3	+	1	2	1	+	+	2	1			7	3		10
Water	+			1		1			4				3	6		8
SHRUBS																
Salix polaris	6	+	3	1	5	4	3	2	4	3	3	4		2	V	20
HERBS																
Artemisia arctica	3		2	3	1	3	2	3	+	1	3	5			IV	11
Bistorta vivipara	+	+	1	1		+	+	+			+	+			IV	+
Carex podocarpa			1	1	3				2		3	5			III	7
Carex microchaeta	1	+		1			3	2		1					III	3
Sibbaldia procumbens	1		1	+			2			1	3	+			III	3
Saxifraga nelsoniana			2	1	1	1			1	+	1				III	2
Veronica wormskjoldii	1		1	1	1							1		1	III	1
Poa sp.	+	1	1	1						1				1	III	1
Stellaria longipes		+	1	1	+	+		1			1	+			III	1
Luzula arcuata		+	1			+				+		+	+		III	+
Antennaria monocephala	+			+	+	1	+		1	1					III	+
Sanguisorba canadensis	1	1	4	5											II	6
Luetkea pectinata			3				1							+	II	2
Carex sp.			+			3								1	II	2
Poa arctica								3			1				II	2
Epilobium anagallidifolium	1	3	1								1				II	2
Sedum rosea	+	1		2	1	1									II	1
Ranunculus nivalis			1		1	1			1	+					II	+
Potentilla diversifolia				1	1	1					1				II	+
Ranunculus eschscholtzii	1	1		1										1	II	+
Equisetum palustre		+			1	1			1						II	+
Trisetum spicatum		+			+					+	1				II	+
Juncus drummondii	+	1												1	II	+
Aconitum delphinifolium	+			1				1							II	+
Carex bipartita							+		1		1				II	+
Poa leptocoma					1		+					1			II	+
Gentiana glauca						+	+	+							II	+
Ranunculus pygmaeus										+	+			+	II	+
LICHENS																
Crustose rock		2	+	+	1	1	1	+	1	3			6	3	IV	9
Stereocaulon tomentosum	+		+	+	1	1	1		1	2	+			+	IV	2
Rhizocarpon geographicum		1		+	1		1		1	1			3	1	III	3
Peltigera aphthosa						1	1		+	1					II	+
Cetraria islandica							+	1	1		+				II	+
Cladonia gracilis								+	1	1					II	+
Umbilicaria hyperborea				+			+			1					II	+
BRYOPHYTES																
Bryum sp.	5	3	1	3	3		+	1	1	2	1	1	1	1	V	9
Drepanocladus uncinatus	1	3	1	1	1	2	+		1	2				1	IV	4
Aulacomnium palustre	3		2	3		4	1	3	1			4			III	9
Polytrichum alpinum	1	1			1		2		1	1	2	1			III	2
Barbilophozia sp.	1		1				2		2	1				1	III	2
Brachythecium sp.	1	+	1						1					2	III	1
Brachythecium albicans					3					5		1			II	5
Dicranum sp.			+					+	5						II	3
Sphagnum sp.				2		1	1								II	1
Plagiomnium rostratum		1		1	+							1			II	+
Lophozia sp.	1					1		1				+			II	+
Blepharostoma trichophylla			1			+			1						II	+
Total Shrubs	6	+	4	1	5	5	3	2	4	3	3	4		2		22
Total Herbs	5	6	7	6	6	6	4	6	3	3	7	7	+	3		49
Total Lichens	+	2	1	1	2	2	2	1	3	3	1		7	3		13
Total Bryophytes	6	6	5	6	5	5	4	5	7	6	3	5	2	6		47

Other species occurring in less than 20% of the sites with their average cover: Cassiope stelleriana +, Empetrum nigrum +, Phyllodoce empetriformis +, Salix reticulata +, Vaccinium uliginosum +, Anemone richardsonii +, Antennaria alpina +, Caltha leptosepala +, Campanula lasiocarpa +, Draba crassifolia +, Epilobium angustifolium +, E. latifolium 2, Festuca altaica +, Hierochloe alpina +, Juncus biglumis +, Oxyria dygina +, Pedicularis capitata +, P. langsdorfii +, Petasites frigidus +, Saxifraga ferruginaea +, S. rivularis +, S. lyallii +, Senecio sheldonensis +, Cetraria delisei +, C. nivalis +, Cladina arbuscula +, C. mitis +, C. rangiferina +, Cladonia bellidifolia +, C. carneola +, Cladonia sp. +, Crustose ground-gray +, Dactylina arctica +, Lobaria linita +, Nephroma arctica 1, Peltigera canina +, Solorina crocea +, Umbilicaria deusta +, Anastrophyllum minutum +, Anthelia juratzkana +, Cephalozia sp. +, Ceratodon purpureus +, Cynodontium sp. +, Desmatodon latifolius +, Dicranoweisia crispula +, Drepanocladus exannulatus +, Hylocomium alaskanum +, Orthocaulis kunzeanus +, Paraleucobryum inerve +, Philonotis fontana 3, Pleuroclada albescens +, Pohlia sp. +, Polytrichum alpestre 1.

to the scale of this study, and since these units would be too similar to be identified from aerial photography and too small to be mapped, a breakdown of this community type into more floristically homogeneous units is not warranted.

The runoff community occurs on all exposures at elevations between 1402 m in the eastern glacial valley to 1753 m. It attains its best development between 1554 and 1615 m on the East Plateau on the sides of slow gradient streams which are active throughout the summer months. Winter snow cover is heavy and these sites are not free of snow until mid-June to late July. On the East Plateau it covers large areas at the base of the South Saddle and between Avalanche Peak and the East Plateau Pond.

The protection provided by the snow duration combined with the continuous irrigation has resulted in a very diverse herb flora dominated by forbs (Figure 35). Caltha leptosepala, Parnassia fimbriata and Leptarrhena pyrolifolia all reach their highest elevation within this community type. This community differs from the Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta runoff community environmentally by the prolonged duration of snow, the better drainage and lack of stagnation. It also differs in the general floristic composition and in the proportion of moss cover to herb cover. Here they both have almost 50% cover (Figure 36).

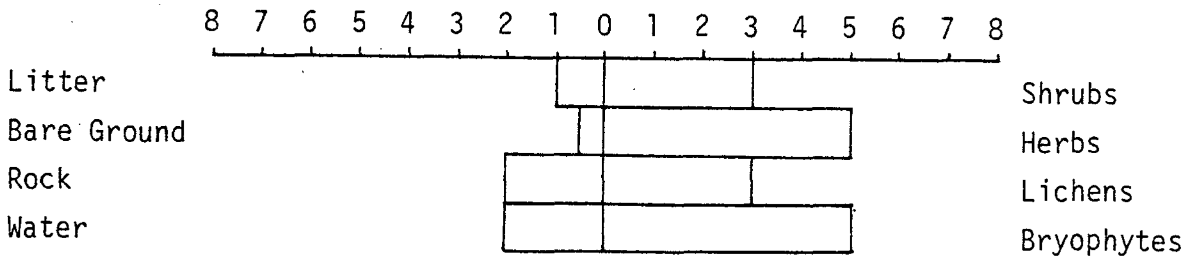


Figure 36: Cover relations in Ranunculus - Carex podocarpa - Saxifraga nelsoniana - moss runoff community type.

Figure 35: Photograph of the Ranunculus - Carex podocarpa - Saxifraga nelsoniana - moss runoff community on the East Plateau taken on July 11, 1975. Note the snow still persisting in the center of the picture. The yellow flowers are Ranunculus eschscholtzii and the clumps of grass in the foreground are Festuca altaica.

Herbs which are characteristic of this community type are Ranunculus eschscholtzii, Ranunculus nivalis, Saxifraga nelsoniana and Carex podocarpa. Other herbs which are frequently encountered include Epilobium anagallidifolium, Sedum rosea, Veronica wormsjkoldii, Sanguisorba canadensis, Sibbaldia procumbens, Ranunculus pygmaeus, Equisetum palustre and Bistorta vivipara.

Bryophytes attain a 50% cover. Dominant species are Bryum spp., Aulacomnium palustre, and Drepanocladus uncinatus. Other species frequently found associated with this community are Philonotis fontana, Hygrohypnum styriacum, Paludella squarrosa, Drepanocladus exannulatus, Plagiomnium rostratum, Sphagnum spp. and Anthelia juratzkana.

Salix polaris is the only significant shrub and has an average cover of 25%. Lichen cover (12%) can be attributed mainly to crustose species covering the numerous exposed rocks found in this community.

In some sites on the East Plateau where the snow remains into July, the surface of the ground is covered with rocks which form a flat pavement. Water is constantly moving around the rocks or over the entire surface like a sheet. Bryophytes form the dominant vegetation. These stone pavements might be the result of frost action. Stone pavements are described by Washburn (1973) and thought to be the combined result of "upfreezing of stones, ground saturation and removal of fines by melt-water, the rotation and shifting of the stones in the saturated ground under their own weight and the weight of overlying snow" (Washburn, 1973).

B.3.2 Transects

Transect results are illustrated in Figures 37, 40, 41 and 43. These figures have been simplified by eliminating the ubiquitous species and those of rare occurrence from the list as they do not follow, and tend to visually confuse the general species pattern. Many species of mosses and lichens were not identifiable because of insufficient material and have been omitted. It should be noted that the species listed in the transect figures are in general those species diagnostic of the 16 communities just described. In each figure a profile of the transect has been superimposed directly above the species lists to show quadrat location on the profile.

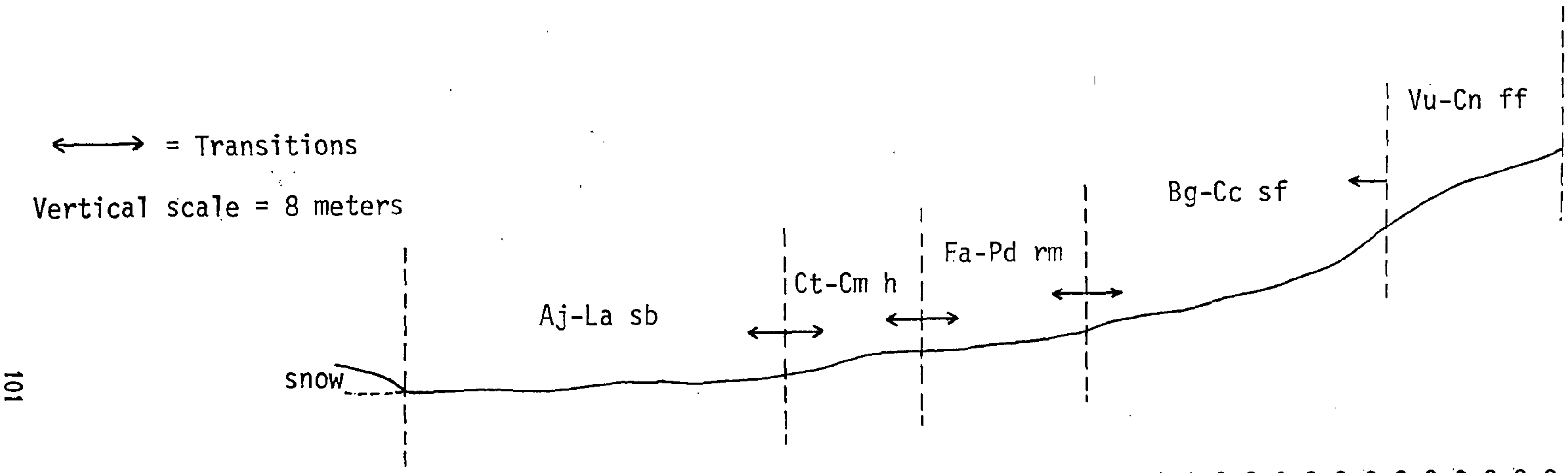
B.3.2.1 Transect 1: North Knoll Transect

The North Knoll transect was established and sampled between August 10 and August 12, 1974. This transect originates in the long snowbed (Saddle Snowbed) on the south side of the North Knoll at the snow line and runs north for 78 m up the south slope of the North Knoll. The results of this transect are shown in Figure 37 and its location is plotted in Figure 67.

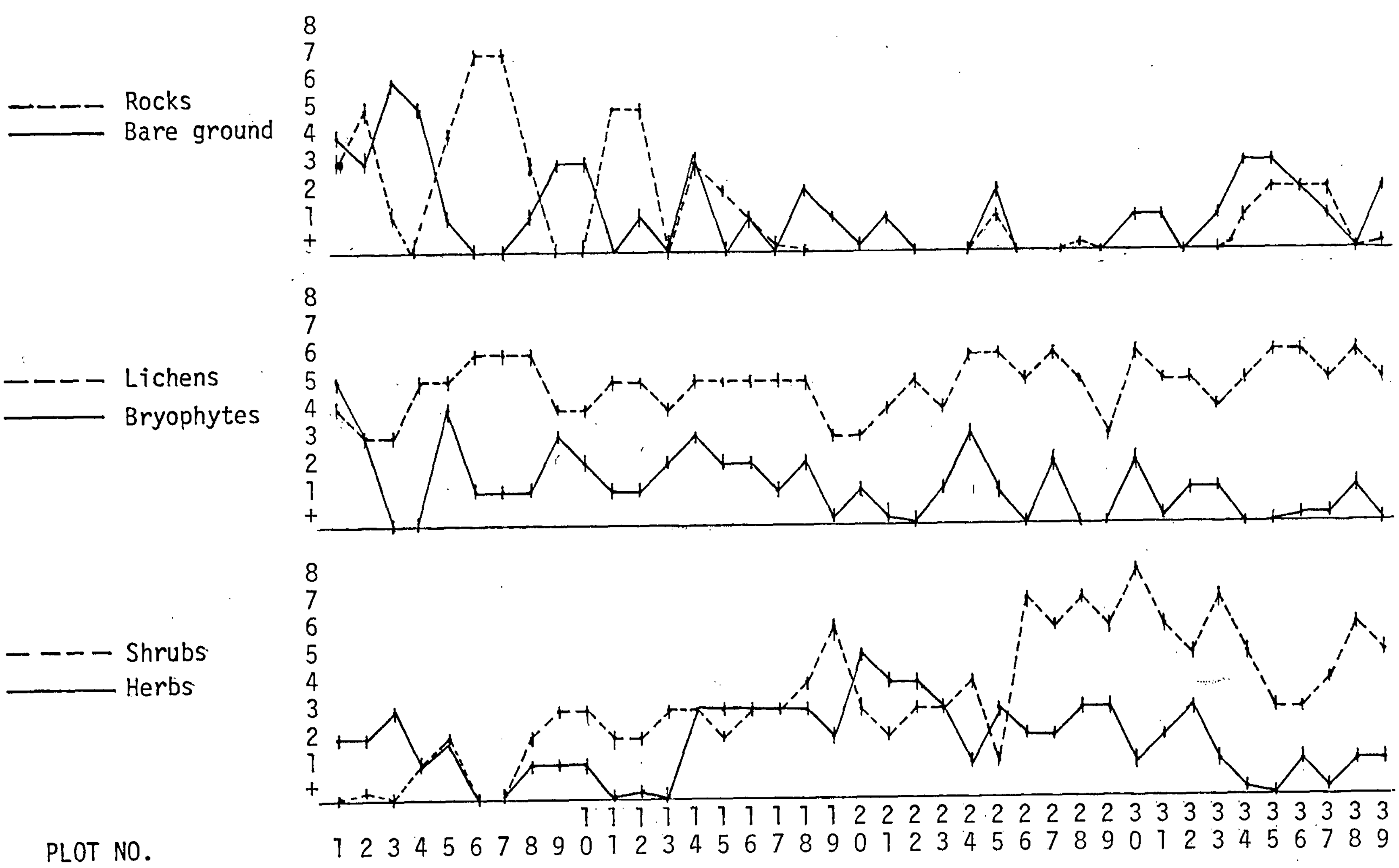
The North Knoll transect reflects a snow duration and moisture gradient, both controlled by the slope or topography. By late June snow still covers quadrats 1-14. At quadrat 1 snow remains until early to mid-August. Snow duration data are not available for the rest of the transect, but because of the exposed position of the North Knoll and the nature of its vegetation, it can be predicted that snow cover is minimal and disappears very early in the spring, possibly in April. The moisture gradient proceeds from subhygric near the edge of the snow to xeric near the top of the North Knoll. The slope is between 2 and 10^{o} and total elevation gain along the transect is approximately 15 m.

For the first 26 meters (quadrats 1-13) the ground surface is dominated by rock stripes alternating with soil stripes. This frost feature is common in snowbed areas. These stripes did not run parallel to the transect but instead crossed it in a number of places. The change from

Figure 37: Results of the North Knoll Transect showing changes in species composition and cover. A profile of the transect has been superimposed directly above the species lists to show quadrat location on the profile. Species values and values used in the graphs are cover classes.



PLOT NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Anthelia juratzkana	+	3	1	3	3					2																													
Oxyria digyna		1	+					+																															
Luzula arcuata	2	1	2	1	1				1	1		+		1	1																								
Crustose ground-gray	3	2	1	2	1			1	3		1		2	3	2	3	1	2																					
Salix polaris		+		1	1			2	1	2	2	2	3	2	2	2	1	1	1																				
Cassiope tetragona					+			+	3	2			1		1	2	2	1																					
Antennaria monocephala								+	+	1			+	+	1	1	1	+	1	1	+	1	+		1	+	1	+	+		+	+	+						
Artemisia arctica														3	2	1	2	1	1	3	2	1	3	+	2	1	2	1	2	1		1							
Cetraria islandica														+	1	2	1	+	2		1	1		2	1	+	2	1	1	+	+	1	1	1	+				
Potentilla diversifolia															+	1	1	+																					
Salix reticulata								1						2			1	2		2	2	+	2	1	1	1	1												
Salix planifolia																+			5	3		3																	
Festuca altaica																		2	1	3	3	3	1		3	1	1	1	+	+	+	1							
Dactylina arctica																	+	+		1		1		1		2	+	1		2	+	1							
Cladonia amaurocraea																				+	+	+	+	1	+	+		+		+									
Cladina rangiferina																				1	1	1		2		1	1	+		3	1	1	+			+			
Vaccinium vitis-idaea																			1	+	1		+			+	+	+	1	+	1	1	1						
Betula glandulosa																			1				2	3		7	5	7	6	8	6	5	5					5	
Cetraria richardsonii																						1					1	+	1	1	1	1							
Cetraria nivalis/cucullata																		+		+	2	1	3	1	2	2	1	2	1	1	3	2	3	1	3	3	3	3	2
Thamnolia vermicularis																					+		+	1	+		+	+	+	+	1	+	1	1	1	1	1	1	1
Vaccinium uliginosum									+								+	3	1			1	1										2	5	3	3	4	3	3
Dryas octopetala																																	4	1	1	1			3
Alectoria nigricans																																	+	1	2	2	1	1	1
Alectoria miniscula																										1			+					+	2	2	1	+	1
Alectoria ochroleuca																																				+	+	+	+
Oxytropis huddlesonii																																				1		1	1



rock dominated stripe to bare ground dominated stripe can be followed in the bottom graphs in Figure 37. Lichens and bryophytes form the dominant vegetation in this part of the transect. The high lichen cover in quadrats 6 and 7 reflect the numerous crustose species growing on rocks. These have been deleted from the figure as they tend to parallel the distribution of rocks. Most of the lichens in the snowbed area are unidentified crustose species. The dominant bryophyte is the chionophilous hepatic *Anthelia juratzkana*. *Luzula arcuata* is the dominant herbaceous species with scattered individuals of *Antennaria monocephala*, *Oxyria digyna* and unidentified *Carex* species.

As snow duration decreases shrub cover increases. This increase is attributed primarily to *Salix polaris* and *Cassiope tetragona*. Where snow remains only until late June herbaceous species begin to increase in importance especially *Artemisia arctica*. Herbs tend to increase in importance until quadrat 23. This is accompanied by a decrease in shrubs. In quadrats 21-22 *Festuca altaica* and *Artemisia arctica* dominate the physiognomy. These sites are probably free of snow by late May.

The physiognomy changes after quadrat 22 with the appearance of *Betula glandulosa*. Shading results in a decrease in herbs and bryophytes. *Cetraria richardsonii* is characteristically found beneath the birch as is *Vaccinium vitis-idaea*. Species characteristic of the more exposed xeric sites appear with the birch. These include *Cetraria cucullata*, *C. nivalis* and *Thamnolia vermicularis*. With the increase in shrub cover comes a decrease in herb cover. Herb cover continues to decrease along the remainder of the transect.

At quadrat 33 an abrupt change takes place in the vegetation. Most of the species encountered along the transect up to this quadrat are replaced by a xerophytic flora characterized by lichens. The percentage of rocks and bare ground which had been low after leaving the snowbed area once again increases.

Figure 37 shows clearly that species composition changes gradually along this transect. Sharp discontinuities are not detected except between quadrats 33 and 34. Although discontinuities are not common, various segments of the transect, based on dominance and species composition, can be assigned to specific plant communities described earlier.

The North Knoll transect appears to run through five communities. Quadrats 1-13 can be assigned to the Anthelia juratzkana - Luzula arcuata late snowbed community type. Quadrats 14-18 belong to the Cassiope tetragona - Cladina mitis heath, quadrats 18-23 to the Festuca altaica - Cladina dry meadow, quadrats 24-33 to the Betula glandulosa - Cetraria cucullata shrubfield and quadrats 34-39 to the Cetraria nivalis - Vaccinium uliginosum fellfield. Although some of the quadrats are transitional they can be placed within this community framework. If a map is to be made, lines must be drawn to separate the vegetation units. In Figures 37, 40, 41 and 43 dotted lines crossing the profile indicate the limits of the vegetation unit. The horizontal lines between communities indicate that transitional areas do occur.

B.3.2.2 Transect 2: 1676 m Snowbed Transect

The 1676 m snowbed transect was sampled on August 12, 1976. The 46 m long transect was established so as to bisect a well developed solifluction lobe. The solifluction lobe was at 1676 m on the north slope and within a major drainage pathway. Meltwater from upper snowbeds runs through the site during the entire summer.

The gradient represented along the transect is primarily one of snow duration and moisture. The tread or upper part of the solifluction lobe (quadrats 1-11) is free of snow by early June. Snow collects during the winter in the lee of the lobe (quadrats 14-24) and remains late into the summer. Drainage is poor in this part of the transect because of the late snow melt, delayed thawing of the soil and the horizontal ground surface, and results in ponding (Figure 38). The horizontal position of the tread and the development of thick moss hummocks here cause local ponding conditions at the top of the lobe also. Quadrats 12-14 represent the active front of the solifluction lobe. Runoff here is subsurface until the base of the lobe where water appears above the ground again. The lobe front and base are shown in Figure 39. Snow duration on the front is intermediate.

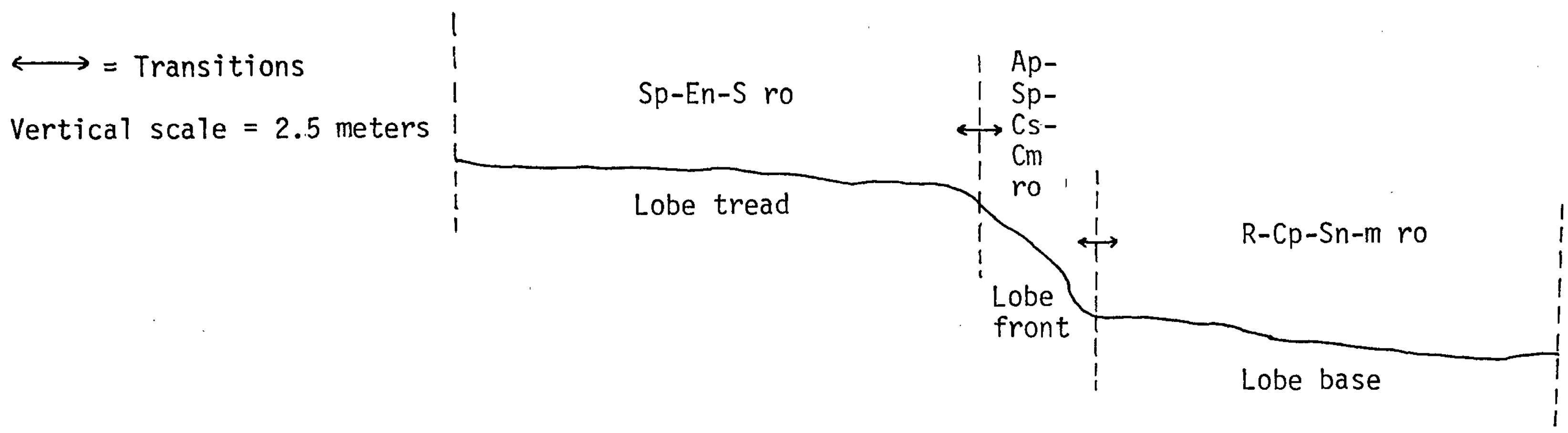
This transect then follows a gradient from an area of short snow duration (May) and moderate-to-poor drainage conditions with occasional ponding on the lobe tread (quadrats 1-10 or 11), to longer snow duration (June) and moderate-to-good drainage on the lobe front (quadrats 11-14),to an area of long snow duration (August),poor drainage and extensive ponding on the lobe base (quadrats 15-24).

Figure 40 illustrates how the plant species segregate out along this transect. Sharper discontinuities exist along this transect than the previous one. Shrubs, particularly _Salix planifolia_ and _S. reticulata_ dominate the tread of the solifluction lobe up to the very top of the front (quadrats 1-12). Figures 38 and 39 both show _Salix planifolia_ at the edge of the lobe front. _Sphagnum_, _Aulacomnium palustre_ and _A. turgidum_ form hummocks on the tread and are codominants with the willows. On the active solifluction front, shrub cover greatly decreases with an increase in herb and bryophyte cover. _Claytonia sarmentosa_, _Petasites frigidus_ and _Saxifraga nelsoniana_ are among the herbaceous taxa that occur here. _Aulacomnium palustre_ is still a major bryophyte species.

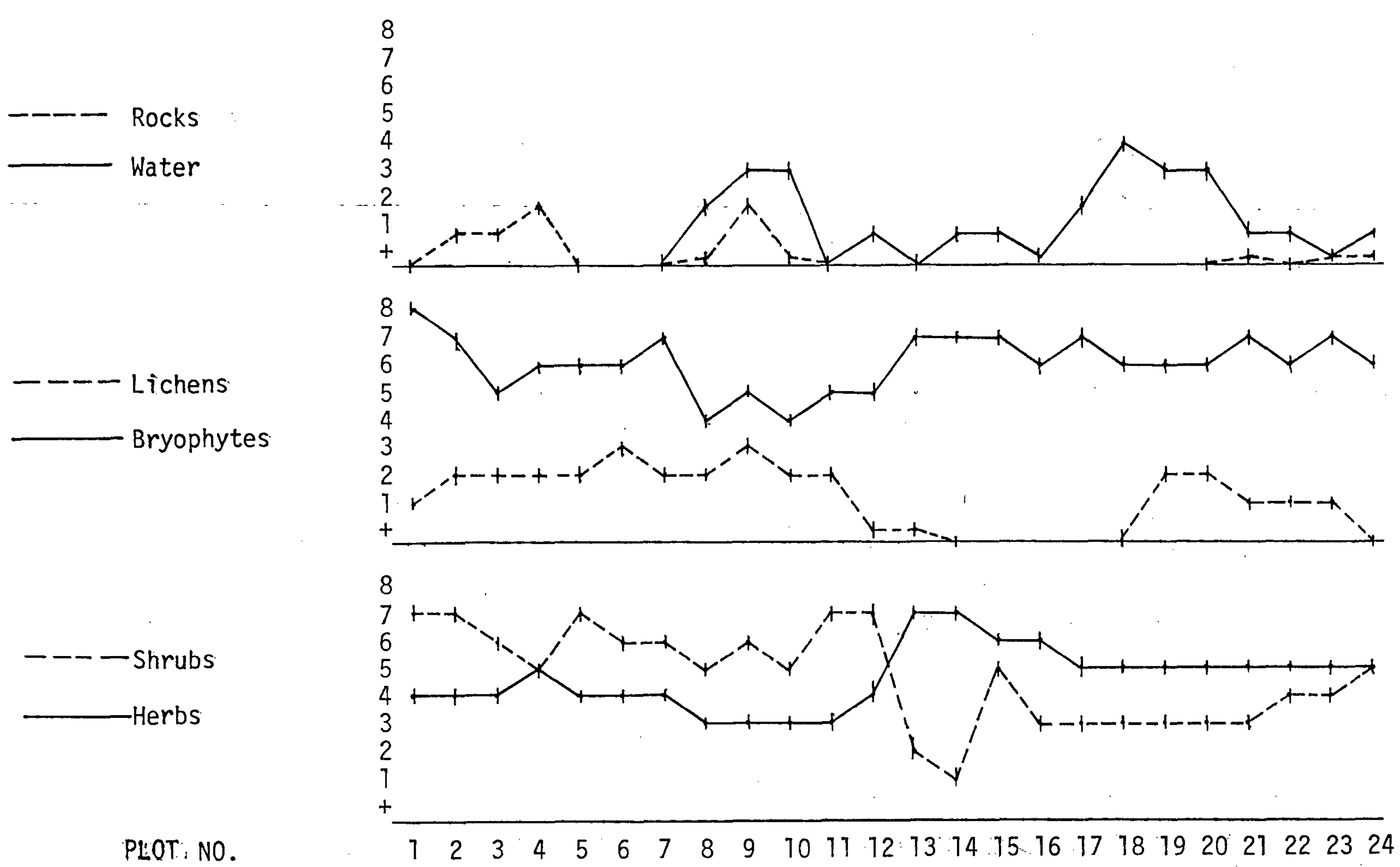
Figure 38: Ponding and late snow duration at lower end of Transect #2. The picture was taken on July 17, 1976, looking over the solifluction lobe front toward the east. Light brown vegetation is Carex pyrenaica.

Figure 39: Solifluction lobe front and base crossed by Transect #2, looking south up the north slope. Yellow flowers are Ranunculus eschscholtzii. White flowers in center and lower right of picture are Caltha leptosepala. Note the moss development, primarily Aulacomnium palustre, in the foreground.

Figure 40: Results of 1676 m Snowbed Transect showing changes in species composition and cover. Species values and values used in the graphs are cover classes.



PLOT NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Pedicularis capitata	1	+	1	1	+	1				1														
Sphagnum sp.	6	2	2	1	2	1	2																	
Cetraria cucullata	+	+	1	+	+	1	1	+	1															
Polytrichum alpestre	1	1	2	2	2	2	2	3	3	2														
Aulacomnium turgidum	2	+	+	3	2	3	3	2	3	3	3													
Salix reticulata	7	4	4	3	4	5	5	2	2	2		1												
Salix planifolia	1	3	2	2	3	3	3	3	6	5	7	7												
Hylacomium alaskanum	1	2		2		+	1	+	1	1	3	3	+											
Aulacomnium palustre	2	4	4	2	3	3	3	2	2	2	2	2	2	4	2									
Hierochloe alpina			2		+	1	+																	
Cetraria islandica			+	1		+	+	+	+	+														
Dactylina arctica				1	+	+	+	+	+															
Potentilla hyparctica			+			+	1	+																
Claytonia sarmentosa											+	3	3	+										
Saxifraga nelsoniana													2	1										
Saxifraga rivularis													1	1										
Petasites frigidus												1	4	1	1	1		+						
Artemisia arctica			+				+	1		1		2	3	2	2	2	2	2	2	2	3	4	2	1
Salix polaris	1	1	1	1		1	+	1	1	+			2	1	5	3	3	3	3	3	3	4	4	5
Polytrichum alpinum												+	1	1	1	2	1	2	2	2	1	1	4	3
Juncus drummondii														3	2	1	2	1	1	1	+	1	1	1
Caltha leptosepala														3	1	1	1	1	1	1	2	1	1	
Ranunculus eschscholtzii														1	2	2	2	1	1	1	+	1	+	+
Epilobium anagallidifolium														2	1			+	+	+	+	1	+	+
Sedum rosea														+	1	+			1	1				
Carex pyrenaica															1	1	2	3	2	2	3	2	1	1
Sibbaldia procumbens															2	5	4	2	2	2	2	1		
Antennaria alpina															1		1	1	2	2	1	1	1	+
Veronica wormskjoldii													1		+		+	+	+	+	+		+	1
Anthelia juratzkana		2		1				2		+								3	4	4	2	1	1	2
Drepanocladus uncinatus												1	1				1				1	1	4	2
Solorina crocea																			+	+	+			



With an increase in snow duration, a number of chionophilous species appear including Sibbaldia procumbens, Carex pyrenaica, Juncus drummondii and Caltha leptosepala. The flora of the base, then, is characterized by a mixture of chionophilous and hydrophilous species.

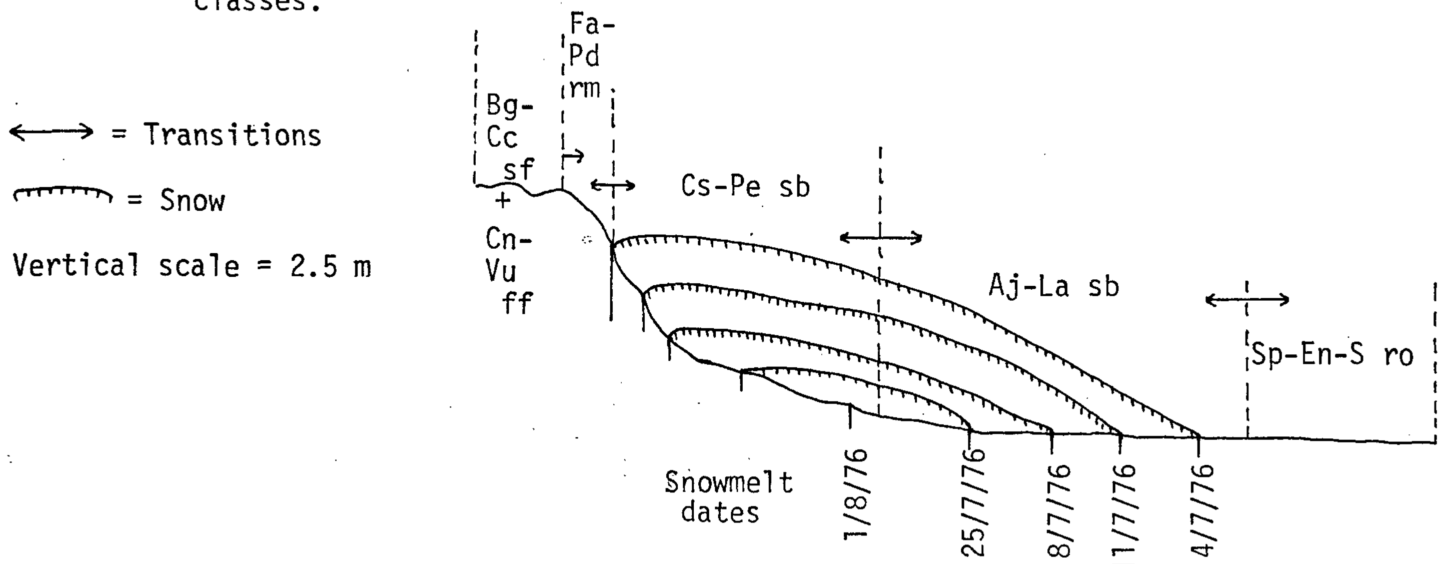
From the distribution of dominant taxa, total species complement, and environmental factors along the transect, three distinct communities can be identified. These are the Salix planifolia - Empetrum nigrum - Sphagnum runoff community found on the level tread of the solifluction lobe (quadrats 1-12); the Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta runoff community on the lobe front (quadrats 12-14); and the Ranunculus - Carex podocarpa - Saxifraga nelsoniana - moss runoff at the base of the lobe (quadrats 15-24).

B.3.2.3 Transect 3: 1615 m Snowbed Transect

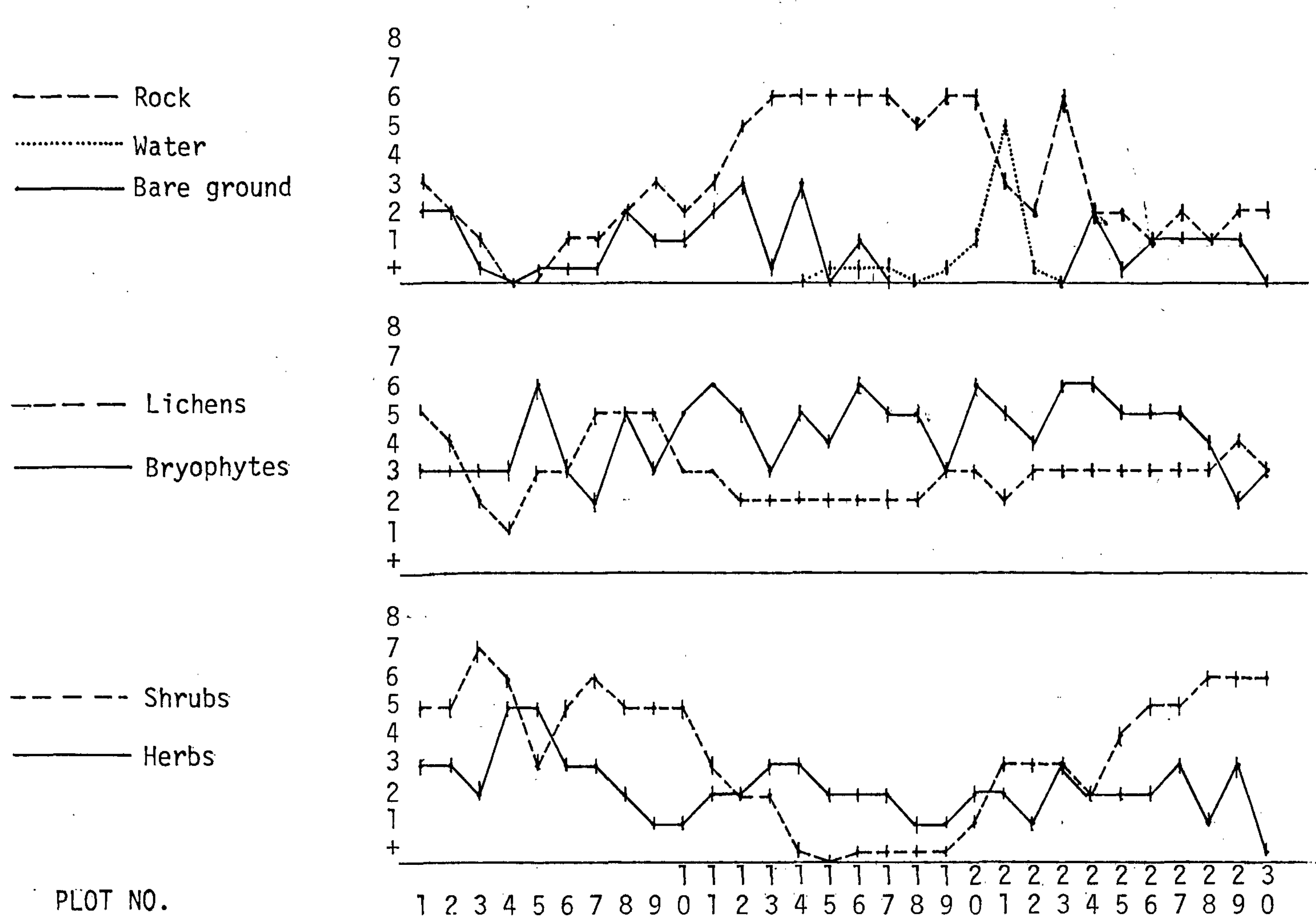
The 1615 m snowbed transect was established across an active solifluction lobe at 1615 m on the north slope. Its location is shown in Figure 67. The lee of the solifluction lobe front acts as a snow accumulation area and retains snow until late July or early August. The 59 m long transect was sampled on July 28, 1975. At this time there was no snow in the snowbed. The quadrats were marked for relocation in 1976. Starting on July 4, 1976, the weekly progression of snowmelt was recorded. The snow did not disappear completely until August, showing that snow duration does vary from year to year although the general melt pattern remains the same. Figure 41 shows the results of the sampling in 1975 in relation to the progression of snow melt in 1976.

This transect represents a snow duration and moisture gradient but unlike the 1676 m snowbed, does not occur in an active runoff area. Moisture comes primarily from the melting snow within the site and seepage

Figure 41: Results of the 1615 m Snowbed Transect showing changes in species composition and cover in relation to snow duration. Species values and values used in the graphs are cover classes.



PLOT NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Sphagnum sp.																								+			1	2	1	1
Aulacomnium palustre		3		2	+																1	1	2	3	2	3	3	2	2	1
Cetraria nivalis	2	1																											+	1
Cetraria cucullata	3	1																							+				+	+
Cladina rangiferina	+	1																									+	+	1	1
Vaccinium uliginosum	3	3	5																				+		1		2	1	3	+
Vaccinium vitis-idaea	2	1	1																							1	1	+	+	1
Empetrum nigrum	1	3	3																							3	4	3	4	6
Dactylina arctica	+	+	+	+																								+	+	1
Cladina sp.	1	2	+																					+	1	2	1	1	1	1
Cetraria islandica	+	+	+	+		+	+											1							+	+	+	1	1	1
Salix reticulata	1	2	2	3	1																			1	2	3	1	1	2	1
Salix planifolia	1	1	6	5																	2	1	1			1	1	3		3
Aconitum delphinifolium			1	1																										
Festuca altaica				3	2																									
Campanula lasiocarpa				1	1	+																								
Ranunculus eschscholtzii					1	1	+																							
Epilobium anagallidifolium					+	+	+	+										+	+											
Luetkea pectinata					2	3	3	1	3	2	+	+																		
Antennaria alpina					1	1	+	+	+	+			+		+		+	+	+								+			
Sibbaldia procumbens					1	1	2	1	+	+	+	+	+	+																
Juncus drummondii					+	1	+	+	+	+	1	+		+	+															
Phyllodoce empetriformis					1	3	4	3	3	3	2	1	1	+		+														
Luzula arcuata					+	+	+	1	1	1	1	1	1	2	1	1	1	+	+	+	+	+	1	1	1	+			+	
Solorina crocea		2			+		2	3	3	2	3	3	2	2	1	1	1							1	+					
Cassiope stelleriana							3	+	+	3	2	1	1												+	1				
Rhacomitrium sudeticum								1	+	1	1	3	2	4	2	2	2	1												
Anthelia juratzkana								3	3	4	6	4	2	2	2	3	2	1	+	1	1	2	3	5	2	2	2		+	
Equisetum palustre												+	+	+	+	+	+	+	+	1	+	+	+	1	1	1	2	+	1	
Drepanocladus uncinatus			1										1	1	2	3	3	4	3	3		1								



from a snowbed above. This transect typifies many of the snowbeds in the area. Figure 42 is a color infrared photograph taken on August 2, 1976, of the 1615 m snowbed, looking upslope south to the front of the solifluction lobe. Pink plants in the foreground and in the distance on top of the lobe are Salix planifolia. The center of the snowbed, quadrat 12, is near the boulder in the center of the picture.

Quadrats 1-3 are in an exposed position at the top of the lobe and are probably free of snow by June. These quadrats represent the xeric portion of the transect. As summer thaw progresses, meltwater moves downslope to the northern (lower) end of the transect. The graph of water cover shows ponding at the bottom half of the snowbed.

The distribution of species is definitely affected by snow duration and moisture conditions. The first two quadrats are xeric with a high proportion of lichens and shrubs. Quadrats 3 and 4 are in areas slightly sheltered by the solifluction lobe front. This increase in protection, moisture and snow duration has favored the development of Salix planifolia. Between quadrats 4 and 5, the snow melts out during June, mesic conditions prevail and Festuca altaica becomes common along with Campanula lasiocarpa. The increased snow duration after quadrat 5, and mesic to subhygric conditions of the lobe front, promote chionophilous species such as Luetkea pectinata, Phyllodoce empetriformis, Solorina crocea and Cassiope stelleriana. The ground surface levels after quadrat 14 and becomes very wet and rocky. Vascular species cover less than 10% of the surface. Most of the vegetative cover is of bryophytes which can withstand the long snow duration and flooding. These are primarily Anthelia juratzkana, Drepanocladus uncinatus and Rhacomitrium sudeticum. Vascular cover assumes greater significance as snow duration decreases, especially the shrub layer which becomes codominant with the bryophytes. Moisture conditions at quadrat

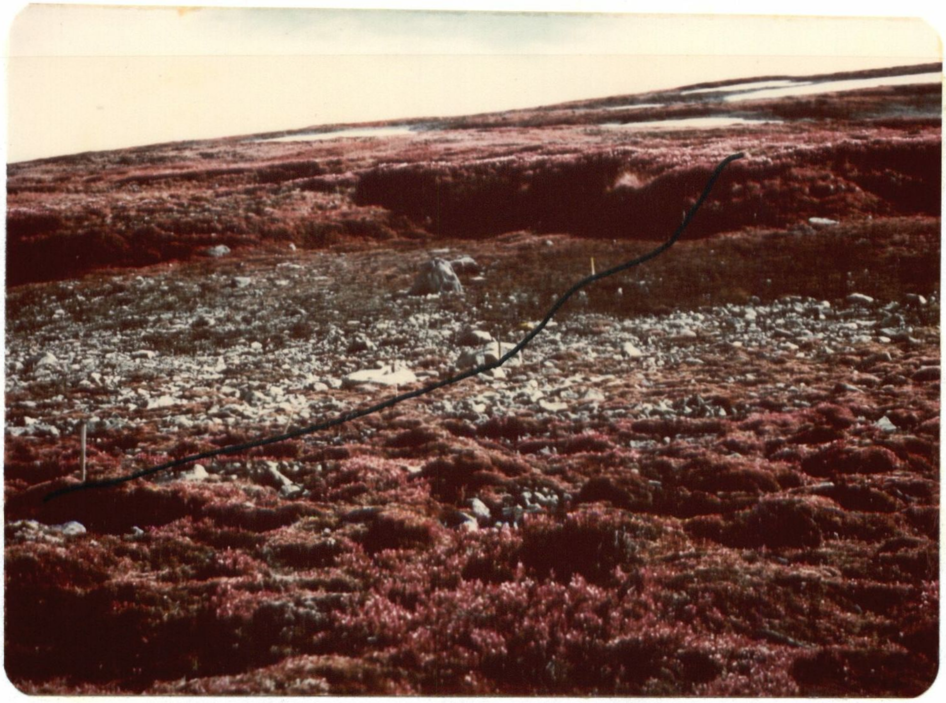


Figure 42: Color infrared photograph of Transect #3 looking north across snowbed to solifluction lobe. Transect baseline is shown in black.

30 are mesic to subhygric.

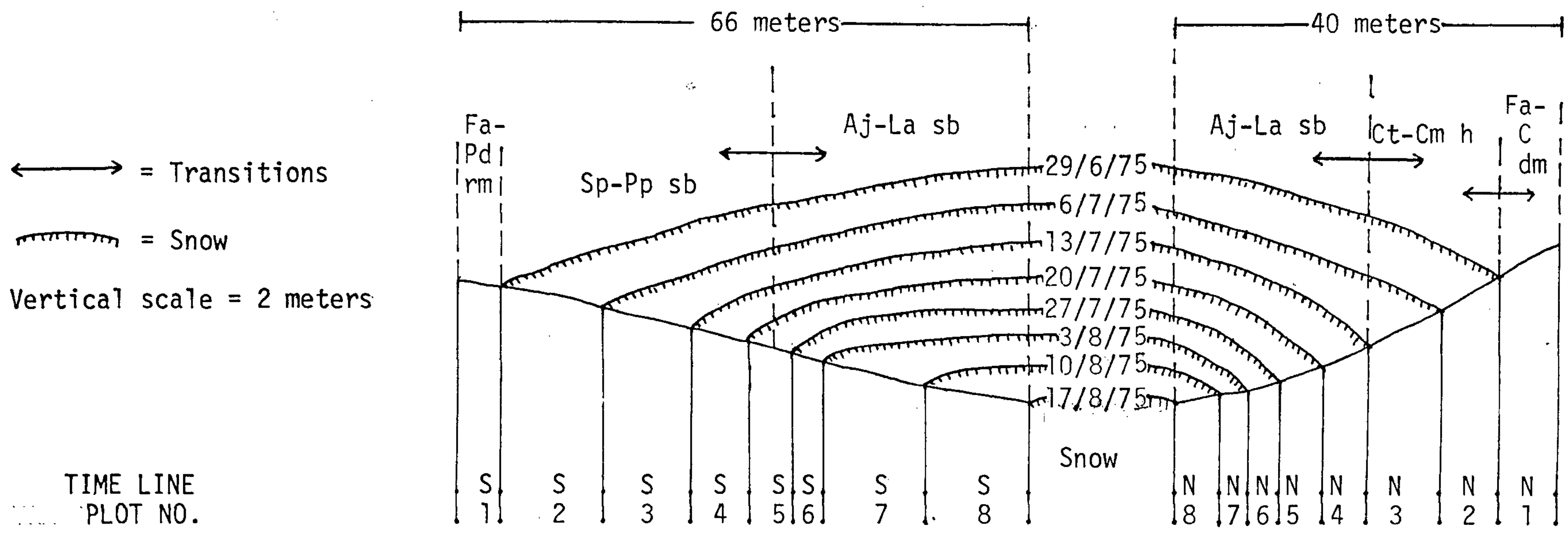
The assignment of communities along this transect is more difficult than in the previous two. Quadrats 1-3 are intermediate between the Cetraria nivalis - Vaccinium uliginosum fellfield and the more mesic Betula glandulosa - Cetraria cucullata shrubfield. Probably because of better moisture conditions and some seepage, Salix planifolia has been substituted for the birch.

Quadrat 4 can be placed in the Festuca altaica - Potentilla diversifolia rich meadow which quickly grades into a Cassiope stelleriana - Phyllodoce empetriformis snowbed community. This community is well developed here, and can be considered to extend from quadrat 6 to 13 with best development in quadrats 10 and 11. The increase in water, decrease in shrubs and increase in bryophytes at the lower half of the snowbed is indicative of the Anthelia juratzkana - Luzula arcuata late snowbed. A poorly developed Salix planifolia - Empetrum nigrum - Sphagnum runoff develops at the base of the snowbed. Missing in this snowbed but common in others is a band of Cassiope tetragona between the Anthelia community and the Salix runoff.

B.3.2.4 Transect 4: Saddle Snowbed Transect

This transect was established in 1975 across the long snowbed in the saddle between the North Knoll and the north slope, very near the origin of Transect 1 (see Figure 67). The purpose of the saddle snowbed transect was to document species distribution in relation to snow duration. To do this, the north and south edges of the snowbed were marked every week from June 29 to August 17 and the vegetation was then sampled between time lines. The results are shown in Figure 43. Figure 44 is a false color infrared photograph taken on July 28, 1975 looking north across the snowbed towards the North Knoll.

Figure 43: Results of the Saddle Snowbed Transect showing changes in species composition and cover in relation to snow duration. Species values and values used in the graphs are cover classes.



TIME LINE PLOT NO.	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8	N 8	N 7	N 6	N 5	N 4	N 3	N 2	N 1
Ranunculus eschscholtzii	1															
Potentilla diversifolia	1															
Nephroma arctica	+															
Trisetum spicatum	+															
Veronica wormskjoldii	1	+														
Festuca altaica	1															2
Dactylina arctica	1														1	+
Campanula lasiocarpa	+															+
Salix polaris	1	1	+								+		+	+	+	+
Artemisia arctica	1	+	+	+				+	+			+		+	+	1
Cetraria islandica	1	+	1	+	+	+				+	+			1	1	+
Crustose ground-gray	2	5	6	3	1	1	1	1	1	1	3	2	3	5	2	
Solorina crocea	+	1	1	1	1	1	+	1			+	1	2	1	1	+
Luzula arcuata	+	1	2	3	1	1	+		1	1	1	1	1	+		
Sibbaldia procumbens	1	1	1	1	1					+		+		+	1	
Anthelia juratzkana		2	1	2	2	1	+	2	2	3	3	5	1	2	1	
Antennaria alpina		+	+	+								+		+		
Phyllodoce empetriformis		1	1	+												
Luetkea pectinata		+	1													
Carex pyrenaica		1			1											
Cassiope stelleriana		1														
Cardamine bellidifolia				+	+	+										
Oxyria digyna									+		+					
Stereocaulon sp.	+	1	+	+		+			2	2	1	3	3	2	3	3
Antennaria monocephala	1	+							+	+	+	+	+	+	+	1
Cassiope tetragona	1			+						+	+	+	1	3	3	1
Cetraria nivalis														+	+	1
Salix reticulata														1	+	+
Vaccinium uliginosum														+		+
Empetrum nigrum																1
Vaccinium vitis-idaea																+
Thamnolia vermicularis																1
Cetraria cucullata																+
Dryas octopetala																1
Cladina rangiferina																+

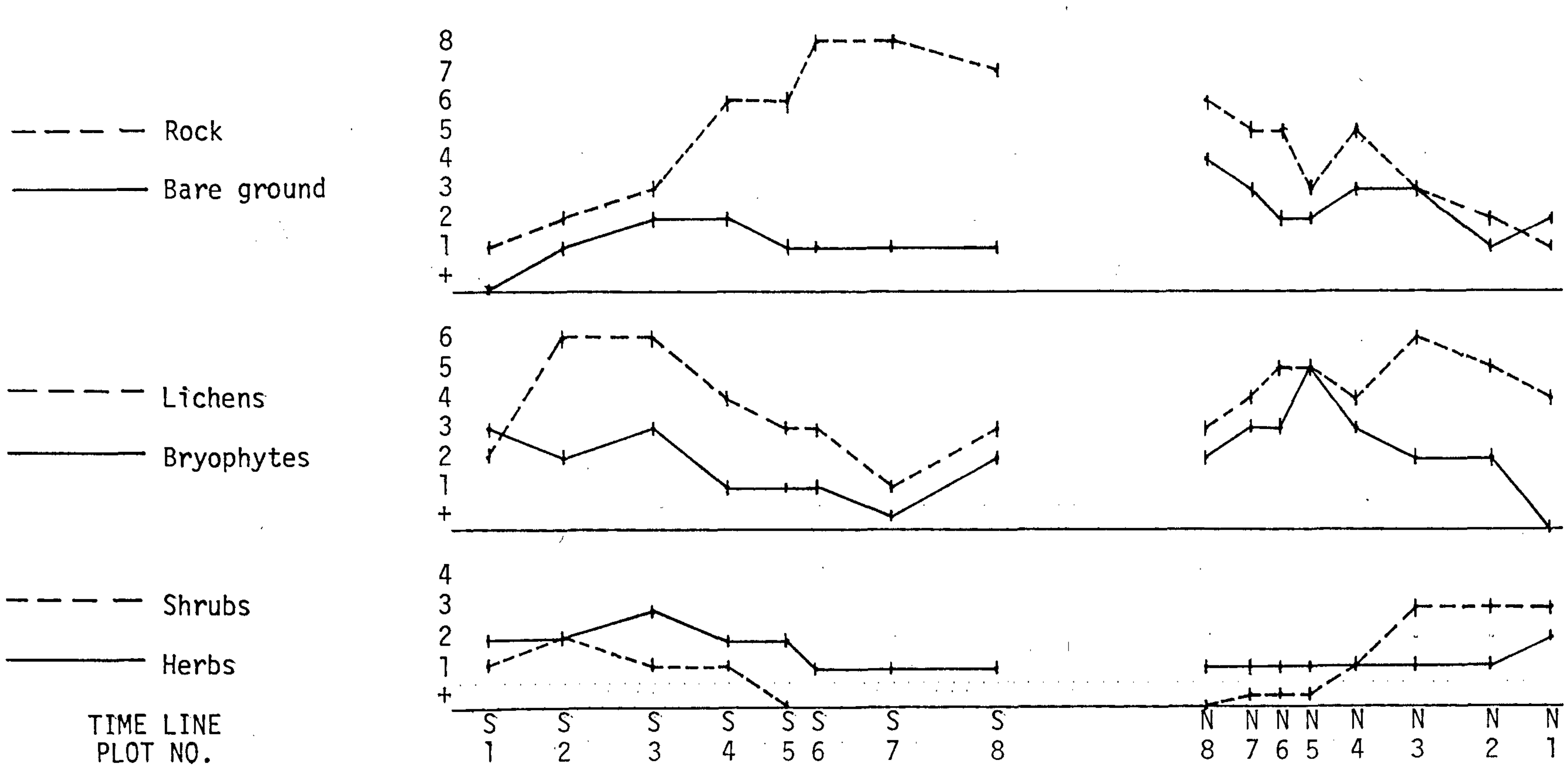


Figure 44: Color infrared photograph, taken July 28, 1975, of Transect #4, looking north across saddle snowbed up the North Knoll.

Since the snowbed lies in a saddle, drainage is lateral (east and west). The north and south edges of the snowbed are on slopes which slope toward the snow and differ somewhat in moisture. No snowbeds develop on the North Knoll, and thus, the northern half of the transect receives no seepage. The southern half of the transect, though, does receive some seepage from melting snowbeds on the north slope. This difference in available moisture influences the distribution of vegetation.

On the south edge at time line 1, there is a characteristic meadow vegetation with Festuca altaica, Potentilla diversifolia, Artemisia arctica and Dactylina arctica. At time line 2, where the snow remains until July, chionophilous species begin to appear (Anthelia juratzkana, Antennaria alpina, Phyllodoce empetriformis, and Luetkea pectinata) or become more prominent (Solorina crocea, Luzula arcuata). As the snow duration increases through the time lines, vegetative cover decreases and rocks become more and more prominent, probably because of nivation processes occurring here. Where the snow remains until August (time lines 6-8) shrubs have disappeared and herbs are of minor importance.

The vegetation at time line 1 on the north end of the transect is, as it is at the south end, dominated by Festuca altaica. The dryness of time line N1, because of lack of seepage, is evidenced by the more diverse lichen flora with some species characteristic of fellfields such as Cetraria nivalis and Thamnolia vermicularis. Vascular species found here which are characteristic of dry sites are Dryas octopetala and Vaccinium uliginosum. Where the snow melts out during the first two weeks in July, Cassiope tetragona dominates and typically chionophilous species occur. Snowmelt later than this results in a decrease in vascular species. Vegetation here is dominated by Anthelia juratzkana, Luzula arcuata, and crustose species of lichens growing on the ground.

Changes in species dominance and floristic composition are distinct enough to allow the recognition of five community types. Time line S1 is placed within the Festuca altaica - Potentilla diversifolia rich meadow. Time lines S2-S4 and possibly S5 with their longer snow duration belong to the Sibbaldia procumbens - Polytrichum piliferum snowbed. The remainder of the southern half of the transect belongs to the Anthelia juratzkana - Luzula arcuata late snowbed. This community type continues on the other (north) side of the snowbed from the edge of snow to time line N4. Time lines N3 and N2 with a shorter snow duration and greater Cassiope cover belong to the Cassiope tetragona - Cladina mitis heath (Cassiope tetragona - Solorina crocea subcommunity). The last time line on the north side of the transect belongs to the Festuca altaica - Cladina dry meadow.

B.4 Discussion

B.4.1 General vegetation - environment relations

B.4.1.1 Environmental factors

The distribution of natural vegetation is environmentally controlled. Low temperature is a dominant environmental factor in the alpine zone, restricting the occurrence of plants to those which are structurally and physiologically adapted to survival in heat-deficient ecosystems characterized by short, cool summers and long, cold winters (Billings, 1973; Bliss, 1971). Excellent surveys and reviews on the adaptation of vegetation to cold environments can be found in Bliss (1971), Billings (1974), Billings and Mooney (1968), and Savile (1972). Alpine vegetation is composed of evergreen and deciduous prostrate shrubs, short-stemmed herbaceous perennials, especially rosette plants, cushion plants, grasses and sedges, and bryophytes and lichens. Cold temperatures and short growing seasons inhibit tree growth. Because of low growth forms, light is not a limiting factor and the erect habit is not needed. The erect growth form is actually a disadvantage, for species sticking above the snow in winter are subject to severe desiccation and ice-abrasion.

Unlike a forest community, the low growth form of alpine vegetation results in little environmental modification and thus the physical environment is very pronounced (Billings, 1974). Topographic diversity modifies other environmental factors and results in a great diversity of habitats within a small area. The patchwork of vegetation, reflecting this habitat diversity, can be most bewildering to a person used to the more uniform nature of forest vegetation.

The physical environmental factors most instrumental in controlling the local distribution of vegetation within the alpine zone are topography, snow duration, moisture (including atmospheric moisture) and wind. Vegetation is sorted out in relation to gradients of these factors. These physical environmental factors are not simple, but complex, and thus form "complex gradients" (sensu Whittaker, 1956). The relative importance of the environmental factors depends on the geographic location of the alpine area. In all cases, topography is of major importance. In the Presidential Range in New Hampshire, atmospheric moisture is prominent along with snow duration (Bliss, 1963). In New Zealand, summer wind is reported to be of primary importance (Billings and Marks, 1961; Bliss, 1969). Studies have shown that the distribution of vegetation in the alpine areas of Western North America is influenced primarily by topography, snow duration and moisture or water availability (Bamberg and Major, 1968; Billings, 1973; Billings and Bliss, 1959; Billings and Mooney, 1968; Bliss, 1969, 1971; Detwyler, 1974; Johnson and Billings, 1972; Marr, 1961; Scott, 1974a, 1974b, 1974c). This is true of the alpine area of Teresa Island

(Buttrick, 1977).

Topography, snow duration and moisture are not independent of each other but are rather strongly interrelated. Topographic gradients on the mountain, called mesotopographic-gradients by Billings (1973), interact with wind to modify snow accumulation which in turn effects runoff (Figure 45). In the Atlin area the prevailing wind is from the south. During the winter this south wind removes much or all of the snow from the summit, ridges and high plateaus and deposits it on the northern lee slopes where large accumulations develop. The north slopes, then, have a heavier snow cover than the south slopes. During the summer, differences in total radiation receipt between north and south slopes is pronounced with south slopes receiving up to four times the amount of radiation received on the north slope (Barry and Van Wie, 1974; Price, 1971).

The low radiation receipt combined with the snow accumulation on these lee slopes results in the development of extensive snowbeds. Permanent snowbeds and annual snowbeds lasting through July are a major feature on the northern and northeastern alpine slopes of Teresa Island. Snowbed development is poor on the southern slopes which retain less snow and receive more radiation. The small snowbeds that do develop here in general melt out by the end of June. This gradient of snow duration has a major effect on species distribution. The snowbed end of the gradient is characterized by chionophilous or snow-loving species. Chionophobous, or snow-intolerant species, are found on the exposed ridges and knolls where snow accumulation is minimal. Habitats intermediate between the two occur on the southern slopes and slopes above and below snowbeds.

Since there is low precipitation in the Atlin area, the moisture regime on the mountain is controlled by snowmelt. Major runoff channels and small ponds are restricted to northern and eastern slopes where

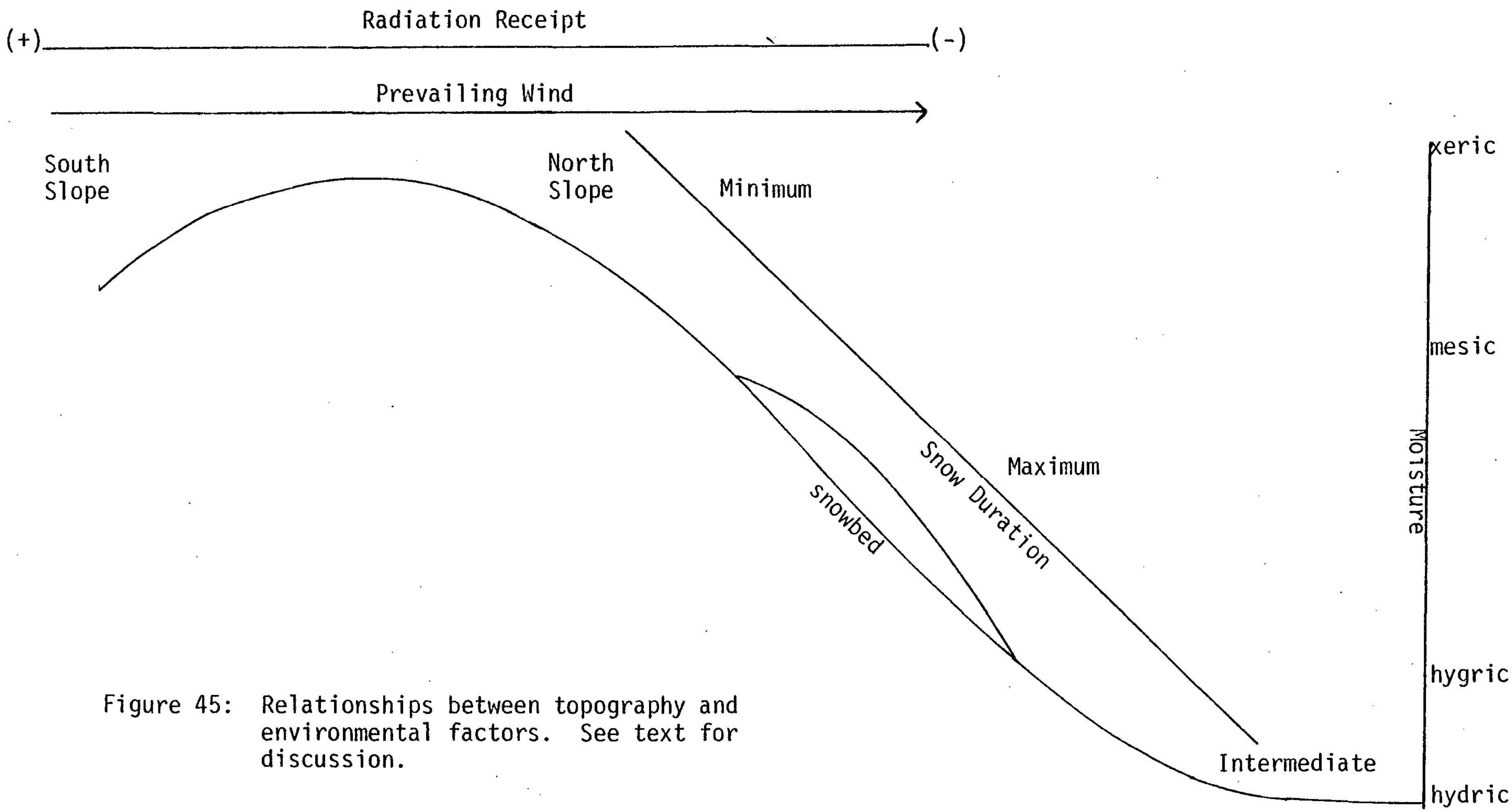


Figure 45: Relationships between topography and environmental factors. See text for discussion.

there is a constant supply of melt water from permanent snowbeds throughout the summer months. Ridges and knolls with coarse well-drained soils and no added moisture from snowmelt represent the most xeric sites on the mountain. Slopes above snowbeds and well-drained slopes below are more mesic. Hygric and hydric sites are found below snowbeds in poorly drained horizontal topography, in basins and beside runoff streams and ponds. Species segregate out along this moisture gradient according to their physiological tolerances.

It can be seen, then, that topography is a major factor affecting the local distribution of snow and also moisture. Exposure to the wind is another effect of topographic position. The effect of wind is most pronounced on exposed ridges, knolls and high plateaus and has much less influence in basins and on lee slopes.

B.4.1.2 Habitat types

A meaningful way to generalize the distribution of Teresa Island's alpine vegetation is in terms of the three major environmental factors discussed above; topography, snow duration and moisture. I have established four environmental classification units defined primarily by these factors which effectively reflect both distribution of taxa and major patterns in the vegetation. These environmental units, here called habitat types, are aerially distinct and can be identified by their topographic position on the mountain and by the floristic and physiognomic characteristics of the associated vegetation.

Habitat type is used here in a broader sense than that used by Daubenmire (1952), who defines habitat type as "the collective area which one association occupies." Environmental variation within a particular habitat type results in differential local distribution of the taxa. A habitat type, then, can be composed of a number of communities which have certain environmental similarities. In this context, the usage of the term "habitat type" is similar to that of Whittaker (1962), who defines it as "a grouping of ecosystems or communities by resemblance of their habitats or environments...". Similarly, Dansereau (1957) believes that such environmentally defined units cannot be tied to a community but are definable only in terms of site factors and that a single unit may contain one or more communities. Similar units have also been used by Elton and Miller (1954) in the study of animal communities.

The four habitat types described in the following section are: 1) fellfields and blockfields, 2) snowbeds, 3) runoff sites, and 4) meadows and shrubfields. Figure 46 illustrates the relationships of these to the three environmental factors.

B.4.1.2.1 Fellfield and blockfield habitat type

Fellfields and blockfields represent the most environmentally severe habitats on the mountain. This habitat type occurs most frequently on exposed slopes, knolls, peaks, ridges and other convex topography where wind is a major factor. The exposed nature of these sites results in a very light and discontinuous snowcover so that the vegetation experiences the abrasive and desiccating effect of the wind throughout the winter.

Moisture is limiting in this habitat type. The lack of snow results in a severe moisture deficit during the summer. Snowmelt occurs rapidly in very early spring and the large rocks of the blockfields and the sandy, gravelly substrate of the fellfields result in rapid drainage, making these sites the most xeric on the mountain.

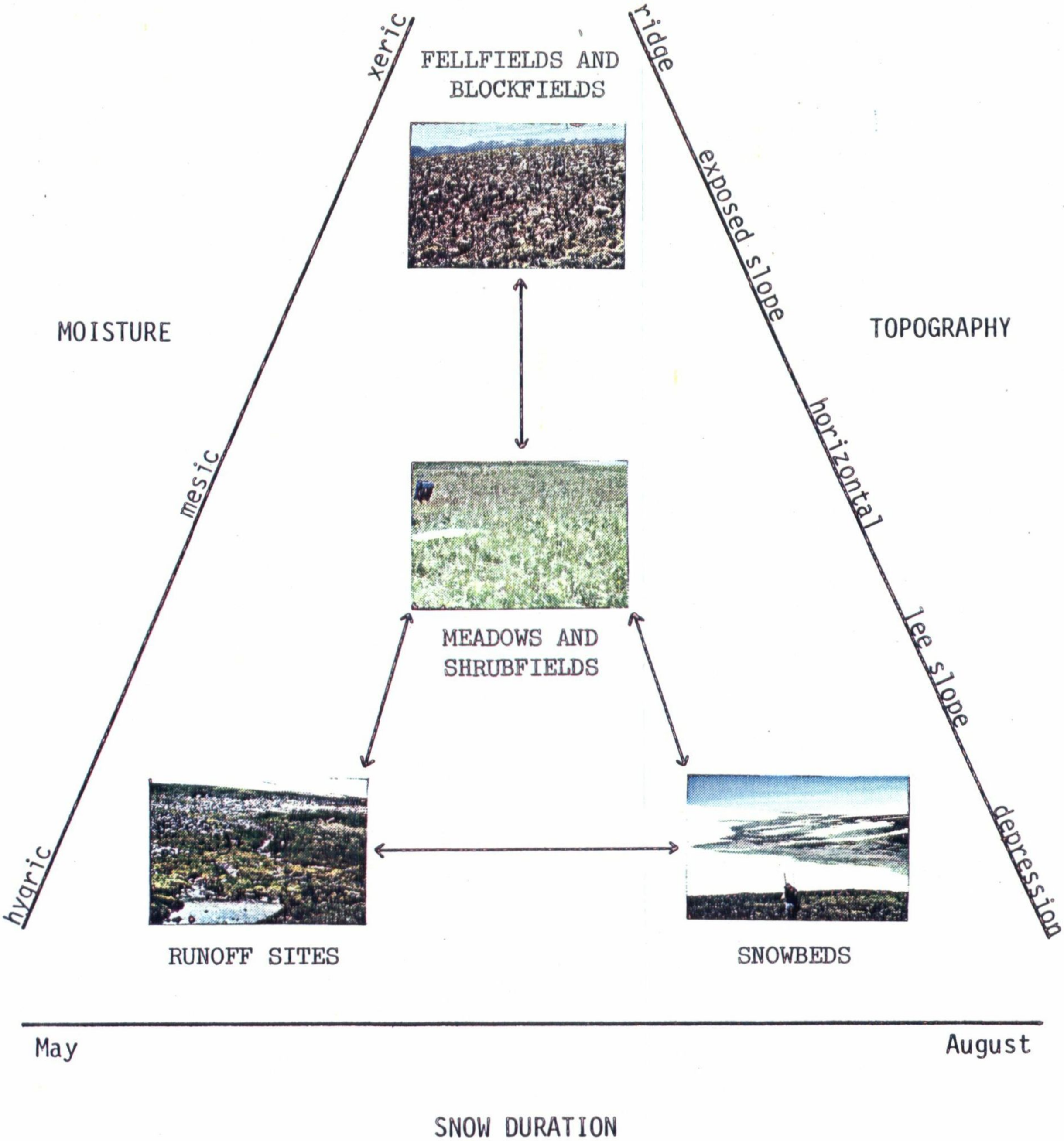


Figure 46: Diagram of the four habitat types in relation to snow duration, moisture and topographic gradients. Arrows indicate transitions occurring between habitat types.

Blockfields, often called felsenmeer, are assemblages of angular rock fragments which completely mantle the surface of the summit and much of the peaks and high ridges. These blocks, caused by frost action, are completely covered with black foliose and crustose lichens.

At lower elevations (ca. 1900 m) where exposure to the wind is not as great and topography is more gentle, these blockfields grade into fellfields which are characterized by fewer large blocks and more sand and gravel with a concurrent increase in vascular plant species and a slight decrease in lichens.

Fellfield and blockfield vegetation is dominated by macrolichens. Mosses are common and vascular vegetation consists of cushion plants, rosette plants and dwarf prostrate shrubs. Black macrolichens such as Umbilicaria proboscoidea, Cetraria commixta, Alectoria minuscula and Parmelia stygia cover the rocks and the yellow Cetraria nivalis and C. cucullata often carpet the ground or grow in between the rocks.

Lichens are well adapted to the rigorous environmental conditions of this habitat type. They have the ability to dry out for extended periods of time without injury and are able to make use of the meagre moisture available to them. The cell walls are hygroscopic, able to take up moisture from atmospheric water vapour (Savile, 1972). The low lichen growth form allows them to make maximum use of meltwater at the rock- and soil-air interface and any precipitation is trapped before it enters the ground (Billings, 1974). Temperature changes on poorly vegetated soil surfaces and on rock are extreme (Barry and Van Wie, 1974) and lichens are able to withstand extremes of heat and cold with minimal injury (Savile, 1972). In fact, optimum temperatures for photosynthesis for many lichens are around 5^{0} C and these lichens also can carry out net positive photosynthesis at temperatures below 0^{0} C (Billings, 1974).

Many of these adaptations also pertain to mosses. The grey moss, Rhacomitrium lanuginosum, occurs almost exclusively in this habitat type and attains higher elevations on the mountain than any vascular species. The same is true with its latitudinal distribution in the Arctic (Savile, 1972). In general, beyond the environmental limits of vascular plants, lichens and bryophytes can still be found.

The most common vascular species occurring in the fell-field and blockfield habitat type are dwarf, mat forming, prostrate shrubs (Dryas octopetala and Vaccinium uliginosum), cushions (Silene acaulis), and rosettes (Saxifraga triscuspidata, S. bronchialis, and Draba nivalis). In these plants, especially the rosettes and cushion species, the sensitive growing points are protected from wind abrasion by the living and dead leaves of previous years. The dense growth form of these species reduces wind movement and thus warm air is trapped within the plants (Savile, 1972). Monocots growing in this habitat type are generally tussock-forming species such as Festuca brachyphylla and F. altaica. By decreasing air movement, the dense growth form of the vascular plants also decreases evaporational loss of water. Leaves are also often heavily cutinized as shown in Saxifraga tricuspidata and Dryas octopetala.

Plants rarely exceed five centimeters in height except when occurring in shallow pockets and in the lee of rocks. These features decrease the laminar flow of the wind. This decrease in wind velocity with a proportional decrease in its desiccating and cooling effects (Wilson, 1959) cause favorable microsites for the establishment of larger species such as Betula glandulosa and Salix brachycarpa.

The wind, cold temperatures and extreme xeric conditions are the most important factors restricting plant life in this habitat type. With low productivity and high winds, humus build-up is minimal, horizon development is weak and soils are regosols. *Dryas octopetala* and *Lupinus arcticus* are important species because of their nitrogen-fixing ability. The extensive temperature fluctuation of the bare ground results in frost heaving and the formation of nonsorted circles which hinder colonization. Directional succession, if occurring at all, is extremely slow and this habitat type represents a common topoclimax in the alpine zone of Teresa Island.

B.4.1.2.2 Snowbed habitat type

Snowbeds are here defined as areas where winter snow remains until early July. Snowbed refers to both the ground area exposed by snowmelt during July and August and the actual snow zones within these areas. Snowbeds are a common feature on the mountain and, as mentioned previously, are concentrated on northern and northeastern lee slopes where they are frequently associated with solifluction terrain. The lee of solifluction benches provides a site for snow accumulation. Interestingly, the melting snow from these banks provides the necessary moisture to generate active solifluction, thus these snowbeds are actually maintaining their own habitat. Most of the snow within the snowbeds on the island melt out by mid-August, but some large permanent snowbeds do occur on the north slope, in the glacial cirques and on the lee side of the high southern ridges. From a distance, snowbeds, even without snow, can be located easily by their topographic position.

The effects of the snowbed environment on alpine vegetation have been well documented (Billings and Bliss, 1959; Dahl, 1956; Detwyler, 1974; Gjaerevoll, 1956; Johnson and Billings, 1962; and Scott, 1974). In the alpine zone of Teresa Island there are in general three effects:

1. The long snow duration of a snowbed provides a protected environment for the underlying vegetation. Species here are protected from the abrasive and desiccating effects of wind. Snowcover insulates the vegetation from the extreme temperature fluctuations of spring and the low temperatures of winter. Temperatures beneath the snow remain at a constant -3^{o} C during the winter months while air temperatures can fluctuate from lows of -37^{o} to -10^{o} C (Zwinger and Willard, 1972). It is not surprising that some species can reach their highest elevations under the protection of snowbeds. On Teresa Island, *Luetkea pectinata* and *Cassiope mertensiana*, both common subalpine species, reach a high elevation of about 1646 m in snowbed habitats (Buttrick, 1977). The protective nature of the snowbed is really manifested only where the snow melts out by late July and even then only at elevations below 1740 m. In these sites the vegetation is complete and forbs and dwarf shrubs dominate.

2. The duration of snow greatly reduces the length of the growing season. This shortened growing season restricts species occurrence to chionophilous and snow-tolerant taxa. The establishment and growth of vascular plants is extremely restricted in snowbeds above 1740 m and at lower elevations in snowbeds melting later than July. Crustose lichens dominate these habitats. The exposed substrate, moisture from the ablating snowbed, and temperature fluctuations at the snowbed front result in extensive frost action. This further hinders the establishment of vascular plants.

3. Important to plants are the extreme moisture conditions of snowbed habitats. Early-melting lower edges of snowbeds and snowbeds which receive constant seepage from other snowpatches above them are moist throughout the summer. Frequently,late melting snowbed habitats are extremely dry. This is primarily due to the poor water holding capacity

of the soils. Because of the impoverished vegetation in sites of late snow release, very little humus is added to the soil. The fine materials that do accumulate are often washed away by the melt water. Warren Wilson (1958) discussed the enrichment of snowbed soils from the accumulation of dirt on the melting snow, but this phenomenon was not noted in the study area. Regosolic soils seem to dominate.

Thus, while the snowbed can provide a protective environment for the vegetation, the environmental conditions in areas free of snow after July and in high elevation snowbeds can be as severe as those in the fellfields. Both face xeric conditions; however, instead of wind and cold temperatures, snowbed vegetation must contend with short growing seasons.

Differential distribution of the vegetation within the snowbed habitat type is due to the tolerances of the species to shortness of growing season and drought. In general, vegetation grades from a complete cover of forbs and dwarf shrubs at the edge to a partial cover of crustose lichens and bryophytes in the center as shown by transects 3 and 4. Vegetation cover decreases proportionately with increase in snowcover.

In the snowbed environment a species' ability to grow rapidly is more advantageous than its ability to withstand cold. It is uncertain at the present time how species in late snowbeds are able to grow quickly (Billings, 1974; Billings and Mooney, 1968). Billings and Bliss (1959) state that species which are released later from the snow grow faster in a shorter time than those released earlier but they are small and produce less dry matter. The evergreen habit is obviously advantageous since the plants do not have to expend excess energy to produce new leaves yearly and photosynthesis can start as soon as environmental conditions allow. There is evidence that some species can commence growth while still under snow

(Savile, 1972). The growing season is frequently too short for species to complete their reproductive cycle so vegetative reproduction is a necessary adaptation. I have noticed that vascular plants become more deeply pigmented with anthocyanins the longer the snow duration. This is especially noticeable in Luzula arcuata and Artemisia arctica. It is thought that anthocyanins in leaves and stems may absorb excess radiation with a resultant increase in leaf temperature (Billings, 1974; Billings and Mooney, 1968). Chionophilous vascular species indicative of snowbeds include Sibbaldia procumbens, Luzula arcuata and Antennaria alpina.

In some late snowbeds the snow does not melt out every year and plants must be able to exist under snow for over a year. In the severe environment of the high elevations (over 1740 m) any prolonged snow duration is detrimental to vascular plants. In these habitats the last plants to be found are frequently Luzula arcuata and Silene acaulis. This latter species is also common in fellfields. Its appearance in both habitat types may be a result of lack of competition. In more moderate environments other species quickly invade the cushion (Griggs, 1956).

A characteristic lichen occurring in all snowbeds is Solorina crocea. At the limit of vascular species, crustose lichens dominate over the soil and exposed rocks. The liverwort Anthelia juratzkana also blankets the bare ground in these sites and is important in holding soil particles together (Zwinger and Willard, 1972). Large foliose lichens such as Umbilicarias are not able to grow in the snowbed environment, and the large light-colored rocks of late snowbeds are easily distinguished from the black, macrolichen-covered rocks of the blockfields.

B.4.1.2.3 Runoff habitat type

Runoff areas occur primarily on northern and eastern slopes where snow accumulation results in a constant summer supply of melt-water. Water is the primary environmental gradient affecting species distribution. These water-dominated sites include spring-lines, stream-edges, pond margins and semi-stagnant bog-like areas, providing a wide range of habitats for the hydro- and hygrophilic species. Runoff sites can occur beneath snowbeds and thus overlap with the snowbed habitat type.

The vegetation of runoff habitats is dominated by bryophytes, the most characteristic of which is Aulacomnium palustre. In basins and level topography below snowbeds, drainage is poor and the moss layer becomes thick and forms hummocks which create semi-stagnant bog-like conditions. Permafrost is most common in this habitat. The water-logged gleysols that develop with their thick layer of moss and peat are poor heat conductors. Because of the specific heat of water, it takes five times as much heat to raise the temperature of wet soil as it does an equivalent volume of dry soil (Zwinger and Willard, 1972). The acidity in these boggy sites is demonstrated by the abundance of Sphagnum, Ledum palustre and Empetrum nigrum.

In runoff habitats where drainage is good and water moves more rapidly, richer conditions develop. The Runoff Habitat Type occurs at all alpine elevations below 1768 m. In the low alpine at elevations below 1555 m, the richer runoff habitats are dominated by a high shrub cover composed of Salix planifolia. At higher elevations these habitats are dominated by mosses and forbs. Where the water is very fast moving, the forbs are replaced by graminoid species, especially Calamagrostis canadensis and Carex podocarpa.

Runoff sites which are covered with snow through June have a vegetation similar to that found along the subalpine streams. Characteristic species include Caltha palustris, Parnassia fimbriata and

Leptarrhena pyrolifolia which attain their highest elevation in these sites.

To summarize, the Runoff Habitat Type is characterized by its topographic position, water-saturated soils, usually with water visible on the surface, and physiognomy dominated by low forbs and mossy hummocks, with local occurrence of tall shrubs and graminoids.

B.4.1.2.4 Meadow and Shrubfield Habitat Type

The meadow and shrubfield habitat type encompasses the mesic areas of the mountain. As such, many of the communities occurring within this habitat type are promoted by good-to-moderate drainage, and a moderate, continuous winter snowcover which remains until mid-May to late June.

These mesic sites are common in scattered patches on the north slopes where snow accumulation often confines them to the upper surface of solifluction lobes and benches, and perimeters of snowbeds. Good development is more widespread on southern slopes because of earlier snowmelt.

The physiognomy of the meadow and shrubfield habitat type changes with elevation and snow duration. One to two-foot high deciduous shrubs (Betula glandulosa with mixtures of Salix planifolia and Salix brachycarpa) dominate the mesic sites at alpine elevations below 1600 m. This is the zonal vegetation of the low alpine and merges with subalpine below 1494 m. At elevations above 1600 m meadows form most of the zonal vegetation. The term meadow is used here for mesic sites dominated by graminoid species with admixtures of forbs. In the mid-alpine, between 1600 m and 1676 m, meadows are dominated by the clump fescue, Festuca altaica and at higher elevations by Carex microchaeta.

At elevations above 1600 m where snow remains until mid-to-late June, the vegetation is dominated by the ericaceous heath _Cassiope tetragona_. These sites are transitional between the meadow and shrubfield and the snowbed habitat types.

The meadow and shrubfield habitat type has a more diverse flora than the other habitat types. The richest sites occur above the East Valley on steep southern slopes influened by seepage from snowbeds above. Species commonly occurring in subalpine meadows such as _Geranium erianthum_, _Valeriana sitchensis_ and _Polemonium pulcherrimum_ attain alpine elevations in these rich sites.

Except for the heath dominated sites, cover by vascular vegetation is complete. This cover insulates the soil and modifies the effects of diurnal temperature fluctuations. This fact combined with the good drainage results in a minimal amount of frost action and resultant mixing of the soil. The high productivity, good drainage and the limited frost action combine to promote soil development. The best developed soils, probably Alpine Dystric Brunisols, occur in this habitat type.

Summer utilization by fauna is highest in the meadows and shrubfields. A number of nests of unidentified birds were found on the ground. This habitat is heavily utilized by Arctic Ground Squirrels, (_Spermophila paryii_), who feed and burrow in the meadows below 1616 m. The good drainage probably prevents excessive flooding of the burrows. The mixture of meadow and _Betula_ shrubs provides ample food and shelter for ground squirrels and other rodents. The meadows at all elevations are also prime grazing area for Osborn Caribou, of which there are about fifteen on the mountain.

B.4.2 Community Type - Environment Relations

The sixteen community types described in this thesis develop in response to the same environmental factors (moisture, snow duration and topography) which define the four habitat types. Each community then, depending on its environmental tolerances, can be assigned to a habitat type. In other words, each habitat type can be subdivided into its component parts or communities which outline the environmental variation within the habitat type. As will be seen, community type and habitat type boundaries do not always coincide.

The Umbilicaria blockfield, Cetraria nivalis - Carex microchaeta fellfield and Cetraria nivalis - Vaccinium uliginosum fellfield all develop within, and are restricted to, the fellfield and blockfield habitat type. These three communities outline variation within this habitat type primarily reflecting the elevational gradient. This gradient reflects the amelioration of climate, particularly wind and temperature, with a decrease in elevation. Consequently, the exposed, xeric sites necessary for the development of this habitat type are of restricted occurrence in the low alpine (ca. 1500 m), become more frequent in the mid-alpine (1675 m), and dominate the landscape at elevations above 1825 m.

The Cetraria nivalis - Vaccinium uliginosum fellfield develops at lower elevations where the less severe environmental conditions promote the development of Vaccinium uliginosum, Dryas octopetala, Saxifraga tricuspidata, Pedicularis capitata and Trisetum spicatum. Above 1700 m these species decrease in importance or disappear, probably because of the increasing wind, decreasing temperature and decrease in winter snowcover. At these higher elevations, Carex microchaeta, Saxifraga bronchialis and Cetraria cucullata become more abundant and the Cetraria nivalis - Vaccinium uliginosum community is replaced by the Cetraria nivalis - Carex microchaeta fellfield.

In the most exposed sites such as high ridges and peaks where soil has not developed, the Umbilicaria blockfield occurs. This community is found at the highest elevations on the mountain (2060 m). I feel that soil has not formed in this community because of the recentness of severe frost action and the very steep slopes (greater than 30^{0}) on which the community often occurs. With the collection of fine material beneath the Umbilicaria and continued breakdown of the rocks, a soil might eventually develop. Indeed, the Cetraria nivalis - Carex microchaeta fellfield appears to be invading the blockfield in a number of places on the steep slopes and plateaus above 1800 m. The relationship among the three communities in relation to the above factors is diagrammed in Figure 47.

The Anthelia juratzkana - Luzula arcuata late snowbed, Sibbaldia procumbens - Polytrichum piliferum snowbed, Carex pyrenaica - Luetkea pectinata - Juncus drummondii snowbed and Cassiope stelleriana - Phyllodoce empetriformis snowbed community types all occur solely within the snowbed habitat type. The distribution of these communities within the habitat type reflects differences in snow duration, elevation and seepage.

The Anthelia juratzkana - Luzula arcuata snowbed has the poorest vegetation development of the four communities because of the duration of the snow. At low alpine elevations, snow duration must extend well into August to effectively impede plant establishment and growth. At high alpine elevations (1830 m), a snow duration as short as early July and late June can inhibit vegetation development. This community type occurs, then, in the latest melting snowbeds at all elevations but becomes more common at elevations above 1650 m. It develops rather independently of seepage, except that at any one elevation the Anthelia juratzkana - Luzula arcuata community requires, in areas influenced by seepage, a longer snow duration for good development than in areas not so influenced. This relationship is clearly shown in the results of Transect #4: Saddle Snowbed transect

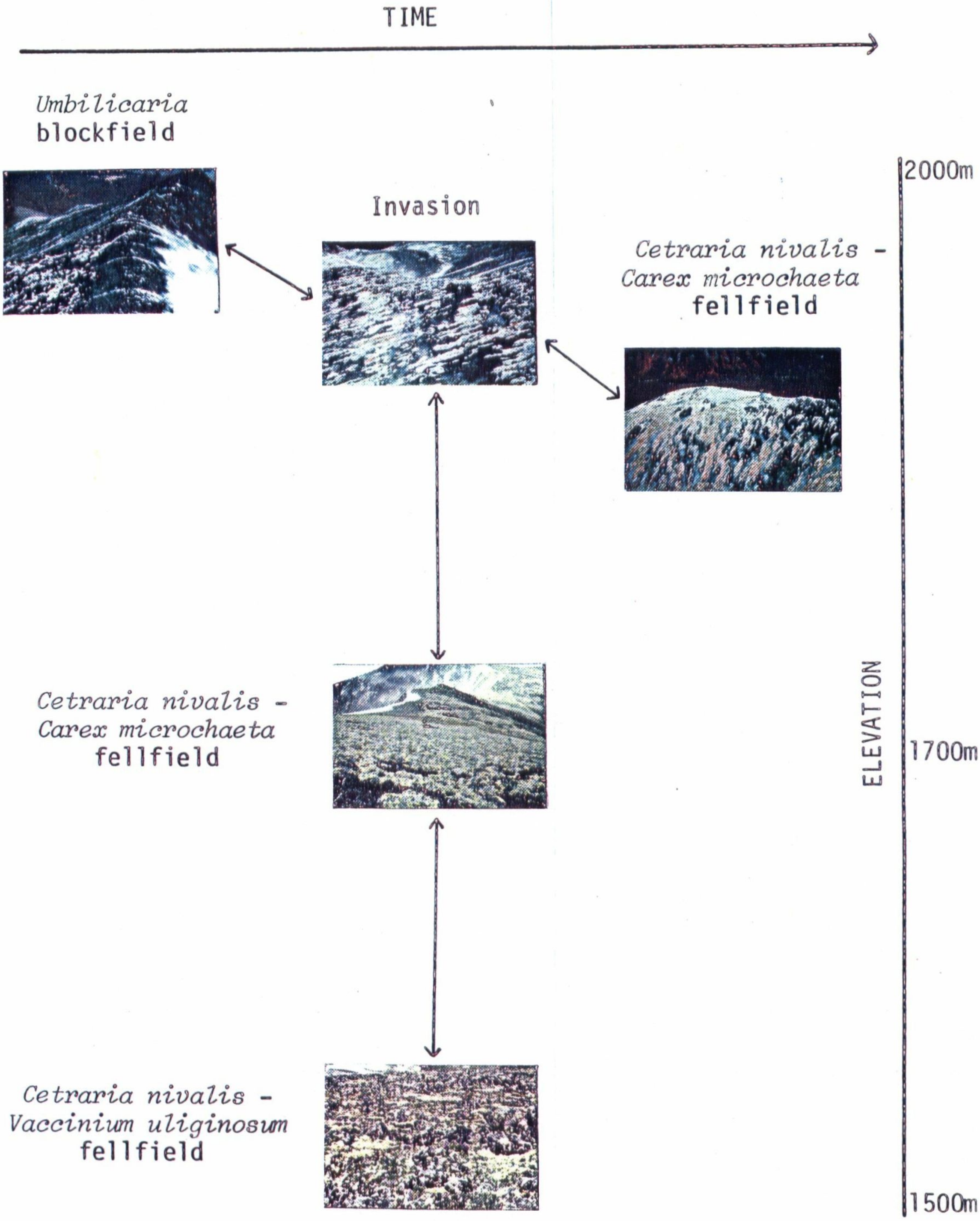


Figure 47: Relationship of communities within the Fellfield and Blockfield Habitat Type with regard to time and elevation. Arrows indicate transitions occurring between communities.

(Figure 43).

The other snowbed communities develop only at lower elevations. The Sibbaldia procumbens - Polytrichum piliferum snowbed community reaches an elevation of about 1700 m. The Cassiope stelleriana - Phyllodoce empetriformis community is most common at subalpine elevations, where Cassiope mertensiana is frequently substituted for C. stelleriana, but often reaches 1600 m on the mountain. The Carex pyrenaica - Luetkea pectinata - Juncus drummondii community is restricted to elevations between 1550 - 1650 m on the East Plateau.

As shown by the results of Transect #3: 1615 m Snowbed transect (Figure 41), the Cassiope stelleriana - Phyllodoce empetriformis community can tolerate a snowcover lasting into August. This community appears to be promoted by seepage and the greater the seepage, the greater the toleration for prolonged snowcover. The Sibbaldia procumbens - Polytrichum piliferum community attains its best development in snowbeds where seepage is minimal, and soils usually dry out during the summer. It develops in snowbeds influenced by seepage only at elevations above the limit of the Cassiope stelleriana - Phyllodoce empetriformis community. Snow duration in the Sibbaldia sites is between early and mid-July, but as with the Anthelia community, becomes less with increased elevation. The last snowbed community, Carex pyrenaica - Luetkea pectinata - Juncus drummondii, is promoted by moderate snow duration and seepage. The exact environmental differences between this community and the Cassiope stelleriana - Phyllodoce empetriformis snowbed is not known and warrants further investigation. The Carex snowbed does, however, occur at higher elevations on the East Plateau than the Cassiope stelleriana dominated community.

The relationship among the four snowbed communities in relation to the above factors is diagrammed in Figure 48.

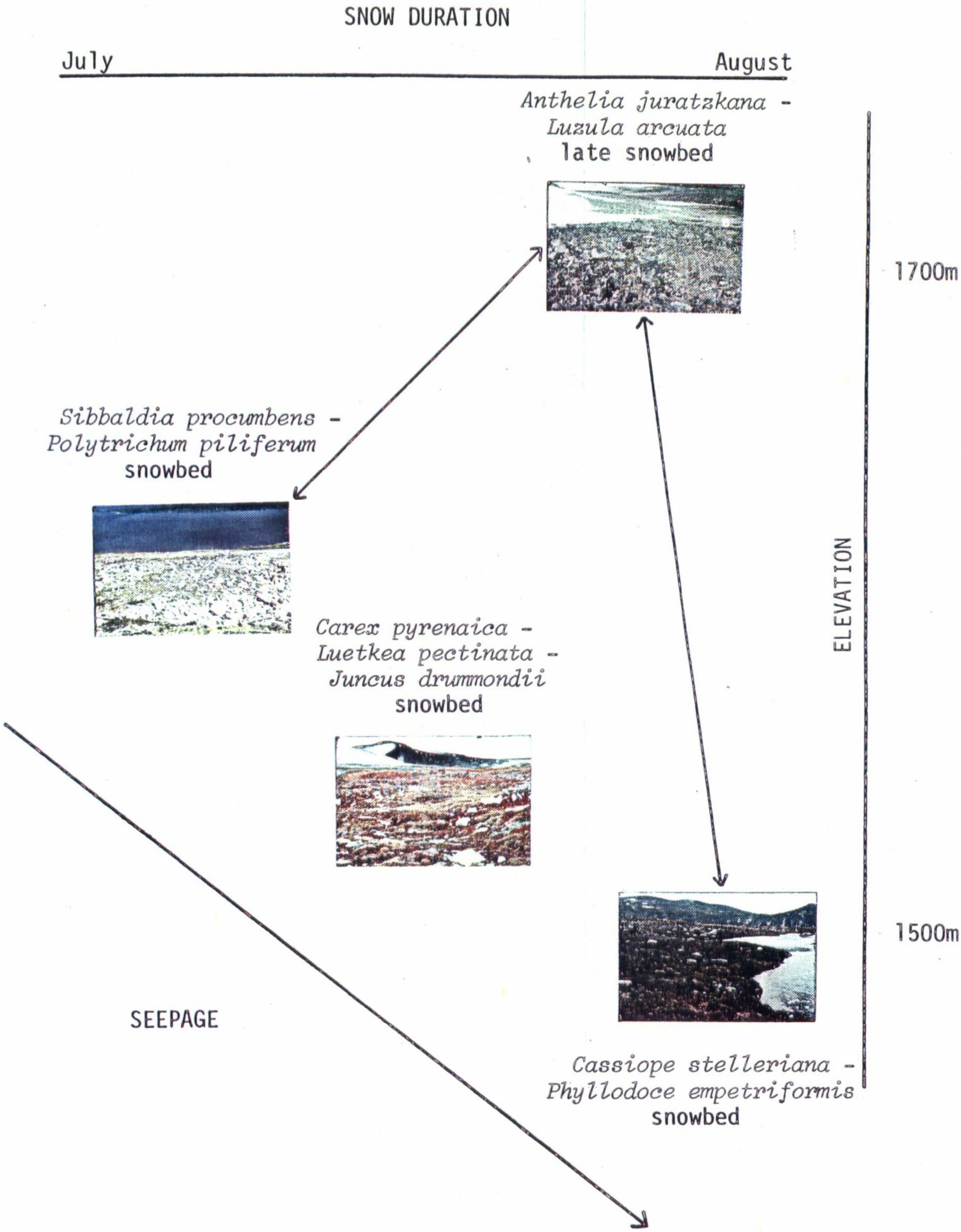


Figure 48: Relationship of communities within the Snowbed Habitat Type with regard to seepage, snow duration and elevation. Arrows indicate transitions occurring between communities.

Four community types occur within the runoff habitat type. These are the Salix planifolia - Empetrum nigrum - Sphagnum community, Calamagrostis canadensis - Plagiomnium rostratum community, Ranunculus - Carex podocarpa - Saxifraga nelsoniana - moss community and the Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta runoff community. These communities outline environmental variation within the habitat type primarily reflecting differences in elevation, snow duration, and drainage.

The Salix planifolia - Empetrum nigrum - Sphagnum runoff develops only at elevations below 1676 m where snow remains no longer than June. Best development occurs where drainage is poor and ponding occurs. These sites are most frequently found at the base of snowbeds on solifluction terrain (Transect #3). With an increase in snow duration, but no change in drainage, the Salix planifolia dominated site is gradually replaced by the Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta community. The Aulacomnium dominated runoff sites are found up to 1750 m on the north slope on stream-edges and spring-lines free of snow by June with moderate drainage. In isolated sites where runoff is very fast and drainage good, the Calamagrostis canadensis - Plagiomnium rostratum community is promoted.

When snow duration increases to mid- or late July, the percentage of forbs increases and the Ranunculus - Carex podocarpa - Saxifraga nelsoniana community is promoted. Environmentally, this community is similar to the Aulacomnium dominated runoff, the only obvious difference being the snow duration. The long duration of the snow raises the question of whether this community should be placed within the snowbed habitat type. In this case, I feel that the snow duration qualifies the runoff rather than the reverse, and its floristic affinities lie more with the other runoff communities than with the snowbed communities. However, the runoff characteristic and long snow duration place this community environmentally between the two habitat types and it can be considered transitional. As runoff or active water movement decreases and is replaced by more gradual seepage, the Ranunculus community merges with the Cassiope stelleriana - Phyllodoce empetriformis snowbed community. On the East Plateau, these two communities frequently occur together.

The general relationships among the four runoff communities in relation to elevation, snow duration and drainage are diagrammed in Figure 49.

The remaining five communities are placed in the meadow and shrubfield habitat type. These communities are the Carex microchaeta meadow, Festuca altaica - Cladina dry meadow, Festuca altaica - Potentilla diversifolia rich meadow, Betula glandulosa - Cetraria cucullata shrubfield and Cassiope tetragona - Cladina mitis heath. These represent the zonal vegetation and the vegetation intermediate between the meadow and shrubfield habitat type and the other habitat types. As with most of the other communities, these segregate out according to gradients of snow duration, moisture and elevation. These relationships are shown in Figure 50.

The three zonal communities, Carex microchaeta meadow, Festuca altaica - Potentilla diversifolia rich meadow and Betula glandulosa shrubfield, are intermediate in snow duration and moisture. Segregation of these communities is along a complex elevational gradient. The Betula glandulosa community attains a maximum elevation of only 1600 m and extends down to between 1400 and 1500 m where the occurrence of Abies lasiocarpa krummholz indicates the beginning of the subalpine. Above 1600 m, Betula occurs only in scattered locations where it is sheltered from the wind and, at the same time, is not subjected to a long period of snowcover extending

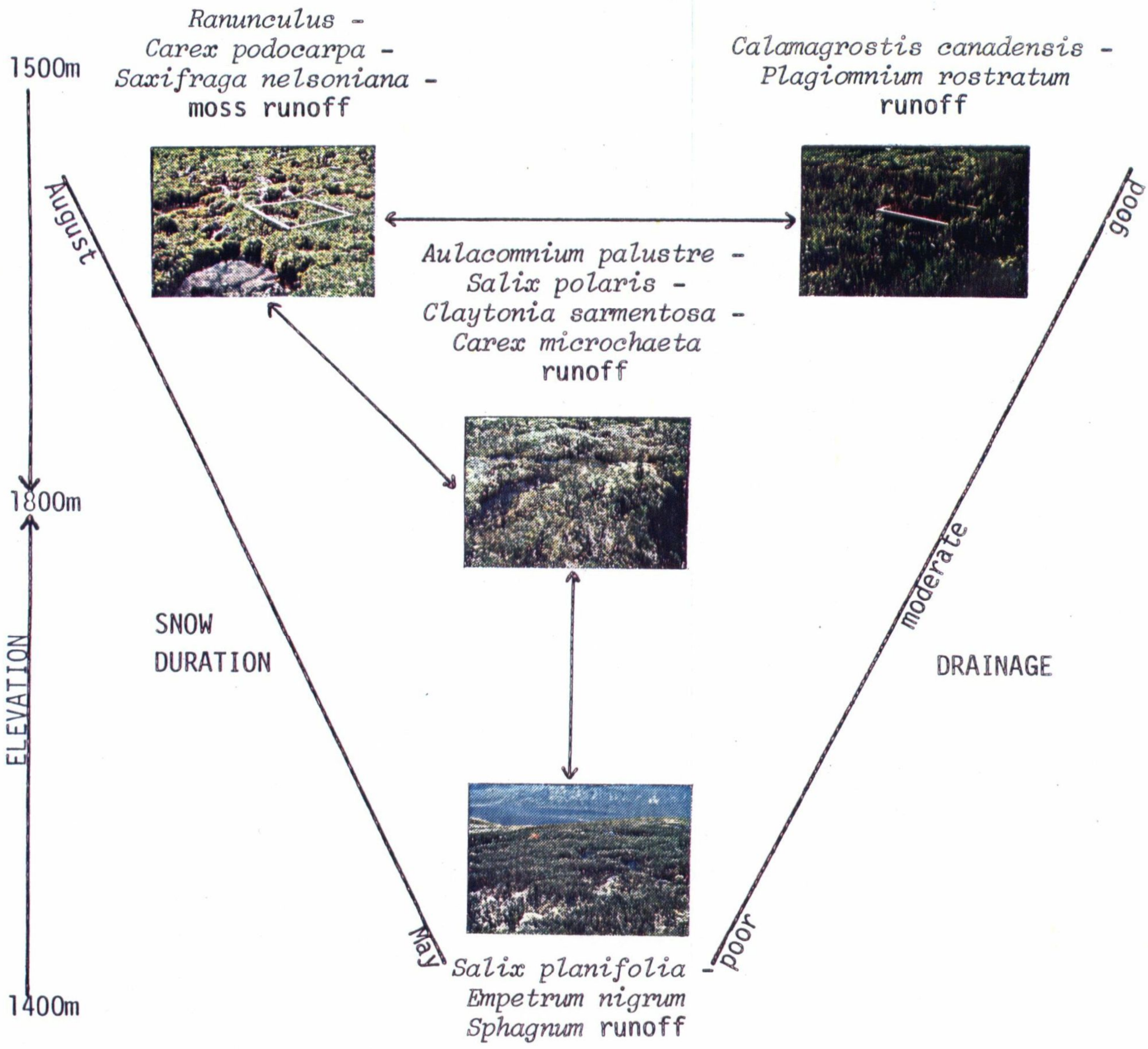


Figure 49: Relationship of communities within the Runoff Habitat Type with regard to elevation, snow duration and drainage. Arrows indicate transitions occurring between communities.

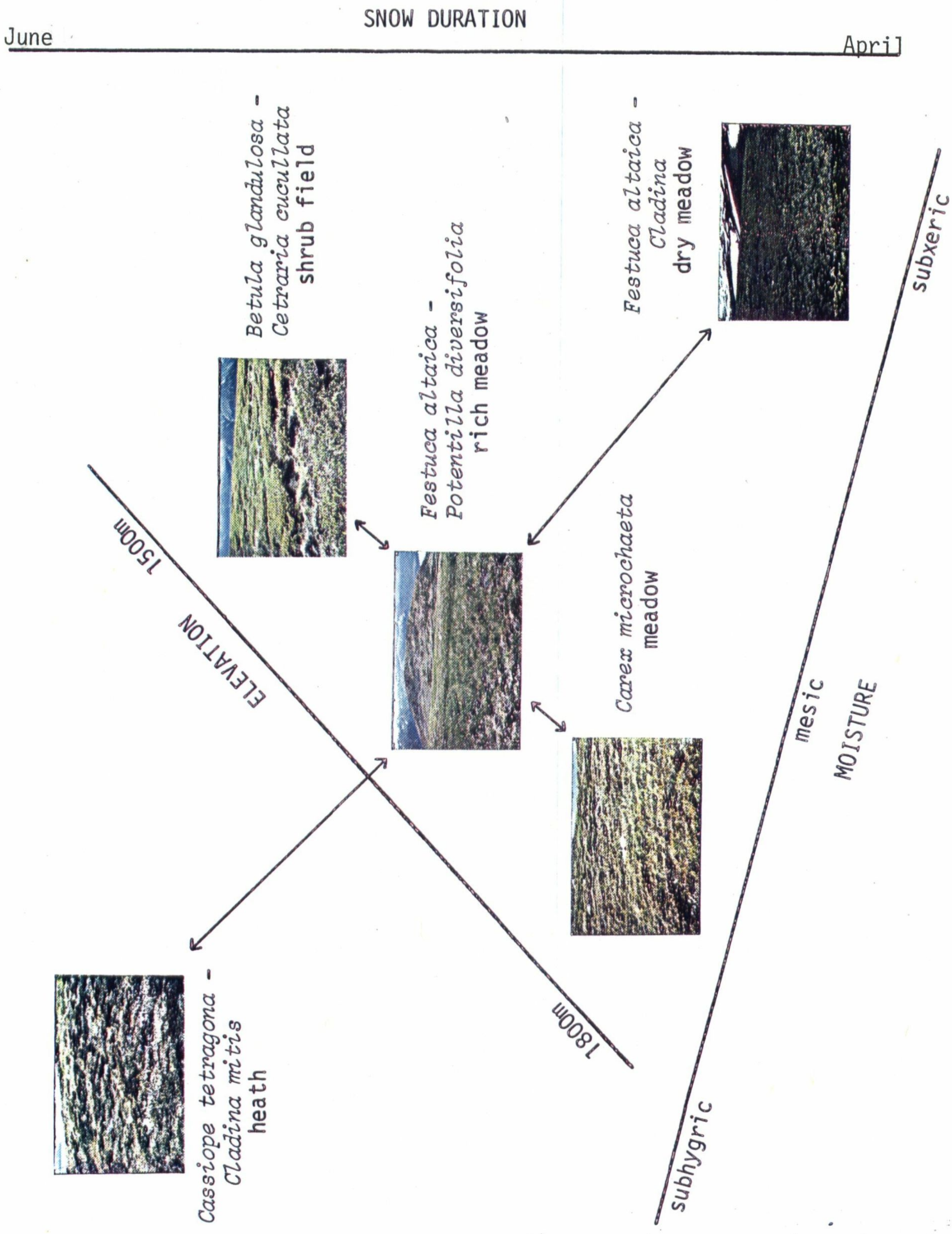


Figure 50: Relationship of communities within the Meadow and Shrubfield Habitat Type with regard to elevation, snow duration and moisture. Arrows indicate transitions occurring between communities.

into the summer.

The *Festuca altaica* dominated rich meadows are restricted to snowbeds and seepage sites at alpine elevations below 1600 m, but as the *Betula* decreases with the gain in elevation, the *Festuca* dominates the mesic sites and the *Festuca altaica* - *Potentilla diversifolia* rich meadow becomes the zonal community. This *Festuca* dominated community occurs from 1750 m down to 1500 m, but has its best development between 1600 and 1700 m.

The *Carex microchaeta* meadow forms the zonal vegetation above 1700 m. This community is well adapted physiognomically to the severe winds characteristic of these high elevations. The woolly leafed, decumbent *Potentilla hyparctica* replaces the glabrous, erect *P. diversifolia*. *Artemisia arctica*, co-dominant in the *Festuca* community, is of decreased importance in the *Carex* community and the prostrate leaves of *Carex microchaeta* have a distinct advantage over the erect *Festuca* habit.

Where it forms the zonal vegetation, the *Carex microchaeta* meadow can occur under a wide variety of moisture conditions. On the solifluction lobe treads where it dominates, it grades frequently into the *Aulacomnium palustre* dominated runoff community. While in drier sites and higher elevations (*ca*. 1800 m), it can grade into the xeric *Cetraria* - *Carex* fellfield. At elevations above 1830 m, the *Carex* community is really restricted to protected sites and probably can not be considered the zonal vegetation. The climatic conditions at these elevations really promote the development of the *Cetraria nivalis* - *Carex microchaeta* fellfield.

The *Festuca altaica* - *Cladina* dry meadow is a community transitional between the *Festuca* rich meadow and the *Cetraria* - *Vaccinium* fellfield. This dry meadow is free of snow probably by early May, has no seepage and is thus subxeric or submesic. The total lack of seepage and high lichen cover distinguish it from the rich *Festuca* meadow. Both *Festuca* meadows occur along Transect #4: Saddle Snowbed transect, the dry *Festuca* meadow on the north side below the fellfield and shrubfield, and the rich *Festuca* meadow on the south side, influenced by slight seepage from upper snowbeds. The *Festuca altaica* - *Cladina* dry meadow has the same elevational distribution as the rich *Festuca* meadow but is of much more restricted occurrence.

The *Cassiope tetragona* - *Cladina mitis* heath is promoted by longer snow duration. As with the snowbed communities, the length of snow duration needed for good development of the *Cassiope tetragona* heath decreases with increased elevation. At alpine elevations below 1600 m, this community develops in areas free of snow between mid-June and early July and forms the transitional vegetation between the meadow and shrubfield, and snowbed habitat types. At these elevations, it generally grades into a *Festuca* dominated community on the side away from the snowbed and one of the snowbed communities (*Anthelia juratzkana* - *Luzula arcuata* late snowbed in the case of Transect #1) on the snowbed side. At elevations above 1600 m, especially on the East Plateau, snow remains only until early June in this community. Where the snow melts out in May, the *Cassiope tetragona* community is replaced by either the rich or dry *Festuca* communities. Elevationally, the *Cassiope tetragona* - *Cladina mitis* heath parallels the distribution of the two *Festuca* communities.

Elevational, snow duration and moisture relationships among all communities are summarized in Figures 51-53.

Figures 54-56 show the distribution of the communities in relation to one another along the mesotopographic-gradient. These figures are for three altitudinal bands representing three subzones within the alpine zone of Teresa Island. This subjective division of the alpine area into low, mid- and high alpine subzones is supported by Figure 51.

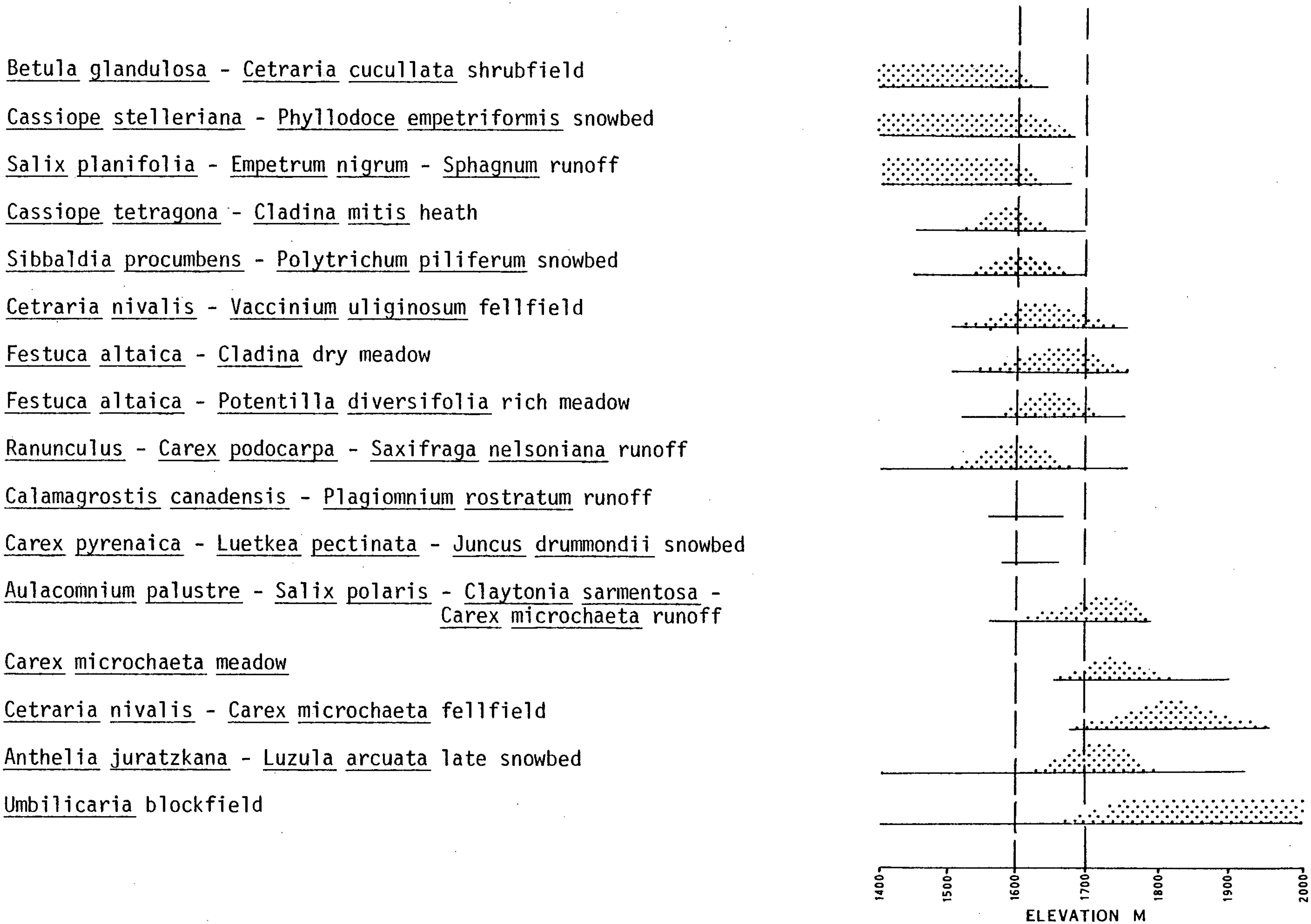


Figure 51: Elevational relationships among community types. Horizontal line represents elevational extent of the community type. Shaded area represents elevations where community most commonly occurs.

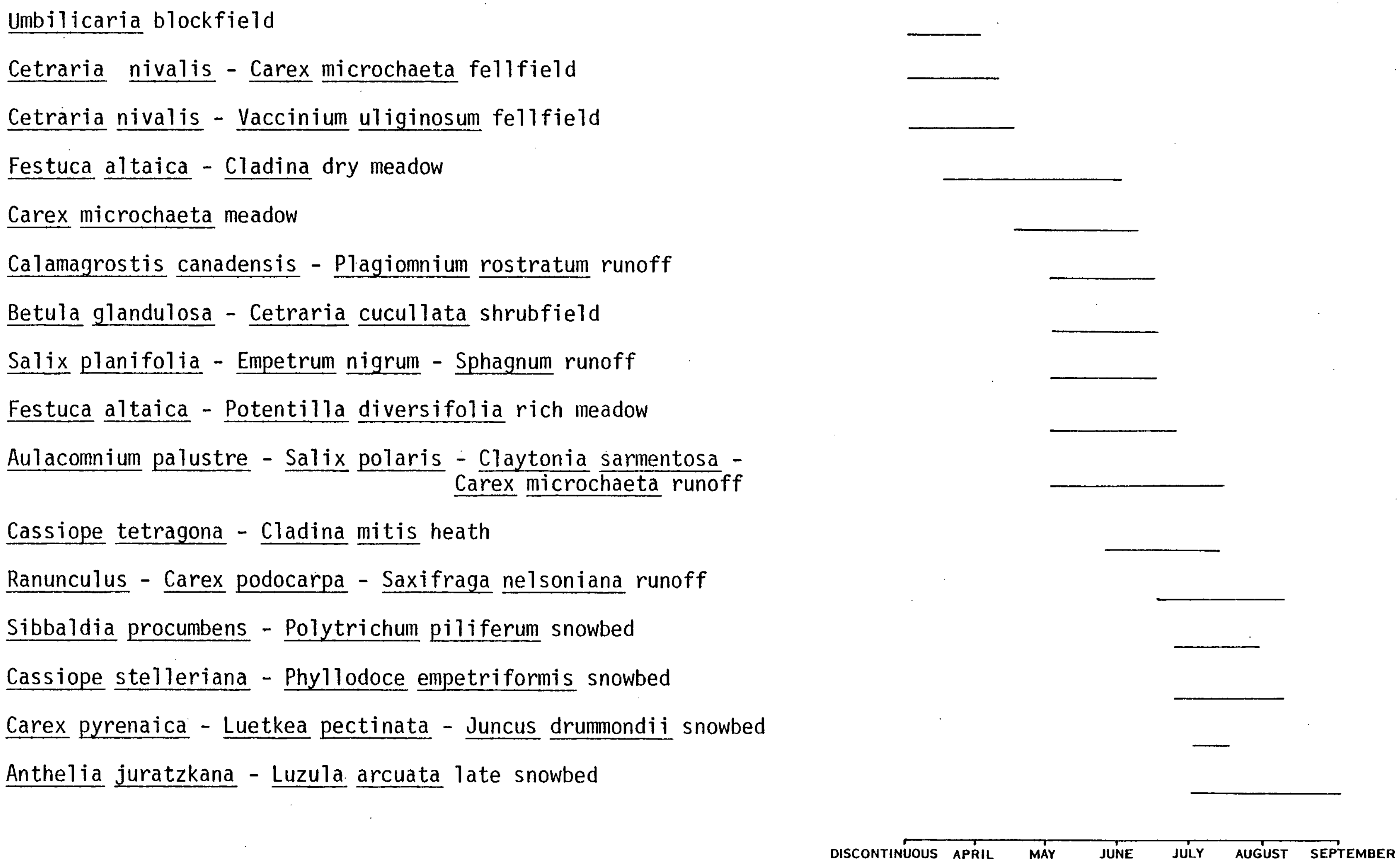


Figure 52: Snow duration relations among community types. Horizontal lines represent estimated snow duration within each community.

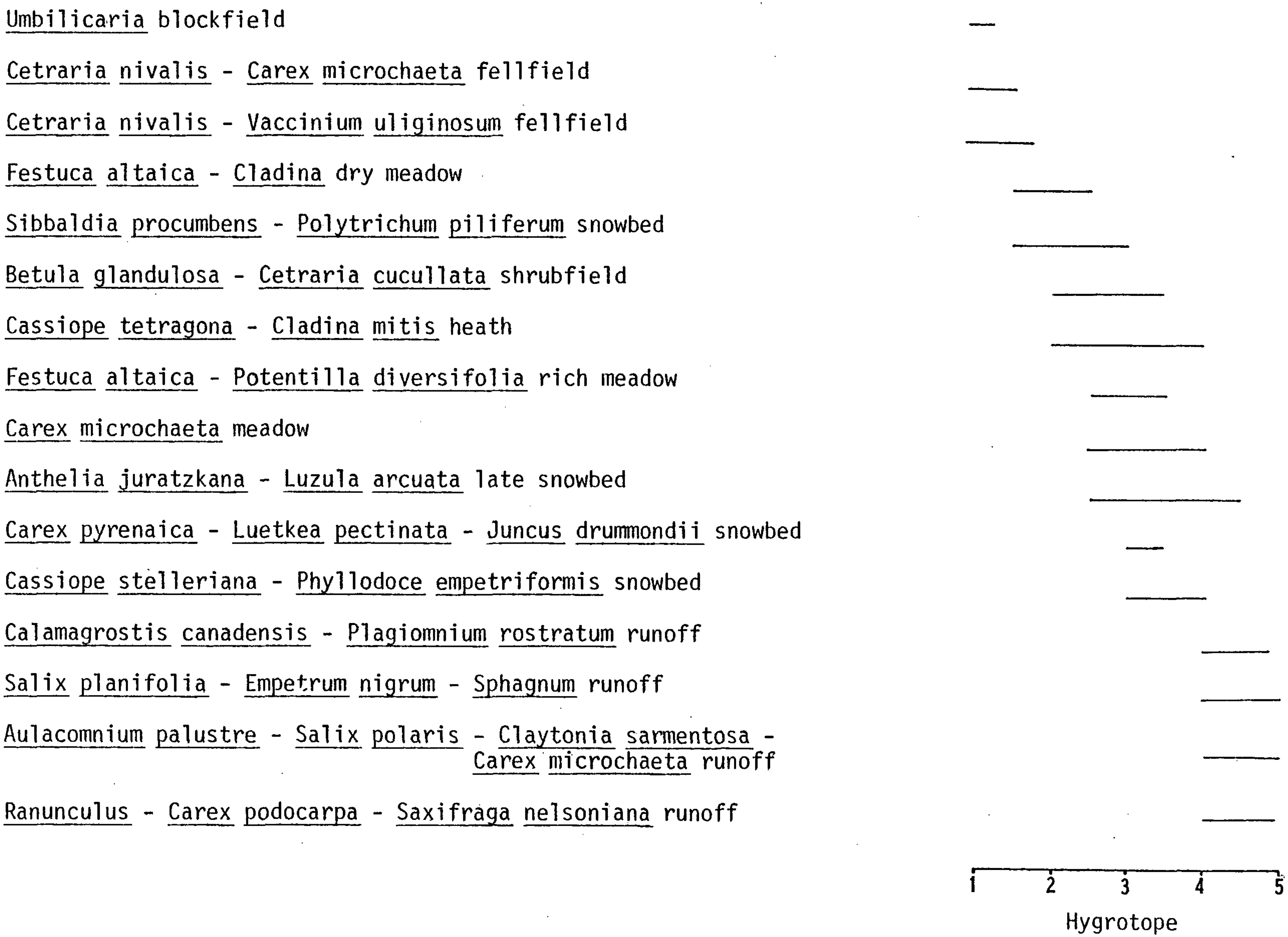
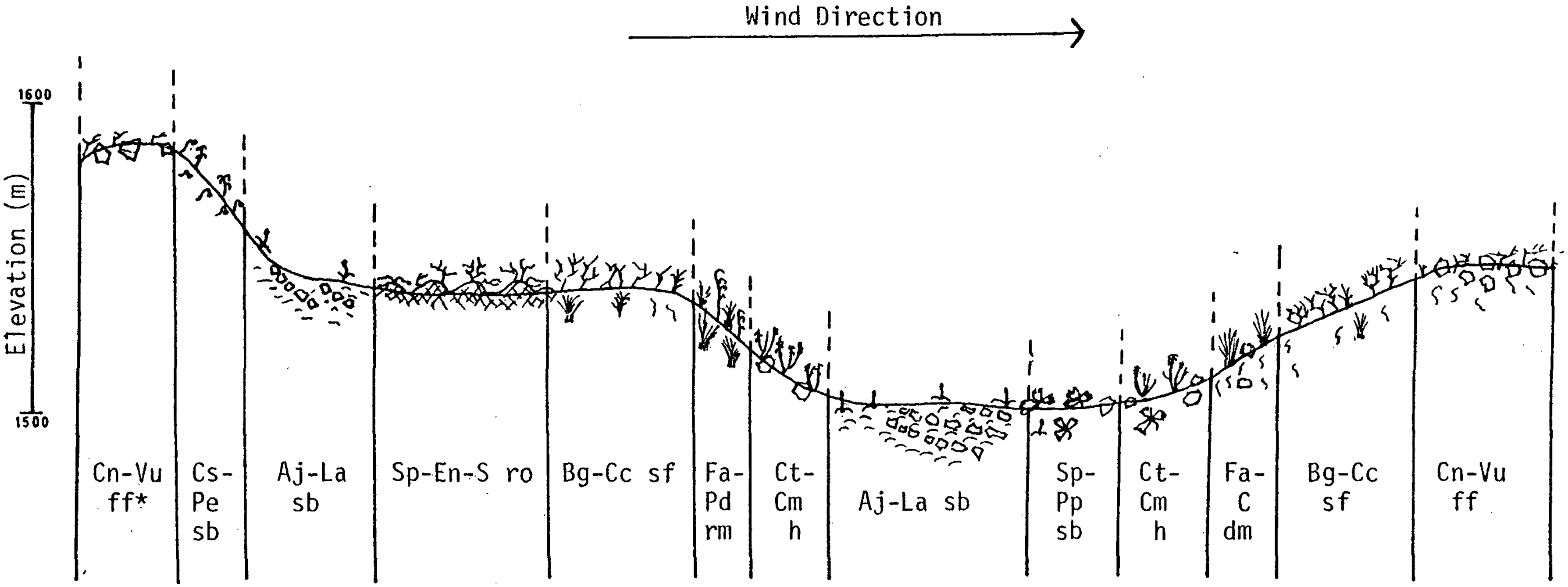


Figure 53: Moisture relations among community types; 1=xeric, 2=submesic, 3=mesic, 4=hygric and 5=hydric.

The low alpine zone extends from the subalpine to approximately 1575 m. The communities occurring in this elevational band have strong affinities with subalpine vegetation. Many species common in the subalpine such as Betula glandulosa, Salix planifolia, Empetrum nigrum, Cassiope stelleriana and Phyllodoce empetriformis also form a major component of the low alpine vegetation. The concentration of shrubs make this subzone physiognomically distinct from the other subzones. The lack of krummholz formation visually differentiates it from the subalpine. The communities giving the low alpine subzone its characteristic appearance are primarily the Betula glandulosa - Cetraria cucullata shrubfield, Salix planifolia - Empetrum nigrum - Sphagnum runoff, Cassiope stelleriana - Phyllodoce empetriformis snowbed and Cassiope tetragona - Cladina mitis heath. The distribution of these communities and the others that occur in this subzone in relation to one another on the mesotopographic gradient is diagrammed in Figure 54.

The mid-alpine subzone extends from 1575 m to approximately 1700 m. The high percentage of shrubs characteristic of the low alpine and subalpine greatly decreases and is replaced by a more herbaceous meadow vegetation dominated by graminoid species, especially Festuca altaica. Communities most commonly found in this subzone include the Festuca meadows, Cetraria nivalis - Vaccinium uliginosum fellfield, and Anthelia and Sibbaldia dominated snowbeds (Figure 55).

The high winds, cold temperatures and discontinuous snow duration encountered frequently in sites above 1700 m (high alpine subzone) result in a marked decrease of vascular plants. Lichens form the dominant vegetation and Umbilicaria blockfield and Cetraria nivalis - Carex microchaeta fellfield communities cover most of the area. Moist meadows are dominated by Carex microchaeta. The relation of these communities to each other on



*Community type abbreviations: refer to page 38.

Figure 54: Distribution of frequently occurring low alpine zone communities along a mesotopographic gradient.

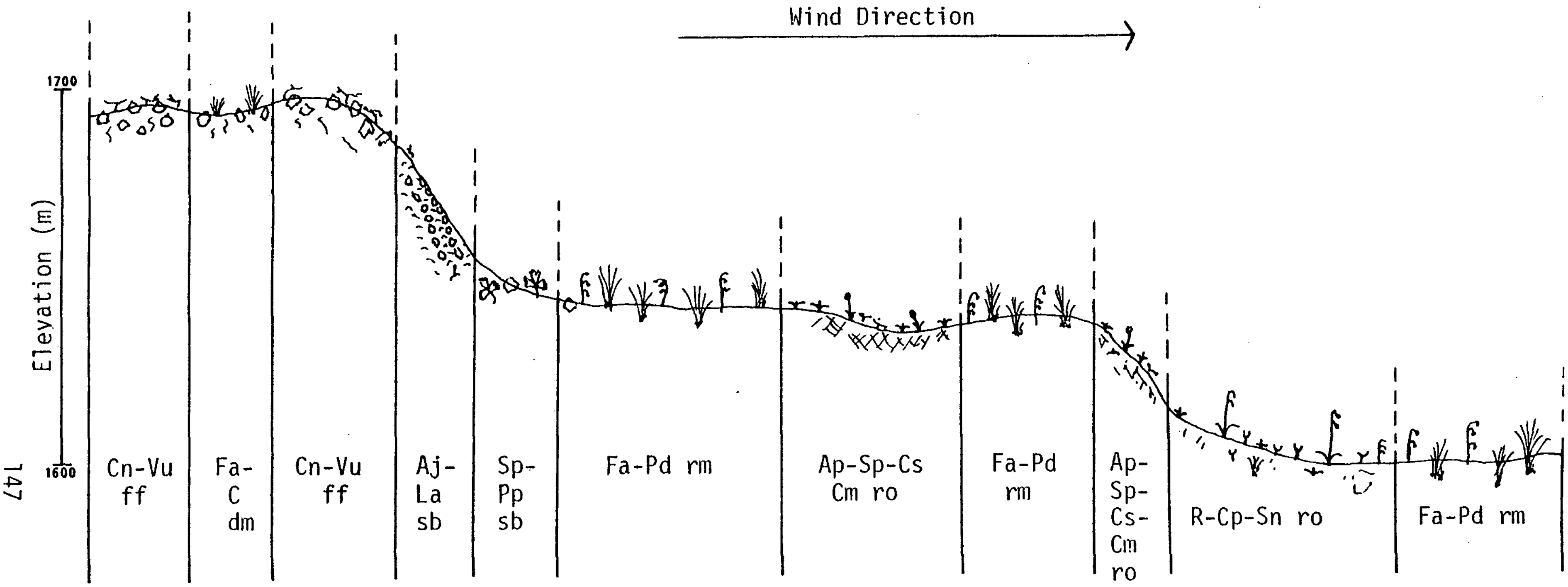


Figure 55: Distribution of frequently occurring mid-alpine zone communities along a mesotopographic gradient.

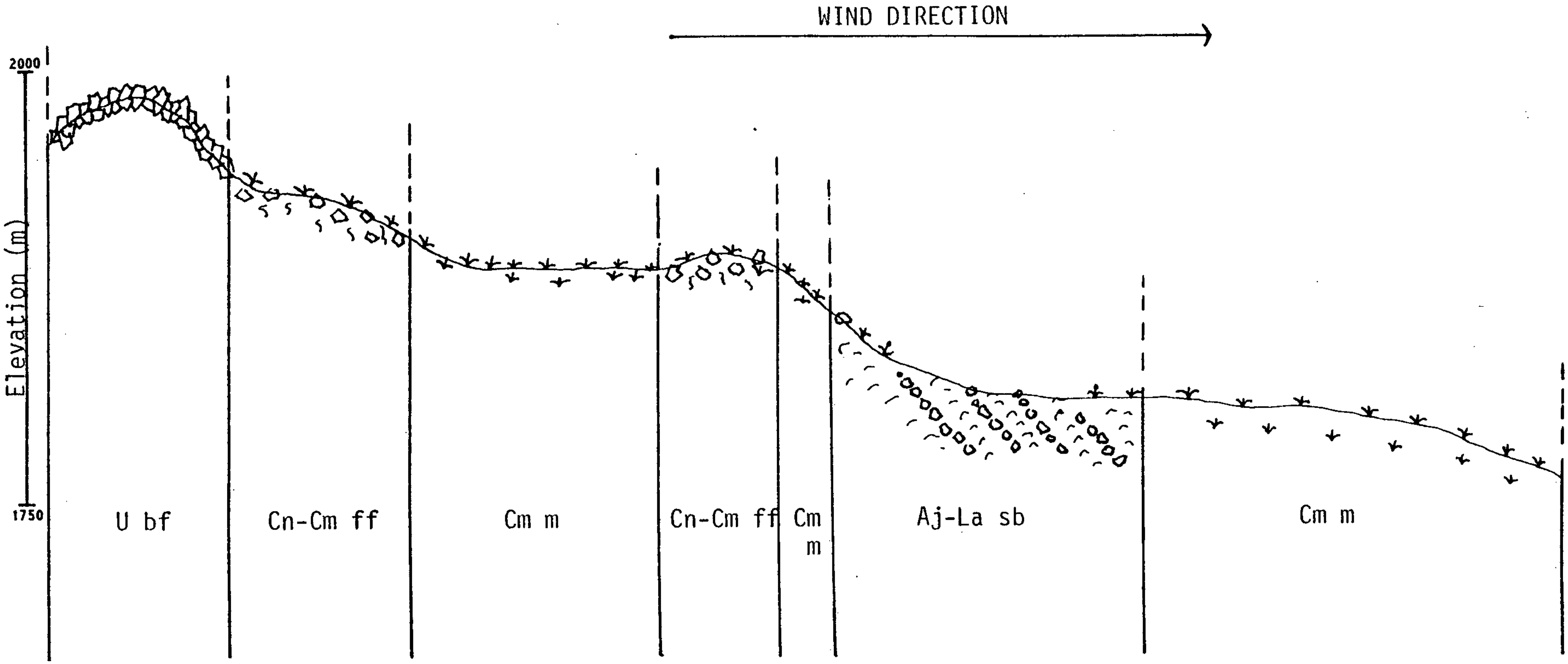


Figure 56: Distribution of frequently occurring high alpine communities along a mesotopographic gradient.

the mesotopographic gradient are shown in Figure 56.

B.5 Climax and Succession

A climax community is considered to be in equilibrium with the prevailing environmental factors of the habitat whereby the member species are in a dynamic balance with one another. The community then is self-generating and does not appear to be undergoing any directional change. The environmental factors in the alpine zone of Teresa Island include wind, temperature, moisture availability and snow duration.

The communities are floristically and environmentally distinct. Each is composed of species whose environmental tolerances are essentially similar. These communities segregate out along the environmental gradients and form mosaics across the landscape which reflect the environmental differences (Figures 54, 55 and 56).

The question remains as to whether these communities are successional or climax. Whether the species are reproducing themselves sexually within the communities could not be ascertained because of extensive vegetative reproduction and lack of seedlings. The area is at present undisturbed by humans. Animal populations are low and grazing by caribou is light. No disturbances by fire are recorded. These facts, and the knowledge that each community has its own position on the complex environmental gradient, leads me to believe that in general, the communities (assuming a stable climate) are adapted to their environment and thus in a climax state (Churchill and Hanson, 1956). The landscape represents a polyclimax (Mueller-Dombois and Ellenberg, 1974) where the climax is controlled not only by climate, but also by edaphic and topographic factors.

Two types of climax communities exist, the climatic climax and the topoedaphic climax. The climatic climax is the community developed on mesic or average sites where macroclimate is the major factor. On Birch Mt. three and maybe four climatic climaxes can be distinguished, separated by elevational differences. These are the *Betula glandulosa* - *Cetraria cucullata* shrubfield in the low alpine, the *Festuca altaica* - *Potentilla diversifolia* rich meadow in the mid-alpine, the *Carex microchaeta* meadow in the high alpine and possibly the *Cetraria nivalis* - *Carex microchaeta* fellfield at the highest elevations. The other communities distinguished by xeric conditions, exposure, excess moisture or prolonged snow duration are topoedaphic (*sensu* Daubenmire, 1952) climaxes perpetuated by these more extreme environmental factors.

The concept of succession and climax is made complicated due to cryoturbation and solifluction causing instability of soil and surficial topographic features. Active congeliturbation results in the formation of sorted and nonsorted circles as discussed in Chapter A.4. These are especially common and active in wet meadows, shrubfields, and fellfields in the low and mid-alpine areas. Bryant and Scheinberg (1970) feel that well established vegetation mats can be disrupted by frost action and wind erosion. At any one time, circles in all stages of formation, stabilization and revegetation can be found. Thus, within a well-established vegetation unit, a number of mini-successional sequences may be taking place. These cycles of circle formation and revegetation are permanent features within many of the communities (given the present climatic conditions), and should be regarded as cyclical climaxes (Bryant and Scheinberg, 1970; Churchill and Hanson, 1956) which fit within the general climax criteria (Churchill and Hanson, 1956).

Of the cryopedogenic processes, solifluction has the greatest effect on community pattern. The active downslope movement of solifluction lobes and benches is constantly altering the topography and thus, the spatial position of the environmental gradients. This does not negate the existence of climax communities in the alpine. As a result of solifluction no habitats are lost, only their position on the landscape is changed. Spatial changes of environmental gradients are simply followed by spatial adjustments of the communities. The relationship of the community with the environmental gradient does not change and the same community patterns will occur.

In 1956, Churchill and Hanson prepared an extensive review and investigation into the concept of climax in alpine and arctic vegetation. My ideas of climax in the alpine are voiced by Churchill and Hanson who write:

> "During a long period of time the actual spatial position of conditions of the environmental gradients may change... The same pattern of communities would persist, even though the spatial disposition of each would change." (p. 147).

and:

> "The steady-state communities in arctic and alpine areas which make up the patterns corresponding to the patterns of environmental gradients are considered as climax. Such changes as do occur in these communities are considered as being within the framework of the climax." (p. 181).

It should be pointed out that these climax communities are relatively stable and self-maintaining relative to the time period involved. Because of macroclimatic fluctuations, the communities are slowly changing. If long-term climatic changes were taken into account, these communities would actually represent part of what Mueller-Dombois and Ellenberg (1974) consider an open-ended succession. Climatic change in the Atlin area within the Holocene period is well documented (Miller and Anderson, 1974). As discussed in Chapter A.3, climatic fluctuations have been common during this period. Figure 2 shows that, at the present time, the Atlin area is undergoing a warming trend which began in 750 B.P.

The alpine zone, being near the altitudinal limit of vascular vegetation and having no trees to buffer it, is greatly affected by the changes in climate. There is evidence of this climatic modification on the mountain. The apparent invasion of the high altitude blockfields by Cetraria nivalis - Carex microchaeta fellfield vegetation is one example. A decrease in snowbed size is apparent on the north slope and in the cirques. This is evidenced by the large patches of relatively lichen-free rocks which surround some of the present snowbeds. However, snow duration in these areas is no longer long enough to preclude development of the larger foliose lichens. Lichens of the family Umbilicariaceae require several hundred years to acquire full growth (Dahl, 1955).

Successional patterns can be hypothesized for a continued warming trend which would result in loss of habitats. These are summarized in Figure 57. Warmer temperatures could result in a slow invasion of the Cetraria nivalis - Vaccinium uliginosum fellfield by Festuca altaica resulting in the Festuca altaica - Cladina dry meadow. If an increase in organic matter and improved moisture retention occurred, a Festuca altaica - Potentilla diversifolia rich meadow could develop. Similarly, at high alpine elevations the Carex microchaeta meadow could invade the Cetraria nivalis - Carex microchaeta fellfield, and at low alpine elevations, the Cetraria nivalis - Vaccinium uliginosum fellfield could be invaded by Betula glandulosa and develop into Betula glandulosa - Cetraria cucullata shrubfield.

A decrease in snow duration would accompany an increase in temperature. If this were to happen, the Anthelia juratzkana - Luzula arcuata snowbed, depending on drainage and elevation, would be taken over by either the Sibbaldia procumbens - Polytrichum piliferum community, Cassiope stelleriana - Phyllodoce empetriformis community or the Cassiope tetragona - Cladina mitis heath. With a further decrease in snow duration, thickening of the organic layer and better soil development, the more mesic Festuca and Carex

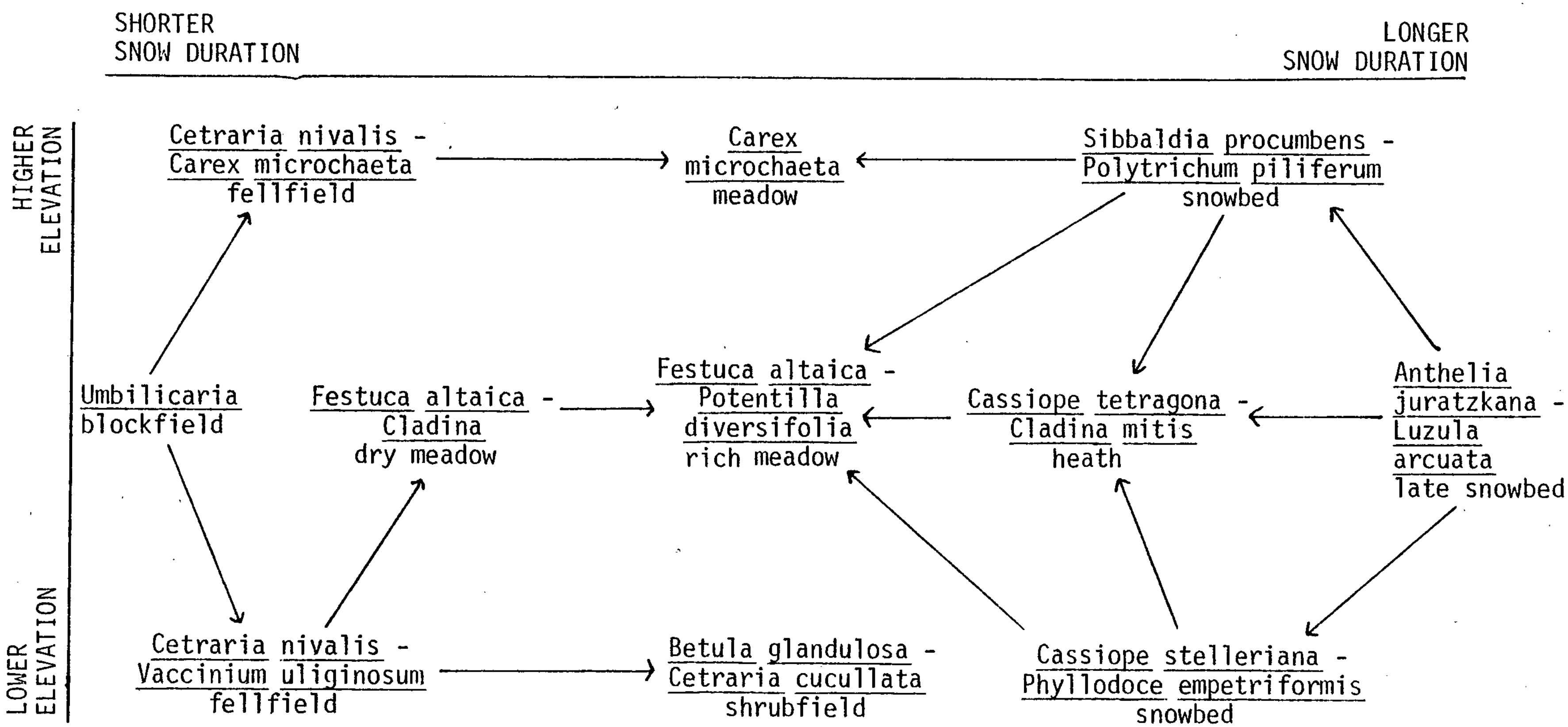


Figure 57: Hypothesized successional patterns resulting from an extended warming trend.

communities could develop.

The decrease in snowbeds, which provides the constant summer-long runoff, would most likely result in the decrease in importance of runoff communities.

It should not be forgotten that climatic modification would cause an elevational increase in the subalpine zone as well as the alpine communities, but the present relationship between communities and environment would not change. This hypothesized succession is a result of elimination of habitats.

B.6 Community Synonomy

Many of the community types occurring on Birch Mt. are comparable floristically and/or ecologically with other alpine communities described in British Columbia, southern Yukon and southeastern Alaska. The purpose of this section is to point out some of the similarities among the published communities and thus place Birch Mt. in proper perspective with the other alpine areas of Pacific North America. The following areas have been used in this comparison: 1) Big White Mt., south-central B. C. (Eady, 1971); 2) the Coastal Mountain Hemlock Zone (Brooke, Peterson and Krajina, 1970); 3) Garibaldi Park, southwestern B. C. (Archer, 1963); 4) Nevis Mt., north-eastern B. C. (Lord and Luckhorst, 1974); 5) Spatsizi Plateau, north-central B. C. (Pojar, 1977); 6) Ruby Range, southwestern Yukon Territory (Price, 1972); 7) Sheep Mt., southwestern Yukon Territory (Hoefs, Cowan and Krajina, 1976); 8) Klutlan Glacier, St. Elias Mts., southwestern Yukon Territory (Birks, 1977); and 9) southeastern Wrangell Mts., southeastern Alaska (Scott, 1974a + b).

The Umbilicaria blockfield has very few counterparts in the published record. Since this community is characterized by the almost complete lack of vascular plants, it might not have been included in the other vegetation studies. The *Umbilicaria* blockfield probably attains its best development in the northern half of the Province. It is mentioned by Scott (1974a+b) as being common in the high alpine (above 2215 m) in the southeastern Wrangell Mts. The Alpine Fellfield terrain unit of Pojar (1977) is in part ecologically and floristically similar.

In depressions and protected areas within Pojar's Alpine Fellfield, vegetation similar to the *Cetraria nivalis* - *Carex microchaeta* fellfield occurs. This fellfield mosaic described by Pojar from the Spatsizi Plateau appears to be equivalent to the high alpine areas of Teresa Island where the *Cetraria nivalis* - *Carex microchaeta* fellfield is invading the *Umbilicaria* blockfield.

The *Cetraria nivalis* - *Vaccinium uliginosum* fellfield was described from the Wrangell Mts. by Scott (1974a+b). Two of his communities can be included here, the *Dryas octopetala* - *Cetraria cucullata* association and the *Dryas octopetala* - *Vaccinium uliginosum* nodum. Floristic and ecological similarities also exist with the *Dryas* - Rough Fescue community of Lord and Luckhurst (1974).

Both *Cetraria* fellfield communities share floristic and ecological similarities with the *Dryas integrifolia* - *Oxytropis nigrescens* - *Silene acaulis* - lichen community of Pojar (1977). One major difference is a substitution on the Spatsizi Plateau of *Dryas integrifolia* for *D. octopetala*. This species replacement indicates a difference in substrate pH. Hoefs, Cowan and Krajina (1976) state that vegetation dominated by *D. octopetala* occurs on acidic or neutral substrates. The acidity of the soil would account for the dominance of *Dryas octopetala* on Birch Mt. with scattered individuals of *D. integrifolia* being restricted to the southern slopes.

Both *Cetraria* fellfield communities occurring on Teresa Island also share floristic and ecological similarities with the dry vegetation unit of Price (1972) developing on southwest and north-facing slopes. The Cetraria nivalis - Carex microchaeta and Cetraria nivalis - Vaccinium uliginosum fellfields are ecologically similar to the Salico (reticulatae) - Sileno (acaulis) - Carico (scirpoides) - Dryadetum integrigoliae and Oxytropo (viscidae) - Artemisio (hyperboreae) - Festuco (brachyphyllae) - Trisetetalia spicati described by Hoefs, Cowan and Krajina (1976) on the basic soils of Sheep Mt.

The Carex microchaeta meadow appears to be the same as the Salix (polaris, reticulata) - Carex microchaeta - Polytrichum piliferum - Cetraria nivalis community described by Pojar (1977) which forms the zonal vegetation at medium-to-high elevations in the Spatsizi area. As with the Carex microchaeta meadow, Pojar's community is found on all aspects in mesic-to-moist conditions on moderately sloping-to-flat topography. Ecological and floristic similarities also exist with the tussock community of Price (1972) and the Salix reticulata - Carex podocarpa community of the Wrangell Mts. described by Scott (1974a+b).

The Festuca altaica dry meadow has ecological similarities with only the Elymus innovatus - Festuca scabrella community of Lord and Luckhurst (1974). Communities similar to the Festuca altaica - Potentilla diversifolia rich meadow have been more commonly described. Pojar (1977) describes this community which he names the Festuca altaica - Artemisia arctica - Polytrichum piliferum - Sterocaulon glareosum - Cetraria (cucullata, nivalis) community, as occurring in the Spatsizi area. Ecological and floristic similarities also occur with the Artemisio (arcticae) - Salico (reticulatae) - Festucetum altaicae of Sheep Mt. and the Festuca altaica - Artemisia arctica and Festuca altaica - Lupinus arctica noda of Scott (1974a+b), the former forming mosaics with Betula glandulosa dominated vegetation at low alpine elevations and the latter forming meadows in the mid-alpine regions of the southeast Wrangell Mts.

Pojar (1977) describes a Betula glandulosa - Artemisia arctica - cryptogam community which is comparable in every way to the Betula glandulosa - Cetraria cucullata shrubfield of Birch Mt. Similarities also exist with Scott's (1974a+b) Betula glandulosa - Vaccinium uliginosum association and Birks' (1977) Betula glandulosa shrub-tundra.

Comparable to the Cassiope tetragona - Cladina mitis heath is the Cassiope tetragona - Dryas integrifolia - Salix (reticulata, polaris) - Distichium capillaceum community which forms the zonal vegetation at elevations up to 1850 m on the Spatsizi Plateau (Pojar, 1977). Pojar states that moist-to-mesic northern and eastern slopes with a continuous moderate-to-deep long-lasting snow cover promote the development of this zonal community. These conditions describe well the habitat of the Cassiope heath community of Teresa Island. However, the Atlin area receives only half as much precipitation as the Spatsizi, decreasing the total area of optimum Cassiope habitat and favoring the more chionophobous Festuca meadows as the zonal vegetation at elevations up to 1800 m.

The Cassiope tetragona - Cladina mitis heath is also somewhat similar to the Salico (reticulatae) - Cassiopo (tetragonae) - Dryadetum integrifoliae of Hoefs, Cowan and Krajina (1975) and the Cassiope tetragona - Vaccinium uliginosum nodum described by Scott (1974a+b).

The Cassiope mertensiana - Luetkea pectinata - Sibbaldia procumbens - Barbilophozia hatcheri community from the Spatsizi Plateau is ecologically and floristically comparable to the Cassiope stelleriana - Phyllodoce empetriformis snowbed community of Teresa Island. The major difference is the lack of Cassiope stelleriana from the Spatsizi community. In fact, C. stelleriana has not been recorded from the Spatsizi Plateau at all (Pojar, 1977; Welsh and Rigby, 1971). Similar snow-promoted heath communities are more extensive in the Coastal Range of B. C. where precipitation is much higher. Archer's (1963) Phyllodoceto - Cassiopetum mertensianae forms the zonal alpine vegetation of the Garibaldi area, and forms a major component of the Parkland Subzone of the Subalpine Mountain Hemlock Zone (Brooke, Peterson and Krajina, 1970). To my knowledge, similar alpine snowbed communities are not reported north of the Atlin area.

The only community comparable to the Sibbaldia procumbens - Polytrichum piliferum snowbed is the Sibbaldietum procumbentis association described from Garibaldi Park by Archer (1963). Sibbaldia procumbens, Antennaria alpina and Polytrichum piliferum are the characteristic species of both communities.

Strong ecological similarities exist between the Anthelia juratzkana - Luzula arcuata late snowbed and the Gymnmitrieto - Polytrichetum norvegici association described by Archer (1963), the Saxifrago (oppositifoliae) - Oxyrio (digynae) - Salicion polaris of Sheep Mt. and the Kaieria glacialis - Grimmia alpicola nodum and Rhacomitrium canescens - Dicranoweisia cirrata association from the Wrangell Mts.

The Salix planifolia - Empetrum nigrum - Sphagnum runoff does not have any published counterparts. Some floristic and ecological similarities are shared with Pojar's (1977) Salix barrattiana - Petasites frigidus - Tomemthypnum nitens community.

Neither the Carex pyrenaica - Luetkea pectinata - Juncus drummondii snowbed nor the Calamagrostis canadensis - Plagiomnium rostratum runoff communities (both of very limited distribution on Teresa Island) have published counterparts in the northwest.

The Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta runoff community is comparable to the Salix polaris - Ranunculus nivalis - Carex microchaeta - moss community of Pojar (1977). His moss dominated community occurs in habitats above 1900 m. The two communities have many species in common including Claytonia sarmentosa. Further similarities between the Aulacomnium runoff vegetation and other published communities are vague. At least ecological similarities occur with the Salix polaris - Hylocomium alaskanum and Petasites frigidus - Aulacomnium palustre associations of Scott (1974a+b).

The Ranunculus - Carex podocarpa - Saxifraga nelsoniana - moss runoff vegetation is floristically and ecologically comparable to the Salix (polaris, reticulata) - Carex podocarpa - Petasites frigidus - moss community of Pojar (1977) and somewhat less floristically similar to the Senecionae (lugentis) - Salicetum polaris - reticulatae of Hoefs, Cowan and Krajina (1976).

It can be seen from the above discussion that similarities do exist among the alpine plant communities in the B. C.-Yukon region. Of the areas compared, the Spatsizi Plateau is the most similar floristically to the alpine zone of Teresa Island. Ecological and physiognomic similarities are more common than floristic similarities, and point out the advantages of the habitat type classification for vegetational comparisons of alpine areas.

C. REMOTE SENSING AND MAPPING

C.1 Introduction

The classification of vegetation is not an academic exercise. Vegetation classification is important not only for communication but as baseline data for future research dealing with such topics as succession, nutrient cycling, productivity, and wildlife habitat, and is necessary for inventory and proper management of our natural resources. To facilitate these uses, analysis of vegetation should include not only description of the units but should also show how they can be cartographically described. All too often the classification units cannot, or have not, been mapped and their value has not been fully realized. In the past, the deemphasis on mapping has been largely the result of the lack of, and poor quality of, available aerial photographs, especially in remote arctic and alpine areas (Sigafoos, 1951).

Recently, remote sensing, "the detection, recognition, or evaluation of objects by means of distant sensing or recording devices" (Avery, 1968), has become a popular research tool in many of the sciences. The development of new techniques and increasing refinement and availability of remote sensing data provide a new tool for the mapping of vegetation (Legge _et al_., 1974; Poulton, 1972; Murtha, 1977; Watson, 1977). The value and use of remote sensing in alpine, boreal and arctic regions have been discussed by the Arctic Institute of North America (1968), Benninghoff (1950), Brown (1974), Reed (1968), and Tarnocai (1972).

C.2 Objectives

The main purpose of this section is to use remotely sensed data in conjunction with the vegetation units developed in the previous section to develop a hierarchical ecological classification system and legend suitable for the cartographic representation of alpine vegetation at different scales and in widely separated geographical locations, and to use this system for the mapping of alpine vegetation on Teresa Island.

C.3 Remote sensor data

Four types of remote sensor data were used during the present study: color-infrared photographs, satellite imagery and conventional color and black and white photographs.

C.3.1 Black and white photographs

Standard black and white (B+W) aerial photographs have a number of advantages among which are availability and cost. B+W aerial photos are available for the entire province, and usually at a number of scales. 9x9 prints are available from the National Air Photo Library in Ottawa and the Map Production Division of the Surveys and Mining Branch of the B.C. Lands Service in Victoria. The resolving power of the sensors is very good. My tents at both camps could be detected at a photo scale of 1:80,000, and a small Stevenson Screen weather shelter at a scale of 1:29,000. A major advantage of this easily available imagery is that stereo pairs can be obtained for stereoscopic viewing. The loss of information by the conversion of spectral reflectance patterns to positions on the gray scale is the primary disadvantage in the interpretation of B+W photographs.

C.3.2 Color-infrared and conventional color photographs

Color-infrared and conventional color photographs are not as available as B+W except for certain selected areas and then they are more costly. The use of color rather than gray scale results in the presence of more information. The typical reflectance spectrum of a green leaf is shown in Figure 58. The leaf is green because it reflects more green light than blue or red. Color film reacts to visible light. The color of the scene is closely approximated on the photo itself. It is easy for the interpreter to relate to the photo as it reflects the scene as he himself sees it. Color-infrared film is sensitive to green, red and near-infrared radiation and thus extends beyond normal vision to .9 mu. The color-infrared film is called "false-color" because the objects in the image scene are not the same color as in the original scene (Figure 58). The value of infrared film for vegetation analysis lies primarily in the fact that plants reflect large amounts of near-infrared radiation, more than they do green, and thus appear magenta on the photograph. Figure 59 shows two aerial oblique photos of the East Plateau Pond and Camp #2, one in color and one in color-infrared. The vegetation along the runoff stream is much more visible in the color-infrared photo. The color range appears to be greater in the color-infrared photo and allows more detail to be seen.

The sensitivity and color balance of the infrared film serves to "enhance and amplify color differences that on conventional color photography may be questionable or overlooked" (Knipling, 1969). The range of red tones associated with foliage is greater than the normally dark shades of green so changes in the vegetation are more easily detected. One reason for this is the effect of foliage overlap on infrared reflection. Unlike the green wavelengths, much of the incident infrared energy that is transmitted through the upper leaves is reflected by the lower leaves and retransmitted through the upper, thus enhancing the canopy reflectivity. Infrared reflectivity, then, increases with an increase in foliage density (Colwell, 1974; Gausman, 1977; Knipling, 1969; National Academy of Sciences, 1971).

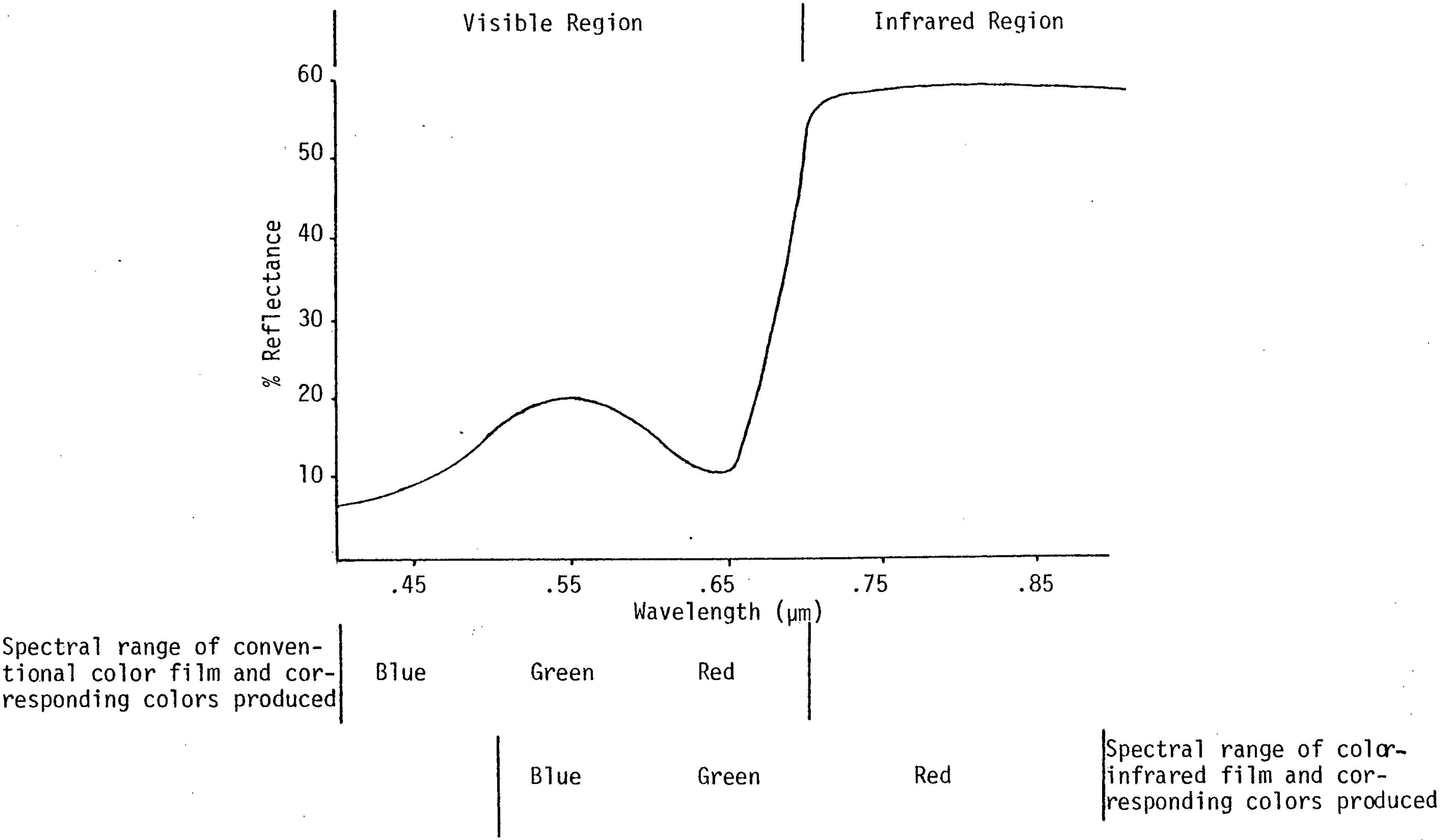


Figure 58: General spectral reflectance curve of a green leaf including spectral ranges for color-infrared and conventional color film. Modified from Murtha 1972, and American Society of Photogrammetry 1975.

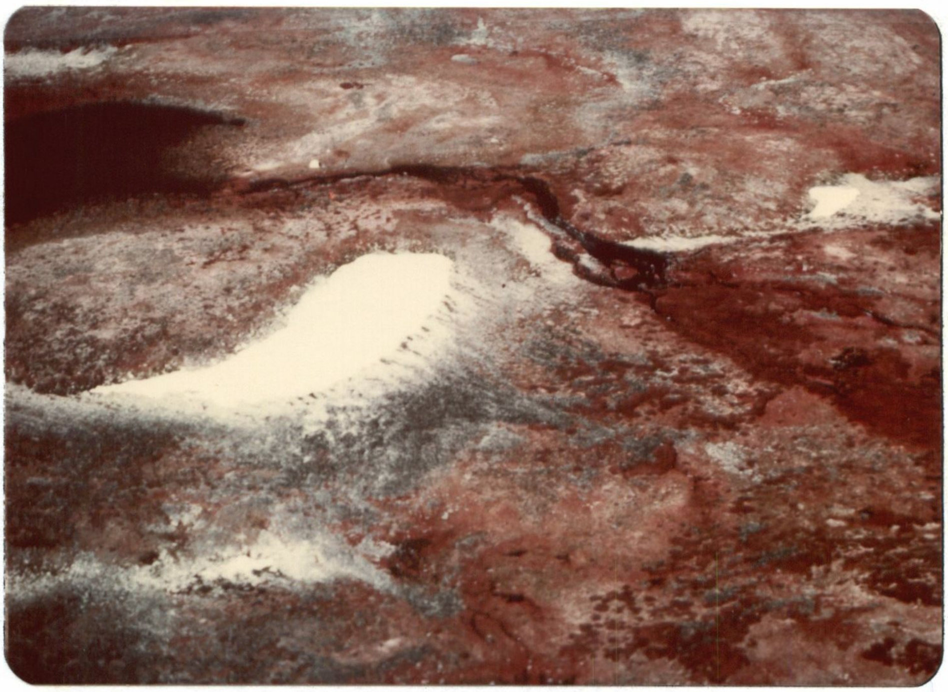


Figure 59: Two aerial oblique photographs of the East Plateau Pond and Camp #2; the upper in normal color and the lower in color-infrared. The color range appears to be greater in the color-infrared photo, and allows more detail to be seen. Both photographs were taken at the same time.

Another advantage of color-infrared over conventional color is in the ease of distinguishing conifers from hardwoods. Conifers appear a very dark magenta compared to the bright magenta of hardwoods (Figure 60). This is due primarily to the large number of contained shadows in the conifer crowns caused by the many narrow needles (Murtha, 1972), and partly to the slightly lower reflectance across the spectrum of the conifers.

Another advantage of infrared film, especially in alpine, arctic and other poorly vegetated areas, is its ability to detect vegetation (Howarth, 1972). Isolated patches of vegetation tend to blend in with the background in B+W and color photographs but stand out as pink or red areas on color-infrared photos (Figure 60).

For these reasons and others many studies have shown infrared film to be superior to B+W and color for distinguishing vegetation types, and it is becoming an increasingly popular tool for vegetation identification and characterization (Brown, 1974; Forest Management Institute, 1974; Komarov, 1968; Lavkulich, 1973; Meier, 1966; Murtha, 1972; Stephens, 1976; Tarnocai, 1972; Thie, 1972).

C.3.3 Satellite imagery

Since the July 1972 launching by NASA of the Earth Resource Technology Satellite (ERTS-1), now called Landsat-1, followed by the more recent launching of Landsat-2, satellite imagery has become a major tool in vegetation analysis, land-use analysis and environmental impact assessment. Landsat orbits the earth at an altitude of approximately 910 km on an eighteen day cycle, thus most of the earth's surface is imaged every eighteen days. Each image produced covers about 185 km x 198 km and has an average resolution between 70 and 100 m (pixel resolution is 79 x 79 m). In areas of high contrast the resolution is greatly improved. The small

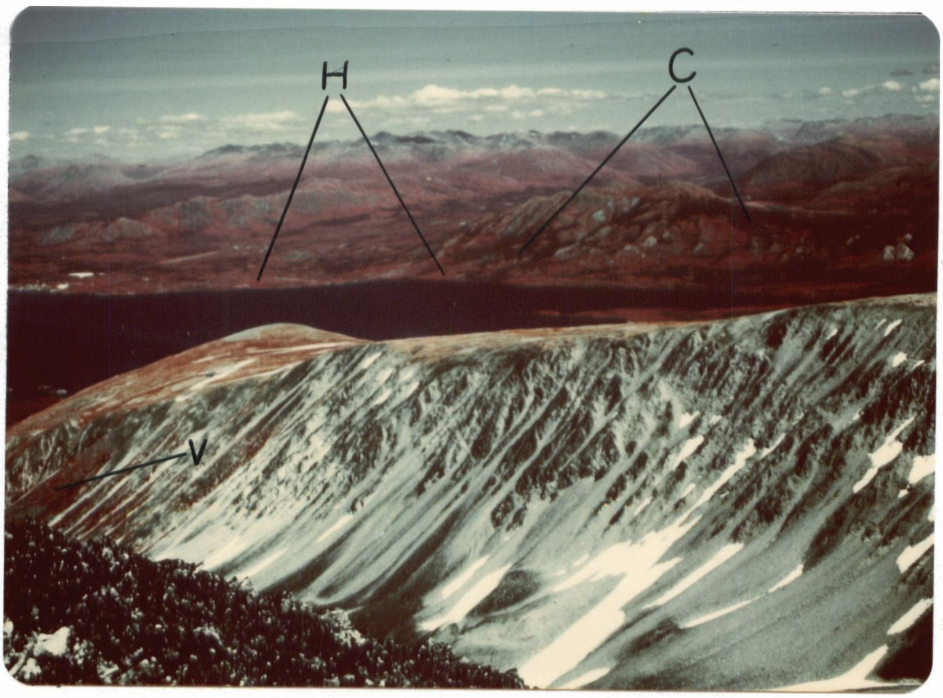


Figure 60: Conventional color and color-infrared photographs showing value of the infrared film for detecting vegetation, and for distinguishing between hardwoods and conifers. Note also the greater haze penetration of the color-infrared film. V = vegetation; H = hardwoods; and C = conifers.

East Plateau Pond (see Figure 59) is recognizable on the satellite imagery (Figure 75). The small two-lane gravel road connecting the town of Atlin to the Alaska Highway can also be identified.

Landsat contains a multi-spectral scanner (MMS) which detects light energy between .5 and 1.1 mu in four spectral bands (bands 4, 5, 6, and 7). Band 4 detects energy in the green range of the spectrum, .5 to .6 mu. Although resolution is poor in this band due to scattering, there is excellent shadow penetration, an important consideration in areas of strong relief. Band 5 detects energy in the red region of the spectrum, .6 to .7 mu. Vegetation has a low reflectance in this portion of the spectrum (Figure 58) and appears dark while man-made objects such as towns and roads have a high reflection. This band shows high vegetation - soil contrast and has good resolution. Bands 6 and 7 are both in the near-infrared region of the spectrum, .7 to .8 mu and .8 to 1.1 mu respectively. Vegetation has its highest reflection in these wavelengths. These are also good bands for detecting water as it has almost complete absorption of near-infrared radiation.

Landsat imagery can be obtained in many formats such as computer compatible tapes, black and white transparencies (one for each band) and whole scene color composites and at various stock scales from 1:3,369,000 to 1:250,000.

Since Landsat imagery is inexpensive, available on a real time basis, covers large remote areas and does so on a regular, repeatable basis, it is being increasingly used for environmental studies and vegetation mapping (Klemas et al., 1974; Murtha, 1977; Murtha and Watson, 1976; Oswald, 1976; Watson, 1977). This increased use has brought about refinements in the interpretation of satellite imagery and new interpretation technology consequently increasing the value of the Landsat imagery.

C.4 Methods

C.4.1 Field work

During the three field seasons extensive photographic coverage of the alpine area was made. This coverage included photographic records of all sample sites and transects, and weekly records of snow melt progression and phenological changes. Photographs from topographic highs such as peaks, knolls and ridges gave a very good over-view of the area. Large-scale aerial oblique photographs were taken from a small chartered plane on August 2, 1976.

All ground and aerial oblique photography was done with two 35 mm cameras using conventional color film (Kodak Ektachrome 64) and color-infrared film (Kodak Infrared Ektachrome). Since all dye layers on the color-infrared film are sensitive to blue light, a minus-blue filter (Wratten #12) was used as recommended by the manufacturer. Fritz (1977) and Worsfold (1976) recommend the use of color compensating filters to obtain optimum color balance and increase in optical density in infrared film. A cc20m filter, considered to be the best for vegetation studies (Murtha, personal communication, 1975)* was used in combination with the Wratten #12.

On site sketch-mapping of selected areas was done in conjunction with the photographic coverage.

White 76 x 102 cm cardboard markers covered with plastic were set out on the ground to relocate on the aerial photography sample sites and ground mapped areas which were not located near prominent physical features.

C.4.2 Laboratory work

All photo-interpretation was done in the laboratory. 35 mm color

* Faculty of Forestry, University of British Columbia

and color-infrared transparencies were interpreted on a light table using a 10x lens. 7.5 x 12.5 cm and 20.5 x 25.5 cm color prints were made from many of the transparencies.

Conventional 23 x 23 cm B+W aerial photos were obtained from Victoria and Ottawa. B+W photos used for interpretation are listed in Table XXI. Although resolution was poor in the 1948 photographs, the extent of snow cover for late May and early June could be observed. All B+W prints were viewed and interpreted using a Cassella/London 2x pocket stereoscope and H.M. Sutherland, B.C. Government Design mirror stereoscope. To aid in interpretation, contour lines were superimposed (approximated) on the photos using a Kail Reflecting Projector.

Satellite imagery was obtained from Integrated Satellite Information Services Ltd. in Prince Albert, Saskatchewan for two dates, February 6, 1973 (#E 1198-19374) and September 6, 1974 (#E 1775-19324), in 18 x 18 cm positive transparency format (scale 1:1,000,000). 70 mm chips were cut from these transparencies and viewed through an I^2S Color Additive Viewer. The scale of the image on the viewer screen is 1:150,000. This image was photographed using Kodak 35 mm High Speed Ektachrome film. 17.5 x 25.5 cm cibachrome prints were made from selected transparencies and used for interpretation. Scale of image on cibachrome prints was 1:180,000.

C.5 Discussion and results

C.5.1 Classification system and legend

There are two factors which determine the development of a cartographical classification system. These are: 1, the scale and resolution of the available imagery, and 2, the ultimate purpose of the map (Küchler, 1951, 1967, 1973; Legge et al., 1974). The availability of remote sensor data from large-scale, low-level aerial photography to small-scale satellite

TABLE XXI: 23 x 23 cm B+W photographs used for interpretation of vegetation on Teresa Island.

Scale	Numbers		Dates	Agency
1:29,000	A11390	332-334 + 339	29 May-11 June 1948	Federal
	A11392	40 + 42	12 June 1948	"
	A11521	103-106	2 June 1948	"
	BC5676	110-112	13 August 1975	Provincial
		212-216	" " "	
		108-109	" " "	
		268-270	" " "	
1:80,000	A24219	171-173	August 1975	Federal

imagery has facilitated the mapping of vegetation at many scales. These data vary greatly in their resolution. This, combined with the limitations set by scale result in image merging or generalization of information with a decrease in scale. Anderson et al. (1976) defined four levels of classification and data acquisition (Table XXII). The amount of information portrayed on a map depends on its ultimate use. Resource managers require high levels of detail while national and regional planning requires broader levels of information generalization (Legge et al., 1974; Poulton, 1972).

Classifications have often been developed for particular purposes, to solve particular problems (Forest Management Institute, 1974; Hoefs, Cowan and Krajina, 1975; Küchler, 1951; Lord and Luckhurst, 1974; Poulton, 1972). Maps so constructed, while useful in themselves, have no common ground and are difficult to relate to each other. There is a need for an ecologically based classification designed to serve the multiple needs of users. This classification must also be suitably flexible to match the resolution and information content needed at any specified scale (Legge et al., 1974; Poulton, 1972).

The most promising classification system to date was developed by Poulton (1972) and expanded by Legge et al. (1974). This system is ecosystematic and, for a multi-disciplinary study, can incorporate soil, geologic and physiognomic information into its legend. This part of the system, though, has not been thoroughly worked out, and while the value of such an input is recognized, only the vegetation part of the system is used here. This system, which has been developed specifically for use with remote sensor data, is hierarchical and incorporates the use of physiognomic and structural characteristics at levels of broad generalizations and ecological and floristic at intermediate and refined levels. The classification levels and legend numbering system are diagrammed in Figure 61.

TABLE XXII: Classification levels and data characteristics after Anderson *et al*. (1976).

Classification Level	Typical Data Characteristics
I	Satellite (Landsat) data (scales 1:150,000 or smaller)
II	High-altitude data taken at 12,000 m or above (scales 1:50,000 to 1:150,000)
III	Medium-altitude data taken at 3,100 to 12,000 m (scales 1:20,000 to 1:50,000)
IV	Low-altitude data taken below 3,100 m (scales larger than 1:20,000)

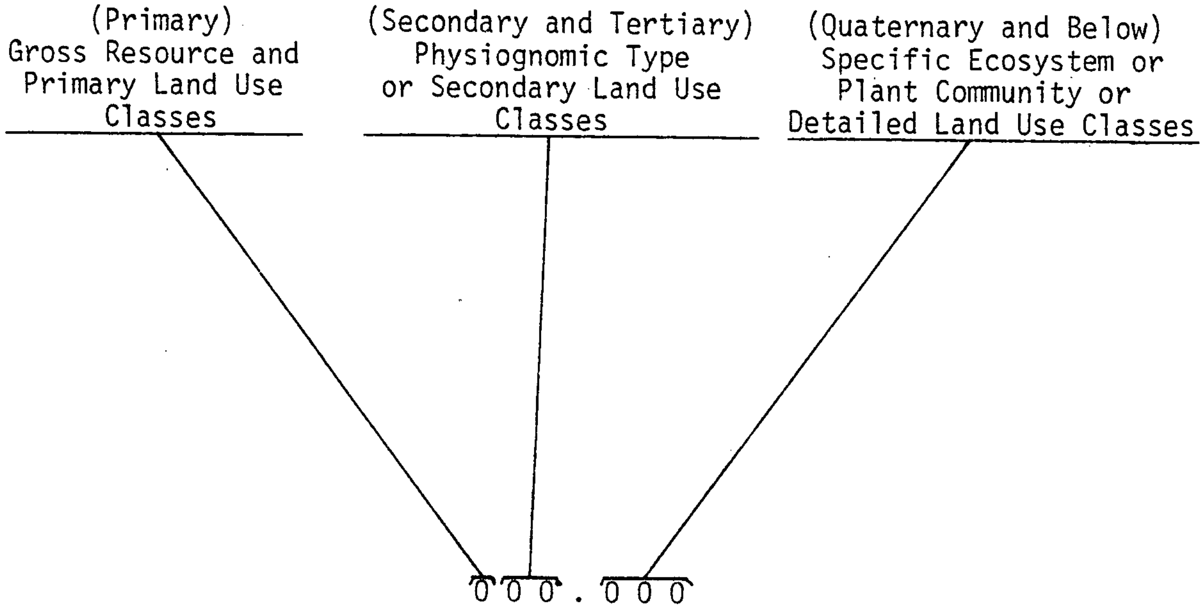


Figure 61: Classification legend format modified from Legge _et al_. (1974).

The legend system has been successfuly used recently by Legge *et al*. (1974) for mapping the Kananaskis, Alberta, remote sensing test corridor which includes alpine tundra and subalpine forests, and by Watson (1977) for mapping the Lac-du-Bois rangelands in Kamloops, British Columbia.

The entire classification and legend system as expanded by Legge *et al*. (1974) is reproduced in Appendix B. The primary, secondary and tertiary classes have widespread applicability. Poulton (1972) suggests that classes representing specific plant communities or ecosystems (quaternary and quinary classes) should be regionalized for maximum effectiveness. Thus, beyond the tertiary level, legends will differ among areas. However, an attempt should be made to standardize units as much as possible among similar regions, at least in the quaternary (000.1) class. The legend, as I have expanded it, is to be used only for alpine vegetation. Hopefully this legend can be further expanded to include all alpine vegetation in B.C. The entire legend system used in the mapping of Teresa Island's vegetation is produced in Table XXIII.

C.5.2 Generalization vs synthesis

Due to the rugged terrain of the alpine zone and resultant steep gradients, plant communities found here are numerous and small. Zwinger and Willard (1972) described the situation well when they wrote, "In the alpine region, one can sit in a gopher garden, rest one's feet in a fellfield and put a hand in a sedge meadow." This situation presents serious problems to the vegetation mapper. Generalizations are necessary when mapping alpine vegetation even at classification level IV (Table XXII). At classification level III the problem becomes more acute.

At levels above the community level the question becomes one of generalization or synthesis. The result is dependent on the physiognomic

TABLE XXIII: Hierarchical legend system and classification used for mapping alpine vegetation of Teresa Island.

Primary Classes
- Secondary Classes
  - Tertiary Classes
    - Quaternary Classes
      - Quinary Classes

100 - Barren Land
- 130 - Rocklands
  - 131 - Bedrock outcrops
  - 133 - Gravels, stones, cobbles and boulders
  - 134 - Scarps, talus and/or colluvium (system of outcropping strata)

200 - Water Resources
- 210 - Ponds, lakes and reservoirs
  - 211 - Natural lakes and ponds
- 220 - Water courses
  - 221 - Natural water courses
- 280 - Snow and ice
  - 281 - Seasonal snow cover
  - 282 - Permanent snowfields and glaciers

300 - Natural Vegetation
- 310 - Herbaceous types
  - 311 - Lichen, cryptogam and related communities
    - 311.1 - Lichen dominated fellfields and blockfields
      - 311.11 - *Umbilicaria* blockfield
      - 311.12 - *Cetraria nivalis* - *Carex microchaeta* fellfield
      - 311.13 - *Cetraria nivalis* - *Vaccinium uliginosum* fellfield
    - 311.2 - Lichen and bryophyte dominated snowbeds
      - 311.21 - *Anthelia juratzkana* - *Luzula arcuata* late snowbed
    - 311.3 - Bryophyte dominated flushes and streambanks
      - 311.31 - *Aulacomnium palustre* - *Salix polaris* - *Claytonia sarmentosa* - *Carex microchaeta* runoff
  - 313 - Forb types
    - 313.1 Forb dominated snowbeds
      - 313.11 - *Sibbaldia procumbens* - *Polytrichum piliferum* snowbed
    - 313.2 Forb dominated flushes and streambanks
      - 313.21 - *Ranunculus* - *Carex podocarpa* - *Saxifraga nelsoniana* - moss runoff
  - 315 - Meadow
    - 315.1 - Fescue dominated meadows
      - 315.11 - *Festuca altaica* - *Potentilla diversifolia* rich meadow
      - 315.12 - *Festuca altaica* - *Cladina* dry meadow
    - 315.2 - *Carex* dominated meadows and snowbeds
      - 315.21 - *Carex microchaeta* meadow
      - 315.22 - *Carex pyrenaica* - *Luetkea pectinata* - *Juncus drummondii* snowbed

TABLE XXIII (con't.)

- 315.3 - Reed grass dominated meadows and streambanks
    - 315.31 - *Calamagrostis canadensis* - *Plagiomnium rostratum* runoff
- 320 - Shrub/Scrub
    - 327 - Macrophyllous shrub
        - 327.1 - Willow predominant vegetation
            - 327.11 - *Salix planifolia* - *Empetrum nigrum* - *Sphagnum* runoff
        - 327.2 - Birch predominant vegetation
            - 327.21 - *Betula glandulosa* - *Cetraria cucullata* shrubfield
    - 328 - Microphyllous dwarf shrub
        - 328.1 - Spruce-fir krummholz type
        - 328.2 - Mountain heath types
            - 328.21 - *Cassiope tetragona* - *Cladina mitis* heath
            - 328.22 - *Cassiope stelleriana* - *Phyllodoce empetriformis* snowbed
- 340 - Forest and Woodland types
    - 341 - Conifer forests
        - 341.5 - Spruce/Fir
    - 343 - Conifer-broadleaf mixed forests and woodlands

900 - Obscured Land
- 910 - Clouds and fog
- 950 - Shadows

nature of the vegetation and the classification system used. The classification just described has its higher units physiognomically defined. If communities next to each other on the ground are physiognomically similar then they can be combined into one physiognomic class as the mapping scale decreases. This is an example of synthesis. In the alpine vegetation of Teresa Island this is not the case. The mosaic of communities on the ground often reflects a similar mosaic of physiognomies. As the scale decreases, sites will be averaged together. This is an example of generalization. In the first case, information loss is minimized, while in the second case much information is lost. For example, if a moss dominated runoff site is bordered by two willow dominated runoff sites, a decrease in scale will probably result in these three sites being averaged together and mapped as one willow or shrub dominated site. Information concerning the moss dominated site is gone. This is inevitable in this classification system due to its hierarchical nature. However, because of the value of this classification for multilevel mapping, use with remotely sensed data and wide applicability, it should not be overly criticized. A hypothetical example of how generalizations might occur from level IV (large scale mapping level) to level I (satellite level) in the classification of alpine vegetation using the hierarchical legend system is shown in Figure 62.

If this lost information is very important to the user, who might wish to use the map for inventory purposes, then it can be partially rectified by using the habitat type classification described in section B of this thesis. In this case, communities mapped at level IV could be synthesized at level III into habitat types. A hypothetical example of this using the same community sequence as in Figure 62 is given in Figure 63. The ecological information inherent in the habitat type could also be important to the user. At levels II and I the habitat type classification suffers

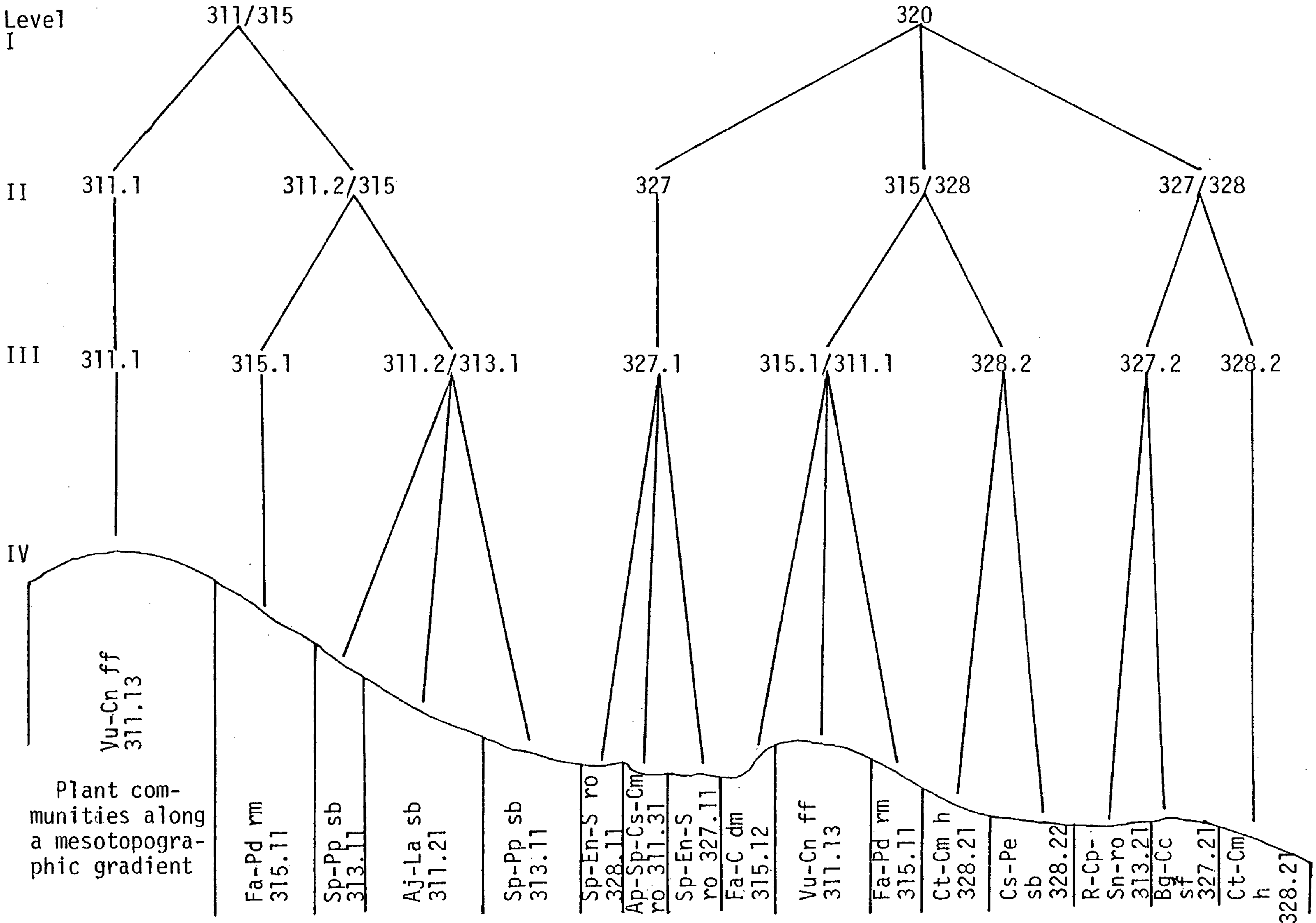


Figure 62: Hypothetical generalizations resulting from decrease in scale when mapping the ecological classification units.

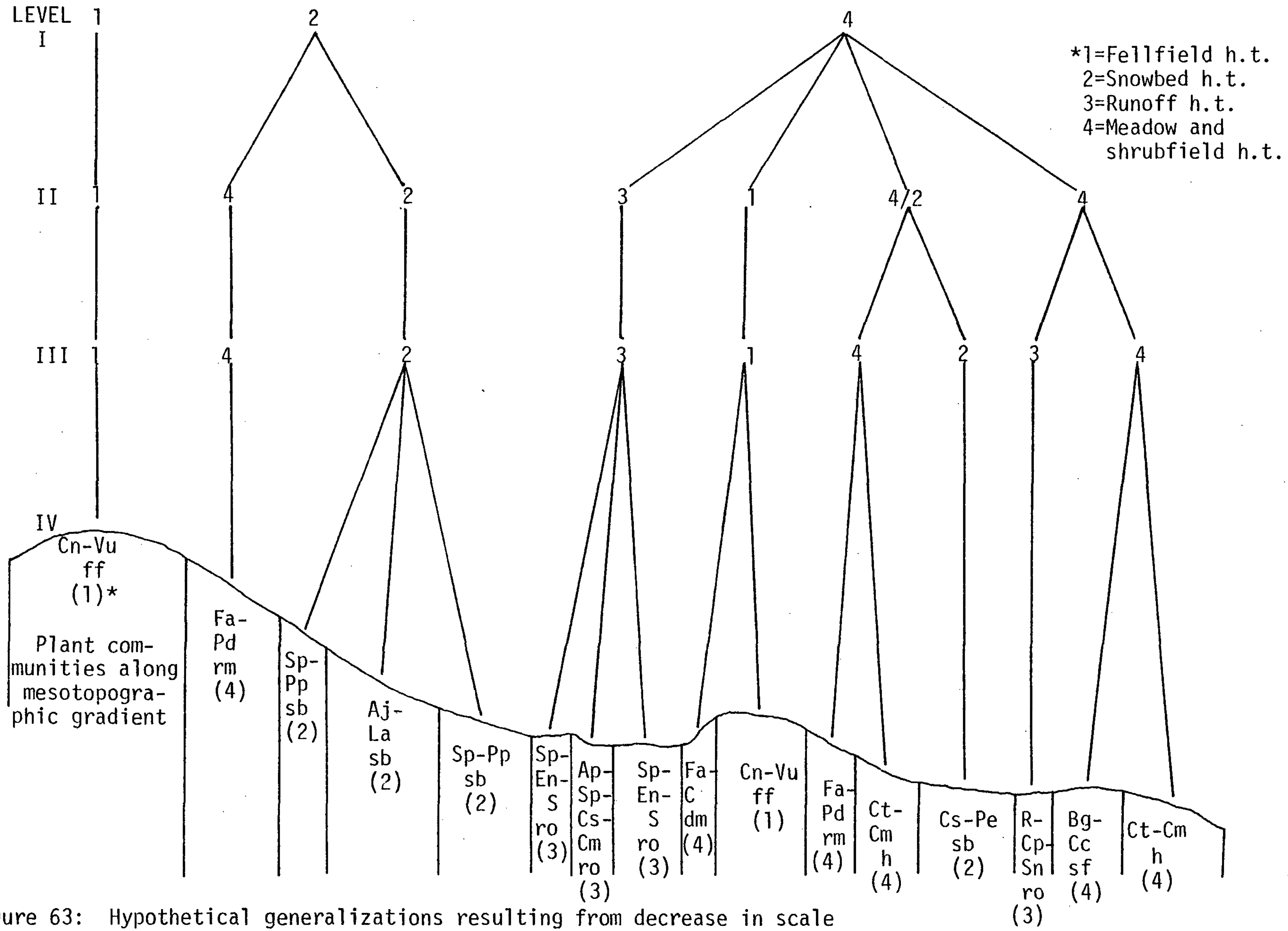


Figure 63: Hypothetical generalizations resulting from decrease in scale when mapping habitat type units.

from the same problems of generalization as the physiognomic classification. The habitat type classification is applicable to all alpine areas, at least in North America and Europe, and is more easily compared to existing alpine vegetation studies, however, it does not have the wide range, depth of detail and potential as the physiognomically based classification. For comparative purposes both classifications are used on the following vegetation maps.

C.5.3 Mapping

The alpine vegetation of Teresa Island was mapped at four different scales to show: 1, that alpine vegetation can be mapped, and 2, the effectiveness of the hierarchical classification and legend system for multi-scale mapping. The four scales reflect the imagery available for the area and coincide with the four classification levels of Anderson et al. (1976). The four scales and associated imagery are listed in Table XXIV.

Since the vegetation study (section B) was accomplished and the classification and legend system decided on prior to mapping, the approach was a priori. Predefined and predescribed vegetation units had to be detected on the imagery. An alternative approach would be to map homogeneous units first and then develop a classification to circumscribe these units. Küchler (1951) has compared this a posteriori classification approach to the a priori approaches and feels that the latter has the distinctive advantage for "they are world-wide in scope and more or less systematic, i.e., they are based on one or more defined ideas which are then applied throughout the classification to the exclusion of other ideas." Conversely, the a posteriori classifications are suitable for localized studies and result in a multiplicity of unrelated classifications.

With the help of the extensive photographic coverage on the

XXIV: Imagery and scales used for the mapping of alpine vegetation on Teresa Island.

Classification Level	Scale	Imagery
I	1:180,000	Landsat color composite
II	1:80,000	B+W aerial
III	1:29,000	B+W aerial
IV	>1:20,000	color-infrared aerial obliques

ground and selectively placed white cardboard markers, all sample sites were located on the color-infrared aerial obliques and 1:29,000 scale B+W aerial photographs. Mapping could then be done by extrapolation from these known areas.

C.5.3.1 Level IV mapping on color-infrared aerial obliques

Three aerial oblique photographs were mapped intensely. The location of these photographs on a 1:50,000 scale topographic map is shown in Figure 64. Prominent hues could be obtained for communities or individual species by comparing conventional color and color-infrared images of the same object or scene. Figure 65 shows two pictures taken almost in the same spot on the East Plateau looking north toward Camp #2 and across the East Valley. In both cases a backpack is sitting in a *Festuca altaica* dominated area (1). In color-infrared the *Festuca* becomes a characteristic pink. The fellfield in the distance (2) goes from yellow in the conventional color photo to white in the infrared. Between the two areas is another patch of *Festuca* (3) which is not contrasted noticeably with surrounding types in the conventional color picture. Figure 66 is a color-infrared aerial oblique showing the position of two of the white cardboard markers. The upper one (1) can readily be identified as lying in a *Festuca* meadow. The

Figure 64: Location of map areas 1, 2, 3, 4, 5 and 6 on 1:50,000 scale topographic map.

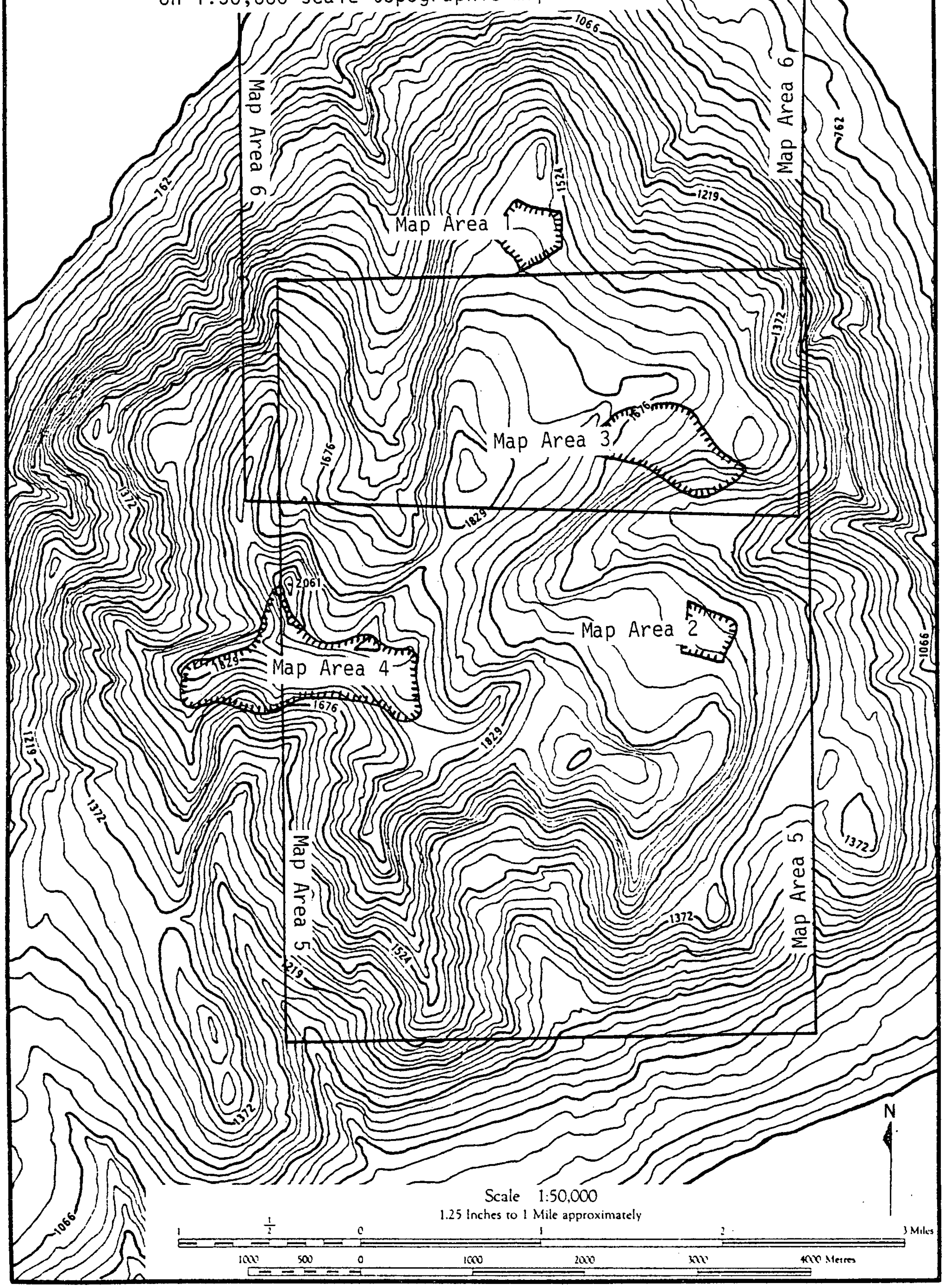


Figure 65: Conventional color photograph (top) and color-infrared photograph (bottom). Pink tone is characteristic of Festuca meadows (1), and can be detected easily from a distance (3). Detection is more difficult on the conventional color photograph. Fellfields (2) appear yellow on color photographs and white on infrared.

Figure 66: Color-infrared photograph showing two white markers on the East Plateau. 1 = white marker in Festuca altaica - Potentilla diversifolia rich meadow. 2 = white marker in Cassiope tetragona - Cladina mitis heath. 3 = Cassiope area blending into fellfield. 4 = Cassiope area blending into Festuca meadow.

lower marker (2) is located in a Cassiope tetragona heath. The Cassiope is evergreen, retaining its closely imbricated leaves every year. Only the new year's growth, however, actually looks green and on color-infrared film the Cassiope appears brown. Just to the left of the marker the Cassiope heath grades into fellfield (3) and to the right it slowly grades into Festuca (4). On color-infrared the tonal signature of the various species and communities are often remarkably distinct. Color separation is better on the 35 mm transparencies so most interpretation was done from these and transfered to the prints. Tonal changes and loss of resolution were characteristic of all color paper prints.

Map area 1 and all the following map areas were mapped twice for comparative purposes; once using the hierarchical vegetation classification and once using the habitat type classification. For the large-scale obliques the habitat type map was made simply by combining vegetation units of the vegetation map.

Map area 1 (Figures 67 and 68) is located on the north slope on the saddle behind the North Knoll near Camp #1 (Figure 64). This area was chosen because it contains three of the four transects discussed in section B.3.2, is typical of the solifluction terrain characteristic of the north slope, and contains the tents of Camp #1 for a reference scale (Figure 67). Comparison can be made in Figure 67 between the results of a normal color photograph and a color-infrared photo. The variation in hues and tones and thus the amount of extractable information is much greater in the infrared photo. The characteristic yellow appearance of Cetraria nivalis dominated fellfields found in the normal color photo is, however, lost in the color-infrared photo. In color-infrared film yellow objects which also reflect near-infrared appear white. Thus, while infrared film is excellent for detecting vascular vegetation in areas of sparse vegetation cover, it is

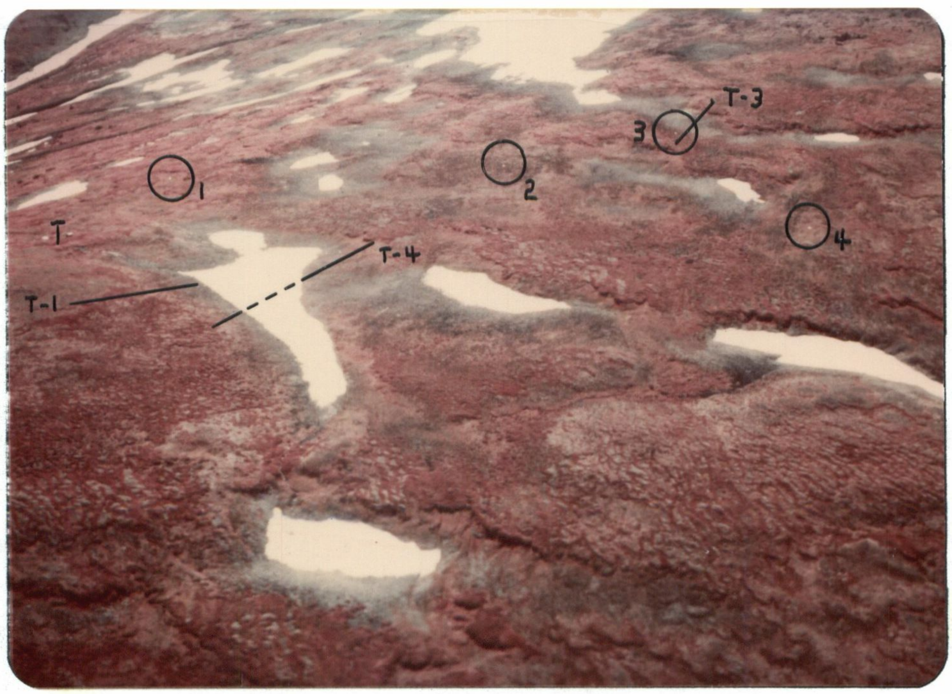


Figure 67: Normal color (top) and color-infrared (bottom) photographs of map area 1. Four white markers are circled. Markers 1 and 4 are in Festuca altaica dominated sites; marker 2 is in a Cassiope tetragona dominated site; and marker 3 is in a Salix planifolia runoff community. T = the tents at Camp #1. T-1, T-3 and T-4 represent the locations of transects #1, #3 and #4.

Figure 68:

Map Area 1. Color-infrared aerial oblique photograph looking west across the north slope of Birch Mountain. The two tents of Camp #1 can be seen in the upper left corner of the photograph. The large east-west lying snowbed is the Saddle Snowbed.

Overlay 1: Vegetation Map

Legend

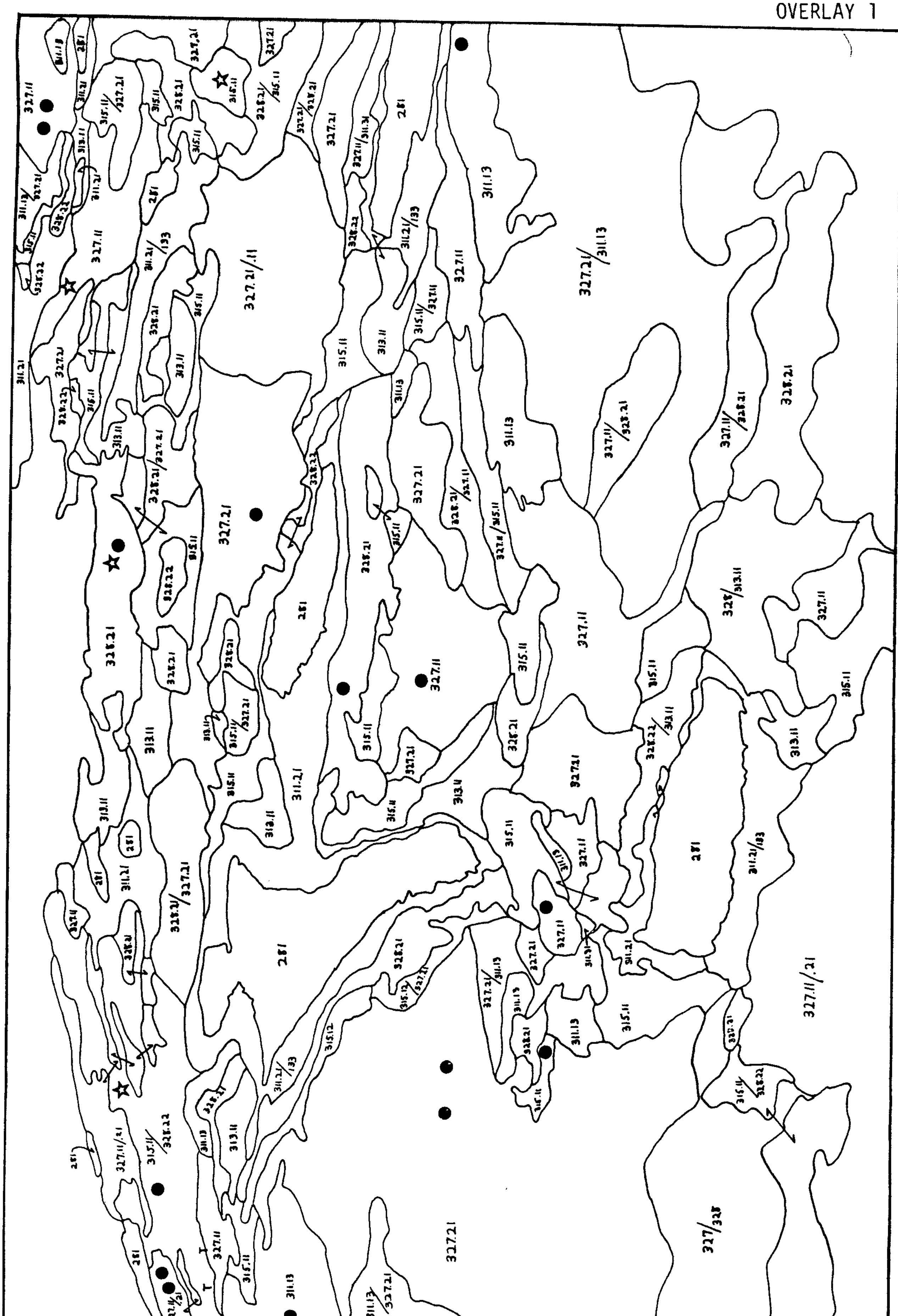
133	- Gravels, stones, cobbles, and boulders
281	- Seasonal snow cover
282	- Permanent snowfields and glaciers
311.13	- Cetraria nivalis - Vaccinium uliginosum fellfield
311.21	- Anthelia juratzkana - Luzula arcuata late snowbed
311.31	- Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta runoff
313.11	- Sibbaldia procumbens - Polytrichum piliferum snowbed
315.11	- Festuca altaica - Potentilla diversifolia rich meadow
315.12	- Festuca altaica - Cladina dry meadow
327	- Macrophyllous shrub
327.11	- Salix planifolia - Empetrum nigrum - Sphagnum runoff
327.21	- Betula glandulosa - Cetraria cucullata shrubfield
328	- Microphyllous dwarf shrub
328.21	- Cassiope tetragona - Cladina mitis heath
328.22	- Cassiope stelleriana - Phyllodoce empetriformis snowbed
●	- Sample site
☆	- Air marker
T	- Tent

Overlay 2: Habitat Type Map (back pocket)

Legend

1	- Fellfield and blockfield habitat type
2	- Snowbed habitat type
3	- Runoff habitat type
4	- Meadow and shrubfield habitat type
[#]	- Sample site number and location

OVERLAY 1



327.21/.11
327.21/311.13
327.11/.21
327/328
327.21
327.11
328.21
281
311.13
315.11
313.11

poor for detecting yellow lichens which tend to blend in with the rocks.

A general statement can be made here that color-infrared film is better for vegetation studies than conventional color film, but the use of both film types together is better than the use of color-infrared film alone.

Four white cardboard markers are visible in Figure 67. Markers 1 and 4 are in Festuca altaica dominated sites. Marker 2 is in a typical Cassiope tetragona heath and marker 3 is in a Salix planifolia runoff site at the base of transect #3. By locating all sample sites on the color-infrared and normal color photos (Figure 68 - Overlays 1 and 2) and extrapolating, the entire area could be mapped.

Map area 2 (Figure 69) is located on the East Plateau (Figure 64) and includes most of the East Plateau Pond, stream and Camp #2. This area shows the typical diversity of low alpine communities, and contains a good example of runoff vegetation, fellfield and snowbanks. Many sample sites were located in this area (Overlays 3 and 4). The ground slopes from the upper left corner to the lower right corner. In the center of the area there is a small but sharp drop in elevation. This is evidenced by the two snowbeds which have developed in the lee of the drop and the white water of the stream in between.

Map area 3 (Figure 70) represents the south facing, gently sloping Northeast Plateau and the steep slope of the East Valley which is out of the picture on the left (Figure 64). Where they are not eroded, the south slopes are covered mostly with meadow vegetation (Overlay 6). Abies lasiocarpa krummholtz appears at the lower left corner (Figure 70 - Overlay 5) and represents the ecotone between the subalpine vegetation of the valley floor and the low alpine vegetation of the upper slopes of the valley. The low alpine, represented by the mats of Betula and Salix, slowly grades into

Figure 69:

Map Area 2. Color-infrared aerial oblique photograph looking west across the East Plateau. The East Plateau Pond and tent at Camp #2 are visible in the upper left corner of the photograph.

Overlay 3: Vegetation Map

Legend

133	- Gravels, stones, cobbles, and boulders
211	- Natural lakes and ponds
221	- Natural water courses
280	- Snow and ice
281	- Seasonal snow cover
311.11	- *Umbilicaria* blockfield
311.13	- *Cetraria nivalis* - *Vaccinium uliginosum* fellfield
311.21	- *Anthelia juratzkana* - *Luzula arcuata* late snowbed
313.11	- *Sibbaldia procumbens* - *Polytrichum piliferum* snowbed
313.21	- *Ranunculus* - *Carex podocarpa* - *Saxifraga nelsoniana* - moss runoff
315.11	- *Festuca altaica* - *Potentilla diversifolia* rich meadow
315.12	- *Festuca altaica* - *Cladina* dry meadow
327.4	- *Salix planifolia* - *Empetrum nigrum* - *Sphagnum* runoff
328.21	- *Cassiope tetragona* - *Cladina mitis* heath
328.22	- *Cassiope stelleriana* - *Phyllodoce empetriformis* snowbed
●	- Sample site
T	- Tent

Overlay 4: Habitat Type Map (back pocket)

Legend

1	- Fellfield and blockfield habitat type
2	- Snowbed habitat type
3	- Runoff habitat type
4	- Meadow and shrubfield habitat type
# (boxed)	- Sample site number and location

OVERLAY 3

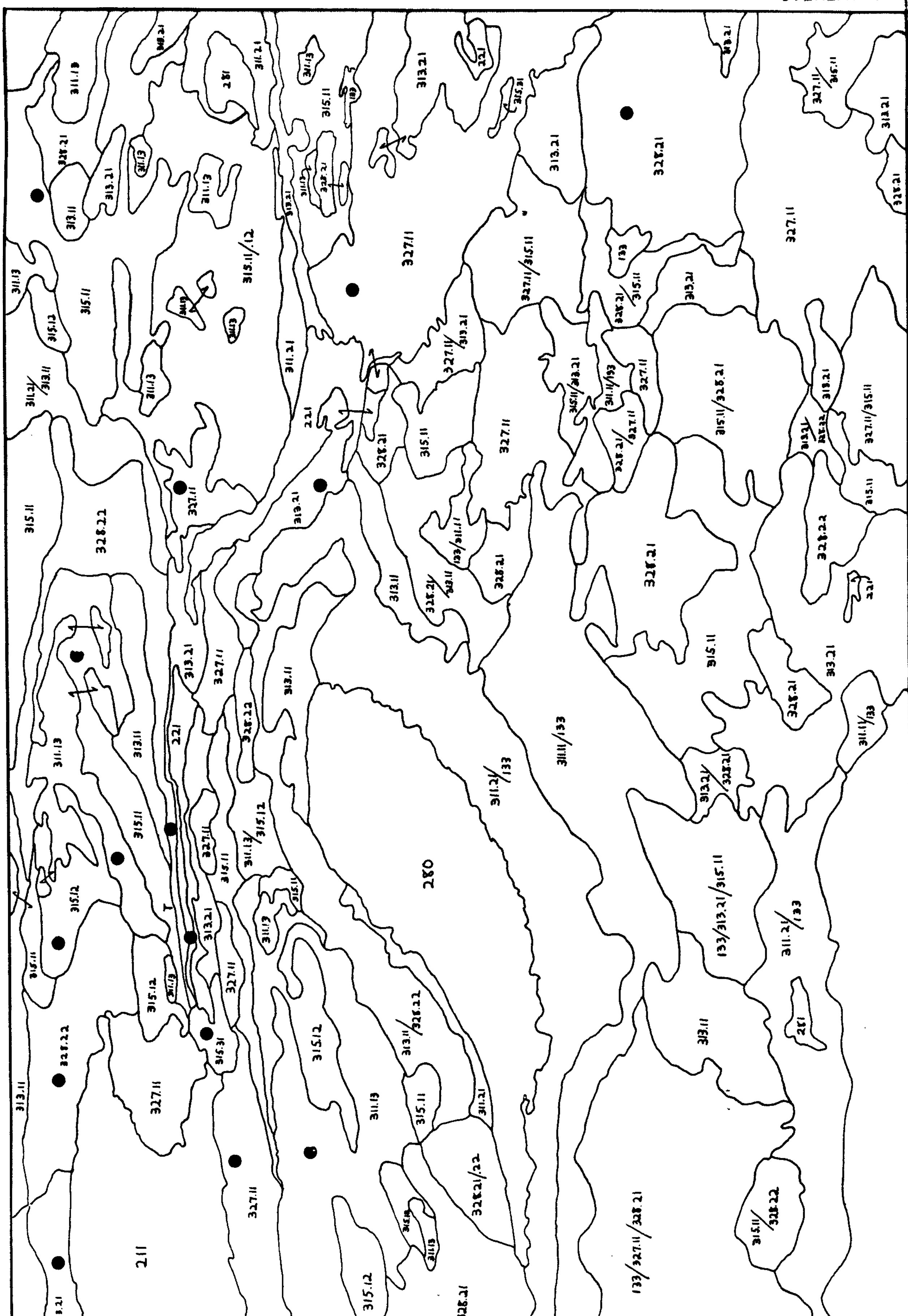


Figure 70:

Map Area 3. Color-infrared aerial oblique photograph looking west across the Northeast Plateau. The terrain is sloping south (left) into the East Valley (out of photograph on left). The gently sloping north slope runs along the upper edge of the photograph.

Overlay 5: Vegetation Map

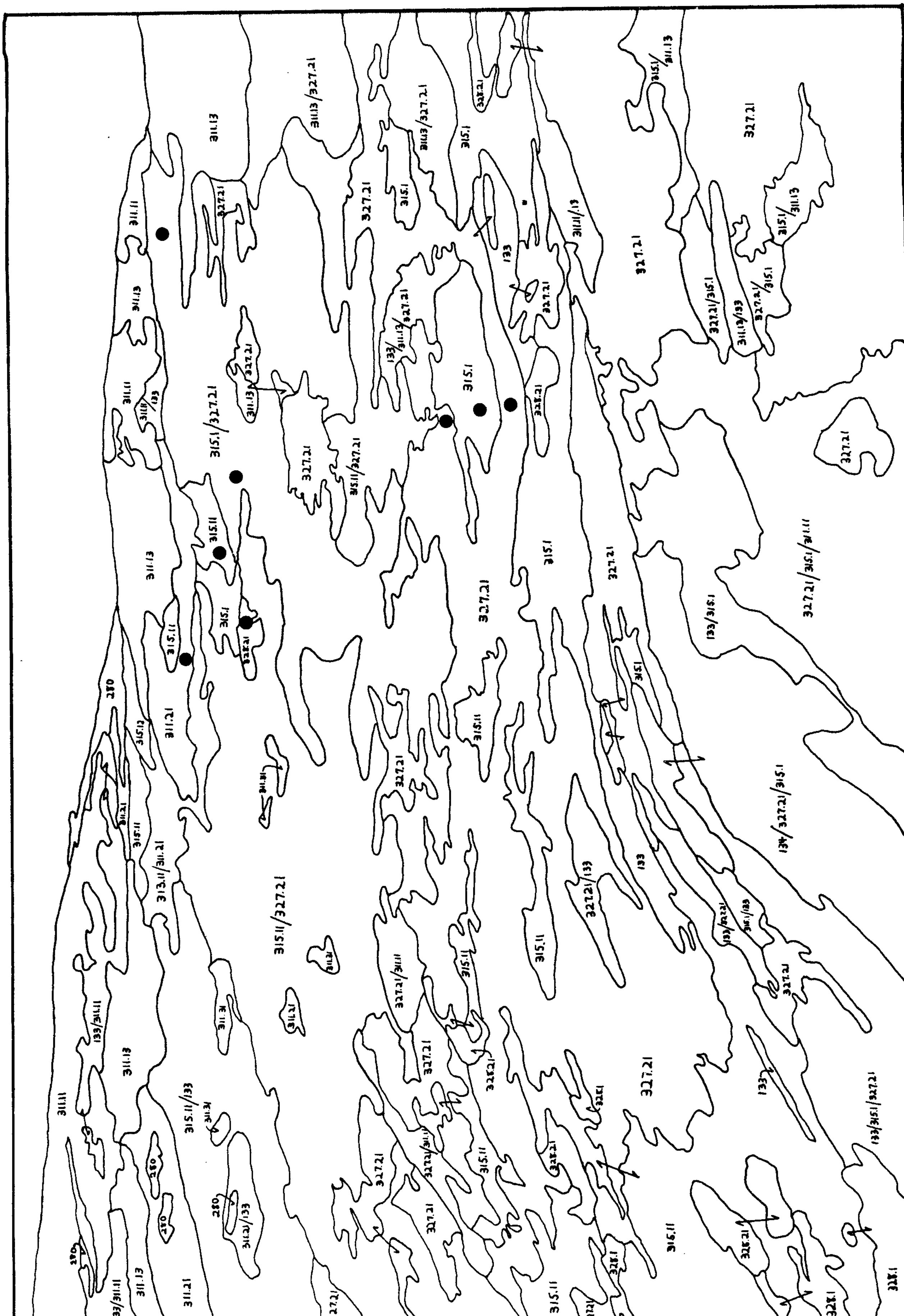
Legend

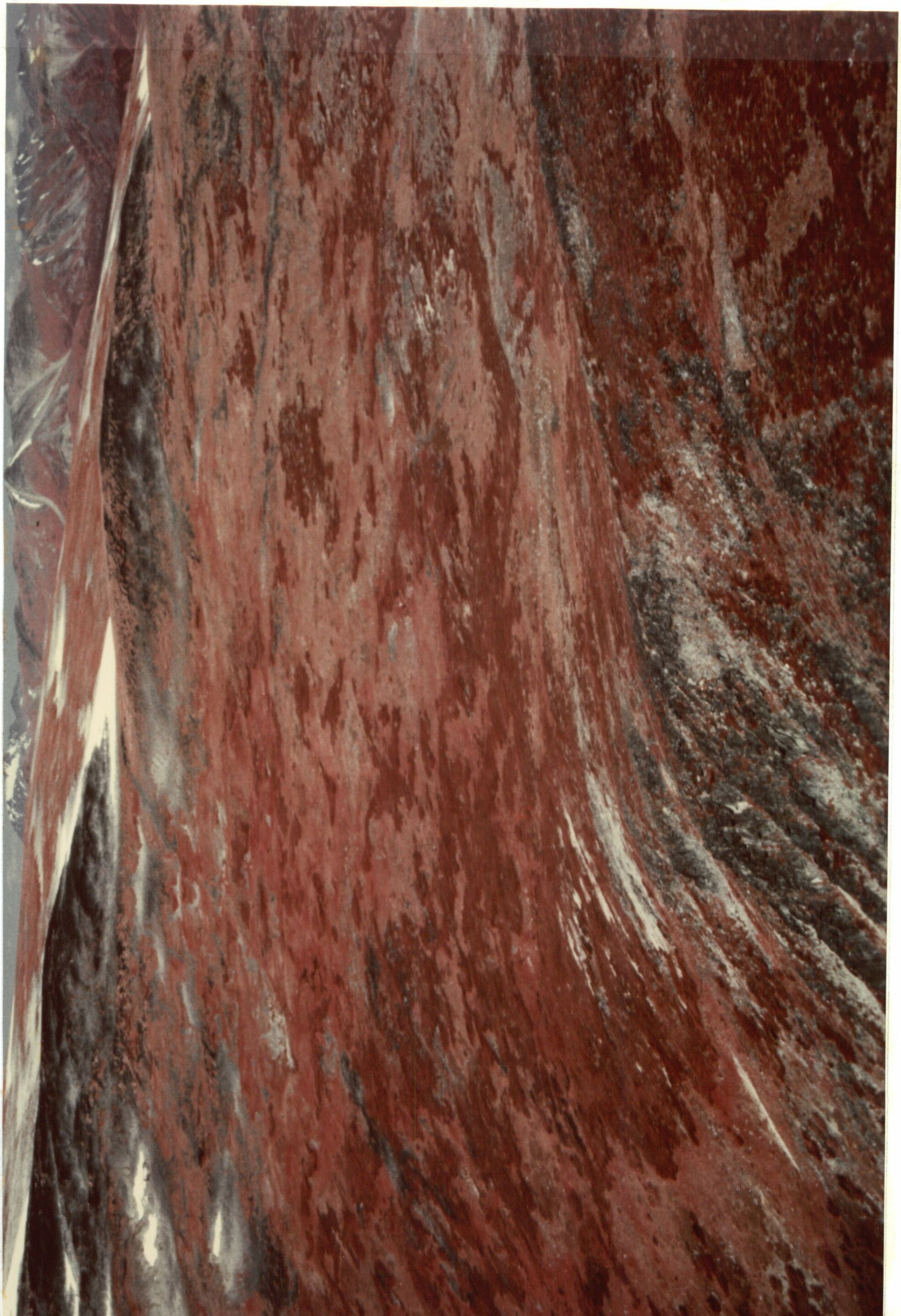
133	- Gravels, stones, cobbles, and boulders
134	- Scarps, talus and/or colluvium (system of outcropping strata)
280	- Snow and ice
311.11	- Umbilicaria blockfield
311.13	- Cetraria nivalis - Vaccinium uliginosum fellfield
311.21	- Anthelia juratzkana - Luzula arcuata late snowbed
311.31	- Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta runoff
313.11	- Sibbaldia procumbens - Polytrichum piliferum snowbed
315.1	- Fescue dominated meadows
315.11	- Festuca altaica - Potentilla diversifolia rich meadow
315.12	- Festuca altaica - Cladina dry meadow
327.21	- Betula glandulosa - Cetraria cucullata shrubfield
328.1	- Spruce-fir krummholz type
328.21	- Cassiope tetragona - Cladina mitis heath
●	- Sample site

Overlay 6: Habitat Type Map (back pocket)

Legend

1	- Fellfield and blockfield habitat type
2	- Snowbed habitat type
3	- Runoff habitat type
4	- Meadow and shrubfield habitat type
[#]	- Sample site number and location


311.13
315.1/327.21
327.21
315.11/327.21
315.1
133/315.1
327.21/315.1/311.11
134/327.21/315.1
133/315.1/327.21
311.13/327.21
315.11
133
311.21



mid-alpine (upper center of picture) characterized by more Festuca and less Betula.

The high alpine areas near the summit are represented by one color-infrared photograph (Figure 71) (map area 4 on Figure 64). Most of this photo is covered by two community types. The black areas are lichen covered rocks and boulders of the Umbilicaria blockfield. The pinkish white areas are Cetraria nivalis - Carex microchaeta fellfields.

Due to exposure and processing inconsistencies, prominent hues could not be extrapolated from one color-infrared photo to another.

C.5.3.2 Level III mapping of B+W aerial photographs

Two 1:29,000 scale B+W aerial photographs were mapped. Together these prints cover practically the entire alpine zone. Map area 5 (Figure 72 - Overlays 7 and 8) encompasses the southern section (see Figure 64) and includes the steep south slopes, high ridges and peaks, the East Plateau and Camp #2 (tent is visible), the East Valley and all the cirques. Map area 6 (Figure 73 - Overlays 9 and 10) covers the gentle north slope with its characteristic solifluction features, the North Knoll and Camp #1 and the North Valley.

With the aid of a 10x hand lens and stereoscope much information could be extracted from these prints. However, interpretations are more difficult on the B+W prints because the characteristic colors of the communities have been reduced to gray tones, some of which are very similar. More important for interpretation of B+W prints are topographic position and texture of the vegetation. Individual community types can often be detected but are much too small to be mapped. Watson (1977) gives two general rules which should be followed when mapping at any particular scale: 1, map units should not be smaller then the symbols used to represent them and 2, a

Figure 71: Map Area 4. Color-infrared aerial oblique photograph encompassing most of the South Ridge. Pink tones are Cetraria nivalis - Carex microchaeta fellfield and black tones represent Umbilicaria blockfield.

Figure 72:

Map Area 5. 1:29,000 scale B & W aerial photograph of Birch Mountain. The photograph encompasses the North Valley, East Valley, Northeast Plateau, East Plateau, the south slopes, ridges, all the cirques and the summit.

Overlay 7: Vegetation Map

Legend

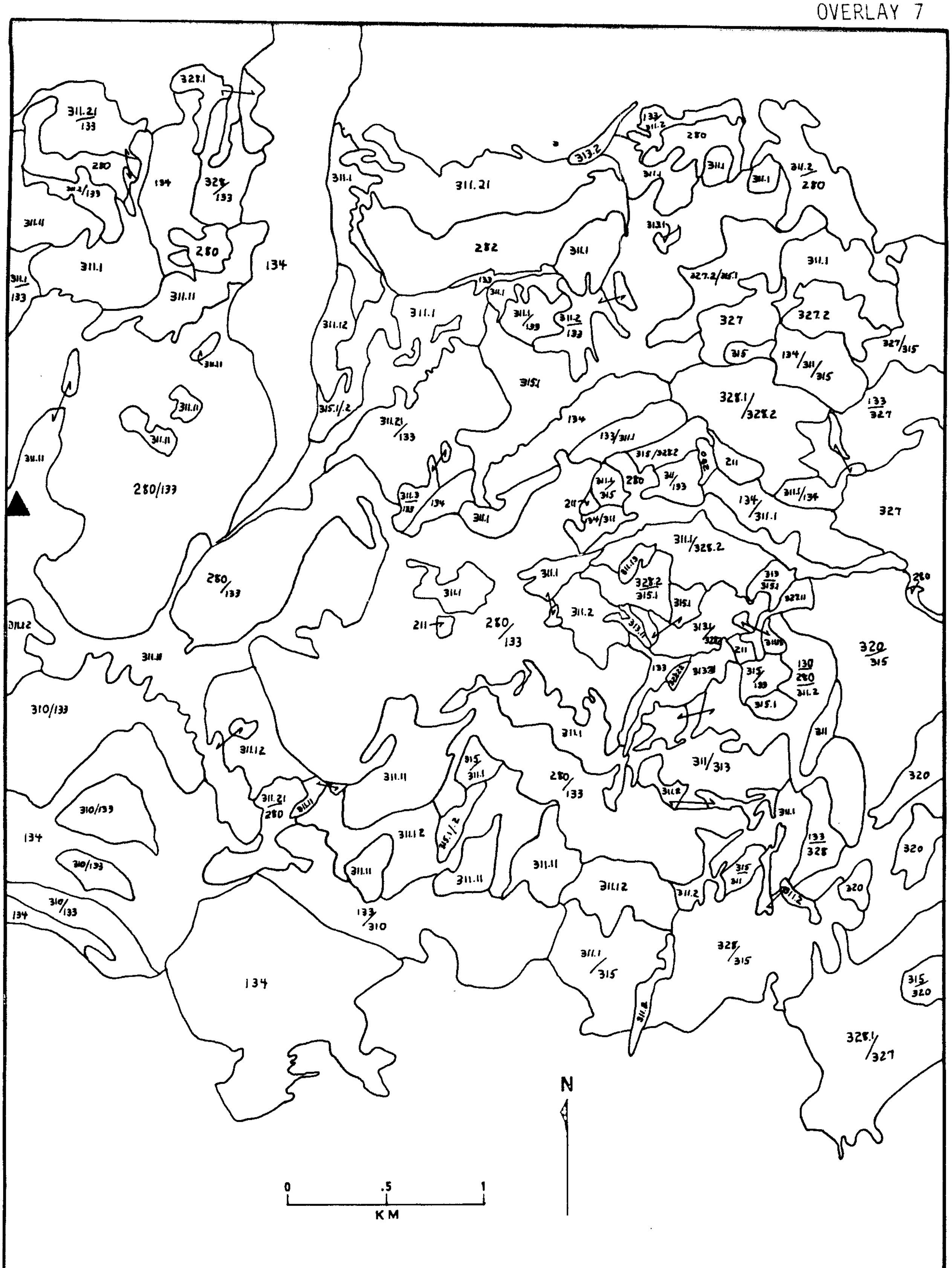
133	- Gravels, stones, cobbles, and boulders
134	- Scarps, talus and/or colluvium (system of outcropping strata)
211	- Natural lakes and ponds
280	- Snow and ice
310	- Herbaceous types
311	- Lichen, cryptogam and related communities
311.1	- Lichen dominated fellfields and blockfields
311.11	- *Umbilicaria* blockfield
311.12	- *Cetraria nivalis* - *Carex microchaeta* fellfield
311.13	- *Cetraria nivalis* - *Vaccinium uliginosum* fellfield
311.2	- Lichen and bryophyte dominated snowbeds
311.21	- *Anthelia juratzkana* - *Luzula arcuata* late snowbed
311.3	- Bryophyte dominated flushes and streambanks
313	- Forb types
313.1	- Forb dominated snowbeds
313.2	- Forb dominated flushes and streambanks
313.21	- *Ranunculus* - *Carex podocarpa* - *Saxifraga nelsoniana* - moss runoff
315	- Meadow
315.1	- Fescue dominated meadows
315.2	- *Carex* dominated meadows and snowbeds
320	- Shrub/Scrub
327	- Macrophyllous shrub
327.11	- *Salix planifolia* - *Empetrum nigrum* - *Sphagnum* runoff
327.2	- Birch predominant vegetation
328	- Microphyllous dwarf shrub
328.1	- Spruce-fir krummholz type
328.2	- Mountain heath types
▲	- Summit of Birch Mountain

Overlay 8: Habitat Type Map (back pocket)

Legend

1	- Fellfield and blockfield habitat type
2	- Snowbed habitat type
3	- Runoff habitat type
4	- Meadow and shrubfield habitat type

OVERLAY 7



311.21/133
328.1
280
134
328/133
280
311.1
134
311.11
311.1/133
311.21
282
311.1
280
313.2
327
327.2
315
134/311/315
328.1/328.2
133/327
327/315
311.12
315.1/2
311.21/133
3151
134
133/311.1
280/133
211
134/311.1
327
311.1/328.2
280/133
311.1
211
280/133
311.2
320/315
311.11
310/133
311.12
311.11
311.12
280/133
311/313
311
320
134
310/133
311.12
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320
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133/310
311.1/315
328/315
315/320
134
328.1/327
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1
KM

Figure 73:

Map Area 6. 1;29,000 scale B & W aerial photograph of Birch Mountain. The photograph encompasses the North Valley, north slope, North Knoll and northern slopes of Teresa Island.

Overlay 9: Vegetation Map

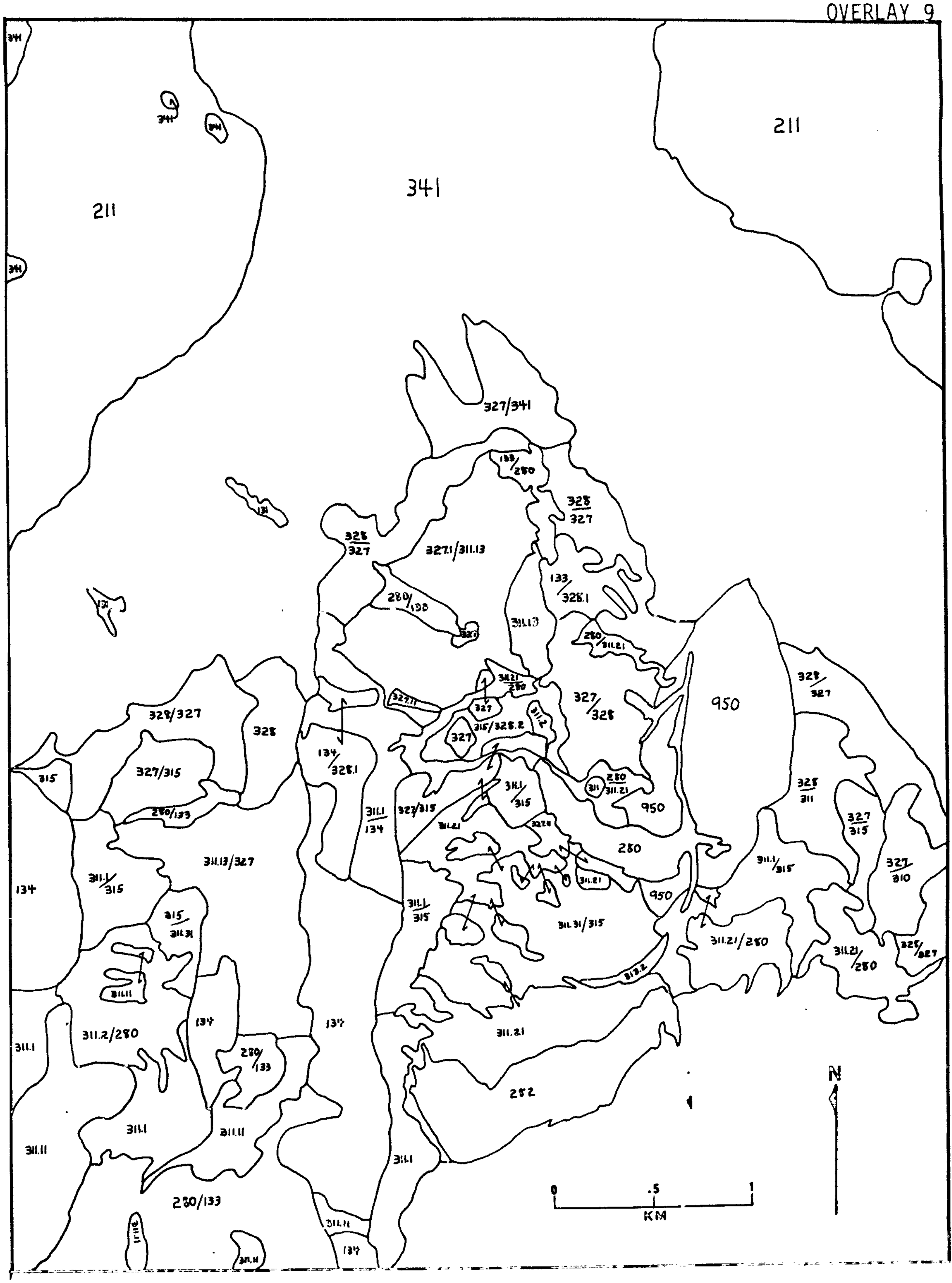
Legend

131	- Bedrock outcrops
133	- Gravels, stones, cobbles, and boulders
134	- Scarps, talus and/or colluvium (system of outcropping strata)
211	- Natural lakes and ponds
280	- Snow and ice
282	- Permanent snowfields and glaciers
311	- Lichen, cryptogam and related communities
311.1	- Lichen dominated fellfields and blockfields
311.11	- _Umbilicaria_ blockfield
311.13	- _Cetraria nivalis_ - _Vaccinium uliginosum_ fellfield
311.2	- Lichen and bryophyte dominated snowbeds
311.21	- _Anthelia juratzkana_ - _Luzula arcuata_ late snowbed
311.31	- _Aulacomnium palustre_ - _Salix polaris_ - _Claytonia sarmentosa_ - _Carex microchaeta_ runoff
313.2	- Forb dominated flushes and streambanks
315	- Meadow
327	- Macrophyllous shrub
327.11	- _Salix planifolia_ - _Empetrum nigrum_ - _Sphagnum_ runoff
328	- Microphyllous dwarf shrub
328.1	- Spruce-fir krummholz type
328.2	- Mountain heath types
341	- Conifer forests
950	- Shadows

Overlay 10: Habitat Type Map (back pocket)

Legend

1	- Fellfield and blockfield habitat type
2	- Snowbed habitat type
3	- Runoff habitat type
4	- Meadow and shrubfield habitat type


211
341
211
327/341
328/327
327.1/311.13
280/133
311.13
133/328.1
328/327
327/315
328
134/328.1
311.1/134
327/315
327/328
950
328/327
328/311
327/315
327/310
311.13/327
311.1/315
134
315/311.31
311.1/315
280
950
311.31/315
311.21/280
311.21/280
311.2/280
134
134
280/133
311.21
282
311.1
311.1
311.11
311.11
311.11
280/133
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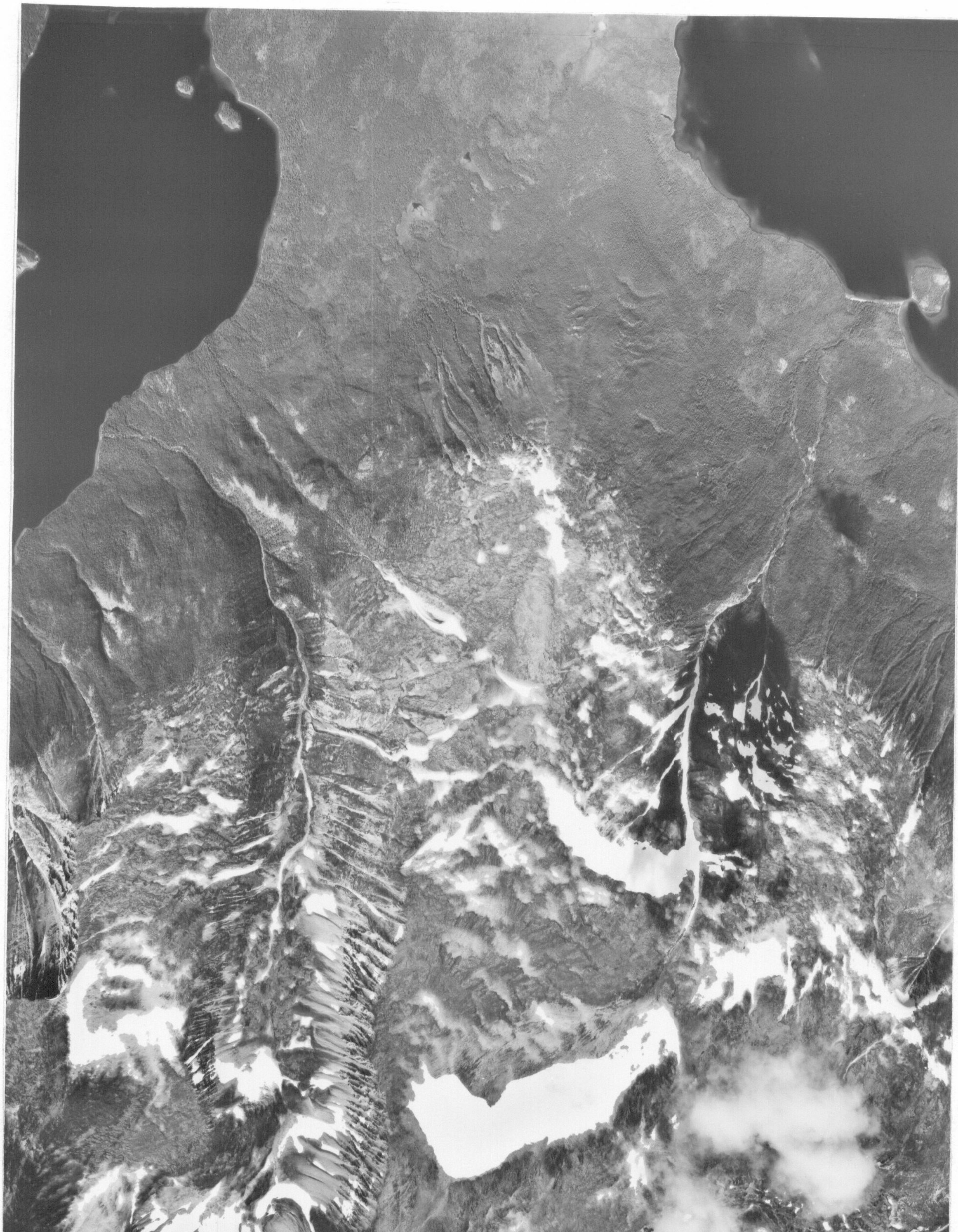
0
.5
1
KM
N



symbol should by placed within its unit whenever possible. The presence of two legend symbols within a map unit indicates that the two classification units are mixed and they both cover equally large areas. This once again is the problem of generalization. The problem of mapping alpine vegetation is one of mapping resolution, not photographic resolution. The amount of generalization that has occurred between classification levels IV and III is evident if map area 1 is compared to its location on map area 6 and map areas 2, 3 and 4 to their location on map area 5.

C.5.3.3 Level II mapping of B+W aerial photographs (Figure 74 - Overlays 11 and 12)

Even though the resolution of this photograph is so good that the tents at camps #1 and #2 can still be seen, generalization of information is extreme due to the very small scale of 1:80,000. If the entire image is to be mapped, then a decrease in photographic scale coincides with an increase in area mapped. In this case much of Teresa Island is now visible. The value of the hierarchical classification at this scale becomes evident. Since this vegetation study was restricted to the alpine zone, the quantitative species make-up of the subalpine and boreal areas of the mountain is not known and at a scale of 1:80,000 species identifications cannot be made. The physiognomy of the vegetation is visible at this scale and since the primary, secondary, and tertiary classes of the classification system are based on physiognomy all the vegetation can be mapped whether species composition is known or not. Vegetation studies and large-scale mapping of the subalpine and boreal zones can be done in the future without having to change the logic of the classification. The legend is simply expanded to add more information.

Figure 74:

1:80,000 scale B & W aerial photograph of Birch Mountain and much of Teresa Island.

Overlay 11: Vegetation Map

Legend

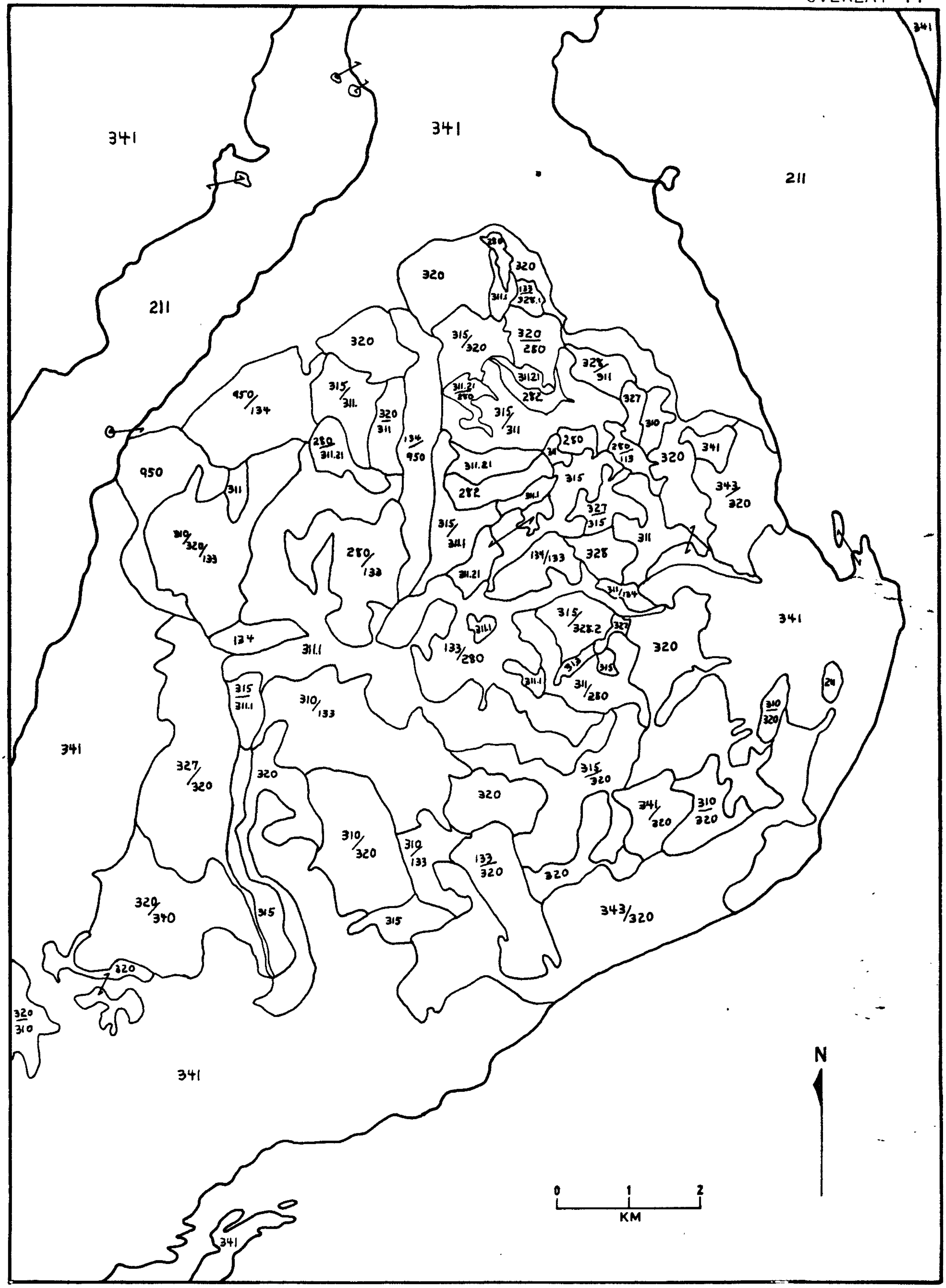
133 - Gravels, stones, cobbles and boulders
134 - Scarps, talus and/or colluvium (system of outcropping strata)
211 - Natural lakes and ponds
280 - Snow and ice
282 - Permanent snowfields and glaciers
310 - Herbaceous types
311 - Lichen, cryptogam and related communities
311.1 - Lichen dominated fellfields and blockfields
311.21 - _Anthelia juratzkana_ - _Luzula arcuata_ late snowbed
313 - Forb types
315 - Meadow
320 - Shrub/Scrub
327 - Macrophyllous scrub
328 - Microphyllous dwarf shrub
328.1 - Spruce-fir krummholz type
328.2 - Mountain heath types
341 - Conifer forests
343 - Conifer-broadleaf mixed forests and woodlands
950 - Shadows

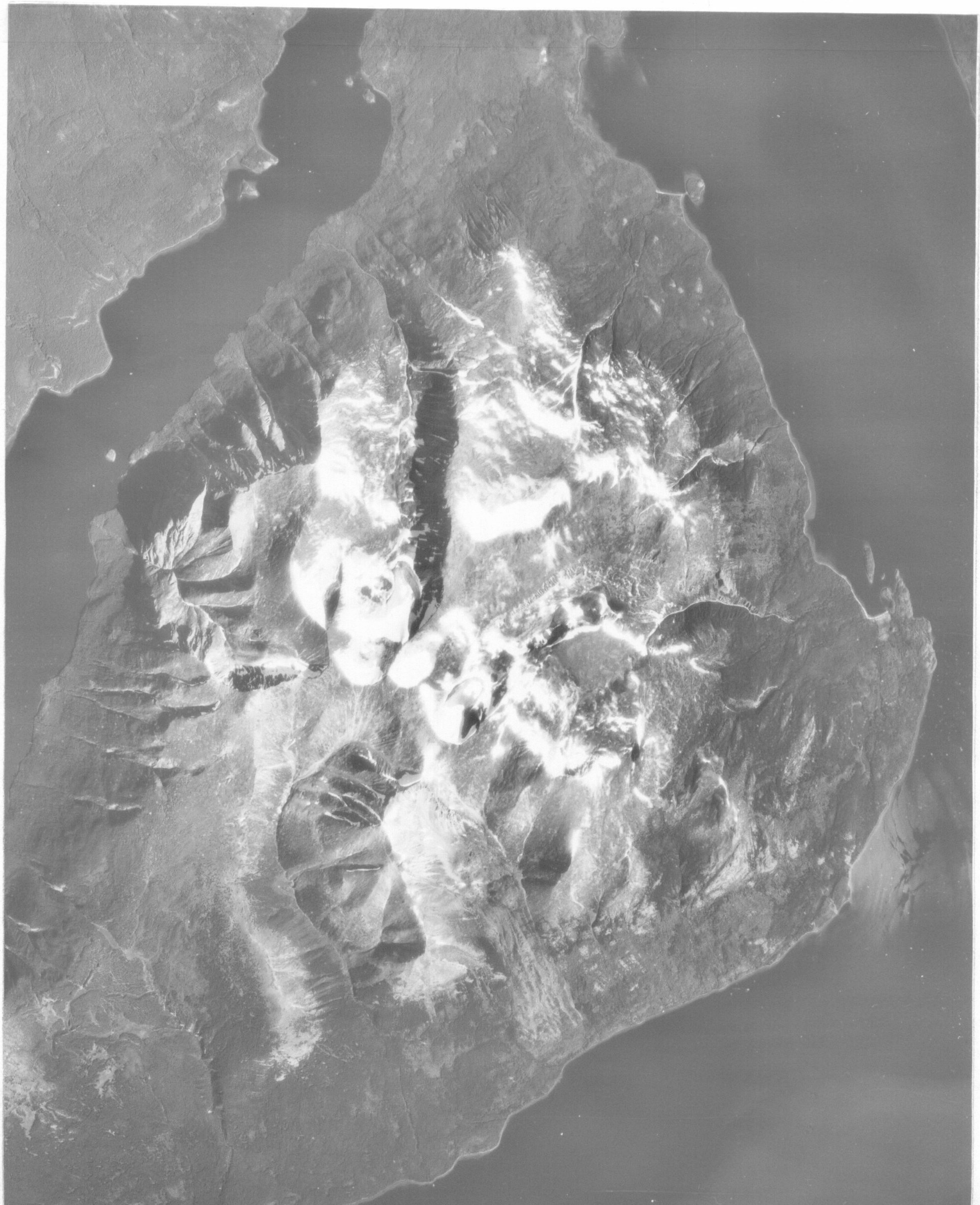
Overlay 12: Habitat Type Map (back pocket)

Legend

1 - Fellfield and blockfield habitat type
2 - Snowbed habitat type
3 - Runoff habitat type
4 - Meadow and shrubfield habitat type

OVERLAY 11





C.5.3.4 Level I mapping from Landsat imagery (Figure 75 - Overlays 13 and 14)

A color composite of the September 6, 1974 Landsat imagery was produced on the I^2S Color Additive Viewer using bands 4, 5, 6, and 7. The Color Additive Viewer adds color (white, blue, green or red) to each of the bands and optically superimposes them on the screen. The best color combination for bands 4, 5, 6, and 7 for vegetation interpretation was found to be green, blue, red and red respectively. The color of the image produced using this combination resembles that of color-infrared photographs and thus aids the interpretation of the satellite image. This composite was photographed off the viewer screen and reproduced on a Cibachrome print with a resulting scale of 1:180,000 (Figure 75).

Interpretation of the Landsat image is based on color and elevation. It can be seen that the vegetation forms bands coinciding with elevation. The dense coniferous forest with its low reflectivity forms a brownish - magenta band around the edge of the island. This probably correlates to Krajina's Boreal White and Black Spruce Zone (Beil et al., 1976). With an increase in elevation there is an increase in reflectivity probably because of the presence of more deciduous hardwood vegetation. This is especially noticeable on the southern half of the island. As reflectivity continues to increase with elevation, red begins to disappear. This is correlated with the overall decrease in vegetation with elevation and the increased contribution of soil and rock to the total reflectivity. Alpine meadows appear whitish - yellow. The subalpine zone, the Spruce - Willow - Birch Zone (Beil et al., 1976; Krajina, 1975), grades from reddish - yellow to red. Bare rock appears gray.

Figure 75:

1:180,000 scale LANDSAT image of Teresa Island, southern Atlin Lake and surroundings.

Overlay 13: Vegetation Map

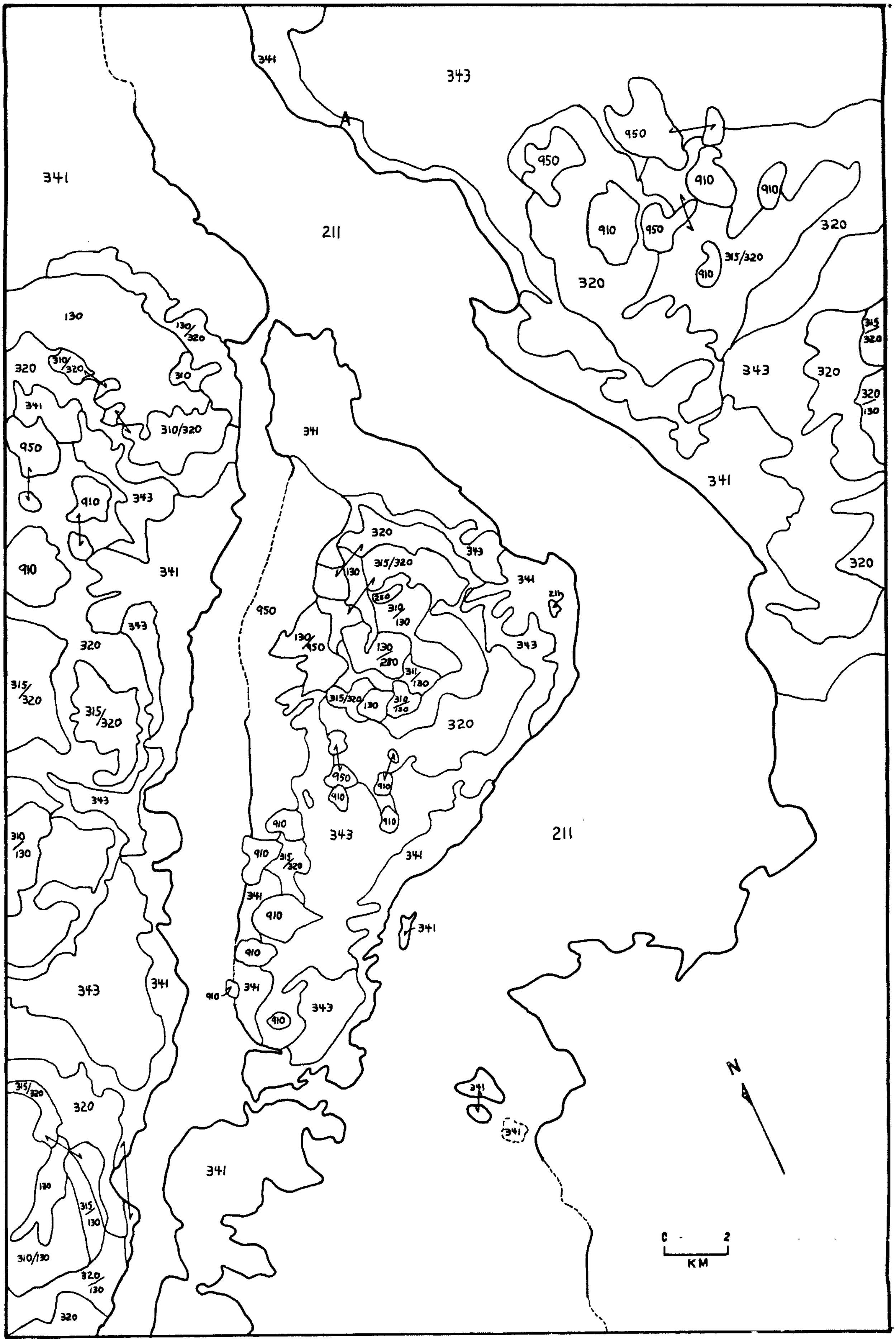
Legend

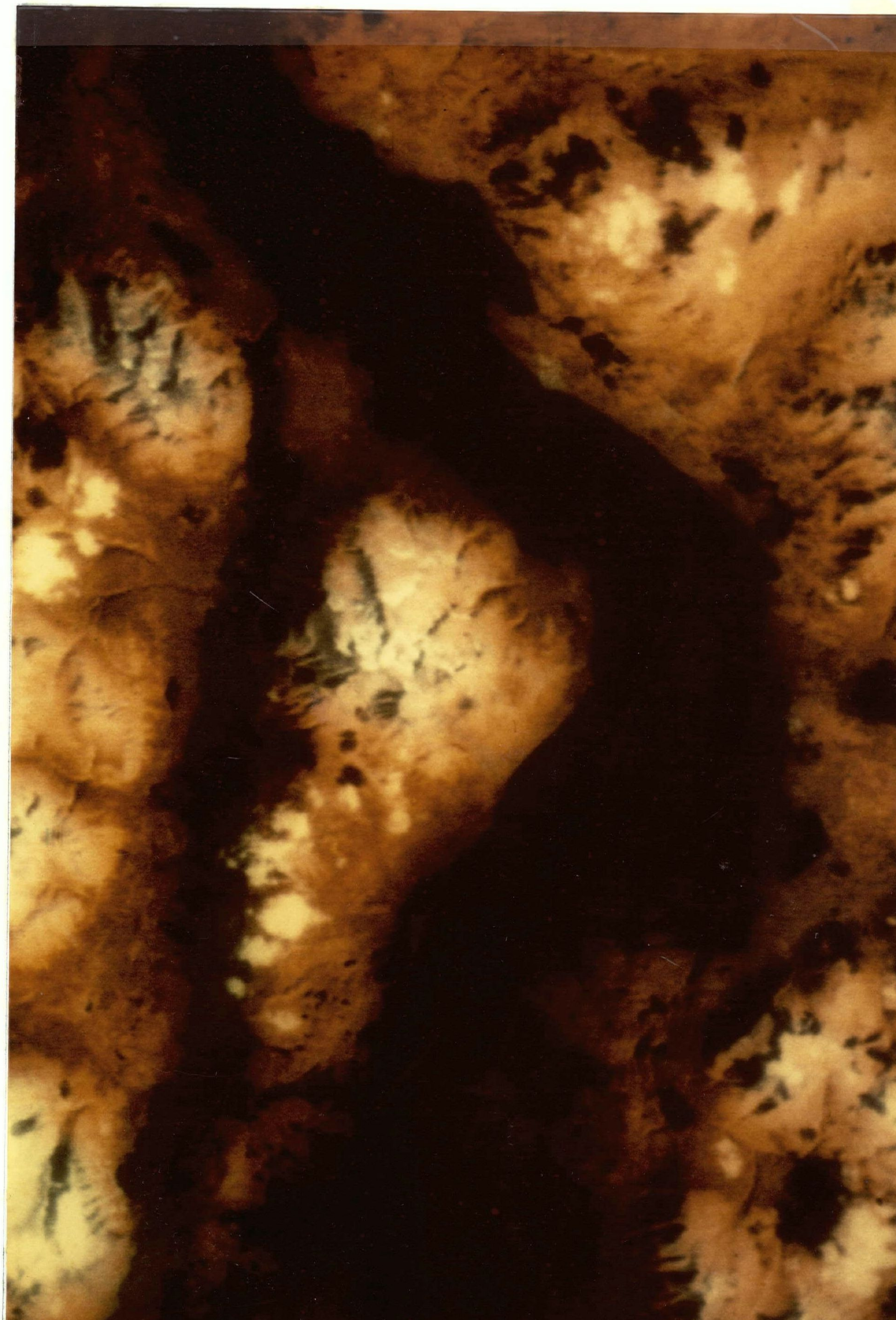
130	- Rocklands
211	- Natural lakes and ponds
280	- Snow and ice
310	- Herbaceous types
311	- Lichen, cryptogam and related communities
315	- Meadow
320	- Shrub/Scrub
341	- Conifer forests
343	- Conifer-broadleaf mixed forests and woodlands
910	- Clouds and fog
950	- Shadows
A	- Atlin

Overlay 14: Habitat Type Map (back pocket)

Legend

1	- Fellfield and blockfield habitat type
2	- Snowbed habitat type
4	- Meadow and shrubfield habitat type
A	- Atlin


343
341
211
950
910
320
315/320
130
130/320
310/320
310
343
341
950
315/320
130/450
130/280
311/130
310/130
320
341
211
N
0
2
KM



C.6 Conclusions

The preceding maps demonstrate the effectiveness of the hierarchical ecological classification for mapping alpine vegetation and its adaptability to varying scales and available remote sensing data. Color-infrared photos are superior for identification and delineation of plant communities and in many cases individual species. Maximum information is obtained when color-infrared photos are supplemented with normal color photographs. B+W aerial photos are useful for mapping but plant community discrimination is reduced. All mapping should be field checked for accuracy of boundaries and units. Satellite imagery is valuable for small-scale mapping of major physiognomically characterized vegetation units. The biogeoclimatic zones occurring in northwestern British Columbia can be discriminated on late-summer satellite imagery.

D. SUMMARY AND CONCLUSIONS

In summary:

(1) The alpine vegetation of Teresa Island, Atlin Lake, in northwestern British Columbia was studied during the summers of 1974, 1975 and 1976.

(2) The bedrock of this alpine area is primarily composed of quartz monzonite with small pockets of siltstone, mudstone and sandy limestone.

(3) These rocks have given rise to poorly developed acidic soils. Soil development is poor because of fairly recent deglaciation, poor productivity and microbiological activity inherent in most alpine environments, low temperatures, wind, and extensive solifluction, cryoturbation and frost shattering.

(4) These periglacial phenomena have been active in the past and remain active today. Common frost features occurring on the mountain include extensive frost-formed boulder fields on the summits and high ridges, active solifluction lobes and benches (especially on the north slope), sorted stripes, stone nets, debris islands, and sorted and nonsorted circles. Presence of these features indicates a constant supply of water and a periglacial climate characterized by frequent subsurface freeze-thaw cycles.

(5) Four weather stations were established during the study period, three on the north slope at 1280, 1540 and 1829 m, and one on the East Plateau at 1540 m. From precipitation and temperature data collected at each station, it was found that temperature greatly decreases with an increase in elevation; precipitation increases with elevation; and temperature and precipitation are consistently greater on the East Plateau, i.e., south side of the mountain, than on the north slope.

(6) One hundred fifty-one (151) sites, chosen on the basis of uniform

appearance (dominant species), uniform ecological conditions and species homogeneity, were sampled during the study period.

(7) These sites were combined into sixteen community types on the basis of dominant species, physiognomic similarity and similar environmental conditions.

(8) The sixteen community types identified were: 1) Umbilicaria blockfield; 2) Cetraria nivalis - Vaccinium uliginosum fellfield; 3) Cetraria nivalis - Carex microchaeta fellfield; 4) Carex microchaeta meadow; 5) Festuca altaica - Potentilla diversifolia rich meadow; 6) Festuca altaica - Cladina dry meadow; 7) Betula glandulosa - Cetraria cucullata shrubfield; 8) Cassiope tetragona - Cladina mitis heath; 9) Cassiope stelleriana - Phyllodoce empetriformis snowbed; 10) Sibbaldia procumbens - Polytrichum piliferum snowbed; 11) Anthelia juratzkana - Luzula arcuata snowbed; 12) Carex pyrenaica - Luetkea pectinata - Juncus drummondii snowbed; 13) Salix planifolia - Empetrum nigrum - Sphagnum runoff; 14) Calamagrostis canadensis - Plagiomnium rostratum runoff; 15) Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta runoff; and 16) Ranunculus - Carex podocarpa - Saxifraga nelsoniana - moss runoff.

(9) Four transects were sampled to document changes in species distributions along environmental gradients.

(10) Observations and transect results show that the physical environmental factors most instrumental in controlling the local distribution of vegetation within the alpine zone are topography, snow duration and moisture.

(11) Four habitat types, defined primarily by these three environmental factors, were established which effectively reflect both distribution of taxa and major patterns in the vegetation. These habitat types are: 1) fellfields and blocks; 2) snowbeds; 3) runoff sites, and 4) meadows and

shrubfields.

(12) Fellfields and blockfields occur on the most exposed areas of the mountain where snow is blown off during the winter and the vegetation is exposed to severe winds and temperatures year-round. Gravelly regosols which are well-drained result in xeric conditions following snow melt. Three community types occur in this habitat type which outline variation due primarily to the elevational gradients. These communities are the Umbilicaria blockfield, Cetraria nivalis - Vaccinium uliginosum fellfield, and Cetraria nivalis - Carex microchaeta fellfield.

(13) Snowbeds occur where snow remains until at least early July, and are most common on the north side of the mountain. Snowbeds protect underlying vegetation from extreme winter temperatures, but at the same time restrict species occurrence by reducing the length of the growing season. Differential distribution of the vegetation within the snowbed habitat types is caused by the tolerances of the species to shortness of growing season and drought. Four community types occur in this habitat type which primarily reflect differences in these two factors. The four communities are the Anthelia juratzkana - Luzula arcuata late snowbed, Sibbaldia procumbens - Polytrichum piliferum snowbed, Carex pyrenaica - Luetkea pectinata - Juncus drummondii snowbed, and Cassiope stelleriana - Phyllodoce empetriformis snowbed.

(14) The runoff habitat type is composed of water-saturated sites including spring-lines, stream edges, pond margins and bog-like areas. Four community types occur within this habitat type which outline environmental variation primarily reflecting differences in elevation, snow duration and drainage. These communities are the Salix planifolia - Empetrum nigrum - Sphagnum community, Calamagrostis canadensis - Plagiomnium rostratum community, Ranunculus - Carex podocarpa - Saxifraga nelsoniana - moss

community and the Aulacomnium palustre - Salix polaris - Claytonia sarmentosa - Carex microchaeta community.

(15) Meadows and shrubfields encompass the mesic areas of the mountain where drainage is good and snow cover moderate. Productivity is highest in this habitat type and soils attain their best development. Five community types occur here which reflect differences in snow duration, moisture and elevation. These communities are the Carex microchaeta meadow, Festuca altaica - Cladina dry meadow, Festuca altaica - Potentilla diversifolia rich meadow, Betula glandulosa - Cetraria cucullata shrubfield, and Cassiope tetragona - Cladina mitis heath.

(16) The alpine zone of Teresa Island can be divided into three subzones based on elevation and floristic makeup. The low alpine subzone occurs from the subalpine to approximately 1575 m, and is dominated by macro- and microphyllous shrubs. The mid-alpine subzone extends to about 1700 m, and is dominated by graminoid species while the high alpine subzone is dominated by lichens.

(17) Many of the community types occurring on Birch Mt. are comparable floristically and/or ecologically with other alpine areas described in B. C., southern Yukon and southeastern Alaska. Of the areas compared, the Spatsizi Plateau is the most similar floristically to the alpine zone of Teresa Island.

(18) The alpine communities appear to be in equilibrium with their particular habitat, but are not fixed in space since periglacial phenomena such as solifluction and cryoturbation constantly change the spatial positions of the habitats.

(19) The recent increase of remote sensing techniques and availability of data has provided a new tool for the mapping of vegetation units. Four types of remote sensing data are discussed: black-and-white; color;

and color-infrared photographs and satellite images.

(20) A classification system is developed which can utilize remotely sensed data. This system is hierarchical and incorporates the use of physiognomic and structural characteristics at levels of broad generalization, and ecological and floristic at intermediate and refined levels. This classification and accompanying legend have been developed to meet the multi-scale needs of the various users and, at the same time, maintain a consistent logic.

(21) Three large-scale, color-infrared, aerial-oblique photographs were mapped. Two B&W, 1:29,000 scale aerial photographs encompassing almost all of the mountain were mapped. One 1:80,000 scale aerial photograph encompassing almost all of the island was mapped as was a 1:180,000 scale satellite image encompassing the entire island and surrounding lake shore.

(22) All photos were mapped twice, once using the hierarchical classification and once using the habitat type units.

(23) The mapping of habitat types is considered to be of limited use as it is confined solely to the alpine and does not incorporate all alpine features such as talus slopes and ponds. Habitat type mapping is most useful at the intermediate scales of 1:29,000 and 1:80,000.

(24) The hierarchical classification is effective at all scales and can incorporate all features visible on the image. Since the primary, secondary and tertiary classes of this classification and legend system are based on physiognomy, all the vegetation can be mapped through photo-interpretation, whether species composition is known or not. The system works, then, for tundra, parkland and forest. Maps can be as general or detailed as information and scale allow without changing the logic of the classification.

(25) Color-infrared transparencies are superior to conventional B&W and color photos for distinguishing vegetation types. The range of red tones associated with foliage is greater than the normally dark shades of green so changes in the vegetation are more easily detected. Conifers can easily be distinguished from hardwoods. Infrared film is able to detect isolated patches of vegetation that tend to blend into the background in B&W and color films.

(26) Satellite imagery is valuable for generalized mapping of large areas.

(27) The best color combination for bands 4, 5, 6 and 7 for vegetation interpretation are green, blue, red and red, respectively.

(28) Color changes on the satellite image primarily reflect vegetation density and shadow. The location of the Boreal White and Black Spruce Zone, Spruce - Willow - Birch Zone, and Alpine Tundra Zone could be approximated. In general, snow, rock, shrubs and herb-dominated areas could be distinguished in the alpine zone.

(29) It is concluded that the description and classification of alpine vegetation in British Columbia is feasible and should be carried out as a prerequisite for any management programs. Using the classification developed here, it is possible to map alpine vegetation at any scale to fit available imagery and the needs of the user. Willard and Marr (1970) described the type of alpine vegetation most susceptible to human disturbance. Graminoid vegetation was least disturbed and wet areas and snowbeds maximally disturbed. Information of this sort, combined with the ecological information and classification developed in this thesis, can provide the base data for park planning. The information presented here can be used with data on wildlife forage needs and habitat utilization to provide the base for wildlife management policies. It is hoped that research will be

continued in the future, and available data utilized so that we may obtain the maximum and lasting benefit of our alpine resources.

LITERATURE CITED

Aitken, J. D. 1959. Atlin map area. Geol. Surv. Can. Mem. 307.

American Society of Photogrammetry. 1975. Manual of Remote Sensing. Falls Church, Virginia. 2 Vol.

Anderson, J. H. 1970. A geobotanical study in the Atlin region in northwestern British Columbia and south central Yukon Territory. Unpublished Ph.D. thesis. Michigan State University, Ann Arbor.

Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. U. S. Geol. Sur. Prof. Paper 964.

Archer, A. C. 1963. Some synecological problems in the Alpine Zone in Garibaldi Park. Unpublished M.Sc. thesis, University of British Columbia, Vancouver.

Arctic Institute of North America. 1968. Symposium on remote sensing in the polar regions. Easton, Maryland.

Avery, T. E. 1968. Interpretation of aerial photographs. 2nd Ed., Burgess Publishing Company, Minneapolis.

Bamberg, S. A. and J. Major. 1968. Ecology of the vegetation and soils associated with culcareous parent materials in three alpine regions of Montana. Ecol. Monogr. 38(2): 127-169.

Barry, R. G. and C. C. Van Wie. 1974. Topo- and microclimatology in alpine areas. p. 73-83. In J. D. Ives and R. G. Barry (eds.) Arctic and alpine environments. Methuen, London.

Beil, C. E., R. L. Taylor and G. A. Guppy. 1976. The biogeoclimatic zones of British Columbia. Davidsonia. 7(4): 45-55.

Benninghoff, W. S. 1950. Use of aerial photographs in mapping vegetation and surficial geology in subarctic regions. Photogr. Engr. 16: 428-429.

Billings, W. D. 1973. Arctic and alpine vegetations: similarities, differences, and susceptibility to disturbance. BioScience. 23(12): 697-704.

______________. 1974. Arctic and alpine vegetation: plant adaptations to cold summer climates. p. 403-443. In J. D. Ives and R. G. Barry (eds.) Arctic and alpine environments. Methuen, London.

______________ and L. C. Bliss. 1959. An alpine snowbank environment and its effects on vegetation, plant development and productivity. Ecology. 40: 388-397.

______________ and A. F. Mark. 1961. Interactions between alpine tundra vegetation and patterned ground in the mountains of southern New Zealand. Ecology. 42: 18-31.

Billings, W. D. and H. A. Mooney. 1968. The ecology of arctic and alpine plants. Biol. Rev. 43: 481-529.

Birks, H. J. B. 1977. Modern pollen rain and vegetation of the St. Elias Mountains, Yukon Territory. Can. J. Bot. 55: 2367-2382.

Bliss. L. C. 1963. Alpine plant communities of the Presidential Range, New Hampshire. Ecology. 44(4): 678-697.

__________. 1969. Alpine community patterns in relation to environmental parameters. p. 167-184. In K. N. H. Greenridge (ed.) Essays in plant geography and ecology. Nova Scotia Museum, Halifax, N. S.

__________. 1971. Arctic and alpine plant life cycles. Annual Review of Ecology and Systematics. 2: 405-438.

Braun-Blanquet, J. 1964. Pflanzensoziologie. Springer-Verlag. New York.

Brayshaw, T. C. 1976. Catkin bearing plants of British Columbia. British Columbia Provincial Museum. No. 18 Occasional Papers Series. Queen's Printer, Victoria.

Brooke, R. C., E. B. Peterson and V. J. Krajina. 1970. The Subalpine Mountain Hemlock Zone. Ecology of Western North America. 2(2): 147-349.

Brown, R. J. E. 1974. Some aspects of airphoto interpretation of permafrost in Canada. National Research Council of Canada, Div. of Building Research, Ottawa, Ontario. Tech. Pap. 409.

______________ and W. O. Kupsch. 1974. Permafrost terminology. Technical Memorandum No. 111. Associate Committee on Geotechnical Research, National Research Council of Canada.

Bryant, J. P. and E. Scheinberg. 1970. Vegetation and frost activity in an alpine fellfield on the summit of Plateau Mountain, Alberta. Can. J. Bot. 48: 751-771.

Buttrick, S. C. 1977. The alpine flora of Teresa Island, Atlin Lake, B. C., with notes on its distribution. Can. J. Bot. 55(10): 1399-1409.

Canada Department of Agriculture. 1974. The system of soil classification for Canada. Publication 1455.

Churchill, E. D. and H. C. Hanson. 1956. The concept of climax in arctic and alpine vegetation. Bot. Rev. 24: 127-191.

Colwell, J. E. 1974. Vegetation canopy reflectance. Remote Sensing of Environment. 3: 175-183.

Dahl, E. 1955. Biogeographic and geologic indications of unglaciated areas in Scandinavia during the glacial ages. Bull. Geol. Soc. Amer. 66: 1499-1519.

Dahl, E. 1956. Rondane: mountain vegetation in south Norway and its relation to the environment. Noske Videnskaps-Akad., Ser. 1, Matematisk-Naturvid. Kl., Skr. 3.

_______ and H. Krog. 1973. Macrolichens. Scandinavian University Books. Universitetsforlaget.

Dansereau, P. 1957. Biogeography, an ecological perspective. The Ronald Press, New York.

Daubenmire, R. F. 1952. Forest vegetation of northern Idaho and adjacent Washington, and its bearing on concepts of vegetation classification. Ecol. Monogr. 22:301-330.

Davies, J. L. 1969. Landforms of cold climates. MIT Press, Cambridge, Massachusetts.

Detwyler, T. R. 1974. Vegetation-snow cover relations in an alpine pass, Alaska. p. 355-360. In V. C. Bushnell and R. H. Ragle (eds.) Icefield Ranges Research Project, Scientific Results. Vol. 4. American Geographical Society, N. Y. and Arctic Institute of North America, Montreal.

Eady, K. 1971. The ecology of the alpine and timberline vegetation of Big White Mountain, B. C. Unpublished Ph.D. thesis, University of British Columbia, Vancouver.

Elton, C. S. and R. S. Miller. 1954. The ecological survey of animal communities; with a practical system of classifying habitats by structural characteristics. J. Ecol. 42: 460-496.

Flint, R. F. 1971. Glacial and Quarternary geology. John Wiley and Sons. New York.

Floate, M. J. S. 1965. Distribution of organic matter and phosphorous fractions in a topographic sequence of soils in southern British Columbia. Can. J. Soil Sci. 45: 323-329.

Forest Management Institute. 1974. Vegetation types of the MacKenzie Corridor. Canadian Forestry Service, Environment Canada. Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development. Rep. No. 73-46.

Fritz, N. L. 1977. Filters: an aid color-infrared photography. Photogrammetric Engineering and Remote Sensing. 43(1): 61-72.

Gausman, H. W. 1977. Reflectance of leaf components. Remote Sensing of Environment 6: 1-9.

Gjaervoll, O. 1956. The plant communities of the Scandinavian alpine snow-beds. Kongel. Norske Videnskab. Selskabs, Skr. 1956, No. 1.

Griggs, R. F. 1956. Competition and succession on a Rocky Mountain fell-field. Ecology. 37: 8-20.

Hale, M. E. 1969. How to know the lichens. W. C. Brown. Dubuque.

Hartley, E. 1973. Man's effects on the stability of alpine and subalpine vegetation in Glacier National Park, Montana. Ph.D. thesis. Duke University, Durham, North Carolina.

Hoefs, M., I. McT. Cowan, and V. J. Krajina. 1975. Phytosociological analysis and synthesis of Sheep Mountain, southwestern Yukon Territory, Canada. Syesis (Suppl. 1), 8: 125-228.

Holland, S. S. 1964. Landforms of British Columbia: a physiographic outline. Bulletin No. 48. British Columbia Department of Mines and Petroleum Resources.

Howarth, P. J. 1972. Film and filter combinations for the study of the periglacial landscape of the high Arctic. p. 379-386. In Proc. First Can. Symp. Remote Sens. Ottawa.

Hubbard, W. A. 1969. The grasses of British Columbia. B. C. Prov. Mus. Handb. 9. Queen's Printer, Victoria.

Hultén, E. 1968. Flora of Alaska and neighboring territories. Stanford University Press, Stanford, California.

Jenny, H. 1941. Factors of soil formation. McGraw-Hill, New York.

Johnson, P. L. and W. D. Billings. 1962. The alpine vegetation of the Beartooth Plateau in relation to cryopedogenic processes and patterns. Ecol. Monogr. 32: 105-135.

Kendrew, W. G. and D. Kerr. 1955. The climate of British Columbia and the Yukon Territory. Edmond Cloutier, Ottawa.

Klemas, V., D. Bartlett, W. Philpot, R. Rogers and L. Reed. 1974. Coastal and estuarine studies with ERTS-1 and Skylab. Remote Sensing of Environment. 3: 153-174.

Klinka, K. 1976. Ecosystem units, their classification, interpretation and mapping in the University of British Columbia Research Forest. Unpublished Ph.D. thesis. University of British Columbia, Vancouver.

Knipling, E. B. 1969. Leaf reflectance and image formation on color infrared film. p. 17-29. In P. L. Johnson (ed.) Remote sensing in ecology. University of Georgia Press. Athens.

Komarov, V. B. 1968. Aerial photography in the investigation of natural resources in the U.S.S.R. p. 143-185. In Aerial Surveys and Integrated Studies. Proceedings of the Toulouse Conference. UNESCO.

Krajina, V. J. 1965. Biogeoclimatic zones and classification of British Columbia. Ecol. West. N. Amer. 1: 1-17.

_____________. 1969. Ecology of forest trees in British Columbia. Ecol. West. N. Amer. 2: 1-146.

_____________. 1973. Biogeoclimatic zones of British Columbia. Map published by British Columbia Ecological Reserves Committee, British Columbia Dept. Lands, Forest, and Water Resources.

Krajina, V. J. 1975. Some observations on the three sub-alpine zones in British Columbia, Yukon and MacKenzie District. Phytocoenologia. 2: 396-400.

Küchler, A. W. 1951. The relationship between classifying and mapping vegetation. Ecology. 32(2): 275-283.

____________. 1967. Vegetation mapping. The Ronald Press Company, New York.

____________. 1973. Problems in classifying and mapping vegetation for ecological regionalization. Ecology 54(3): 512-523.

Lavkulich, L. M. 1973. Soils-vegetation-landforms of the Wrigley Area, N.W.T. Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development. Rep. No. 73-18.

Legge, A. H., D. R. Jaques, C. E. Poulton, C. L. Kirby and P. Van Eck. 1974. Development and application of an ecologically based remote sensing legend system for the Kananaskis, Alberta, Remote Sensing Test Corridor (Subalpine Forest region). Environmental Sciences Centre Kananaskis, University of Calgary, Alberta.

Lord, T. M. and A. J. Green. 1974. The soils of the Tulameen area of British Columbia. Rept. No. 13. B. C. Soil Survey, Resource Branch, Canada Department of Agriculture, Ottawa.

__________ and A. J. Luckhurst. 1974. Alpine soils and plant communities of a Stone sheep habitat in northeastern British Columbia. Northwest Science. 48(1): 38-51.

Löve, D. 1970. Subarctic and subalpine: where and what? Arctic and Alpine Research. 2: 63-73.

Lozinski, W. 1909. Über die mechanische Verwitterung der Sandsteine im gemassigten Klima. Acad. sci. cracovie Bull. internat., cl. sci. math. et naturelles. 1: 1-25.

Luckhurst, A. 1973. Stone sheep and their habitat in the northern Rocky Mountain foothills of British Columbia. Unpublished M.Sc. thesis, University of British Columbia, Vancouver.

Marr, J. W. 1961. Ecosystems of the east slope of the Front Range in Colorado. Univ. of Colorado Stud., Ser. in Biol. 8: 1-134.

Meier, M. F., R. H. Alexander and W. J. Campbell. 1966. Multispectral sensing tests at South Cascade Glacier, Washington. p. 145-159. In Proceedings of the Fourth Symposium on Remote Sensing of Environment. Univ. of Michigan, Ann Arbor.

Miller, M. M. 1964. Morphogenic classification of Pleistocene glaciations in the Alaska-Canada Boundary Range. Proc. Am. Phil. Soc. 108(3): 247-256.

Miller, M. M. and J. H. Anderson. 1974a. Out-of-phase Holocene climatic trends in the maritime and continental sectors of the Alaska-Canada Boundary Range. p. 33-35. In W. C. Mahaney (ed.) Quarternary environments: proceedings of a symposium. Geographical Monographs No. 5. Department of Geography, Atkinson College, York University, Toronto.

________________. 1974b. Pleistocene-Holocene sequences in the Alaska-Canada Boundary Range. p. 197-223. In National Geographic Society Research Reports, 1967 projects.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, Toronto.

Murtha, P. A. 1972. A guide to photo interpretation of forest damage in Canada. Canadian Forestry Service. Publication No. 1292.

__________. 1977. Remote sensing as a tool in ecological classification. p. 157-168. In Proceedings: Ecological classification of forest land in Canada and northwestern U.S.A. FP 2453/477.

__________ and E. K. Watson. 1976. Mapping of forest clearcutting, South Vancouver Island from Landsat imagery. p. 257-263. In Proc. Third Can. Symp. Remote Sens.

National Academy of Sciences. 1971. Remote sensing: with special reference to agriculture and forestry. Washington, D. C.

Nimlos, T. J. and R. C. McConnell. 1962. The morphology of alpine soils in Montana. Northwest Science. 36(4): 99-112.

Oswald, E. T. 1976. Terrain analysis from Landsat imagery. Forest Chron. 42(6): 274-281.

Peterson, R. M., G. R. Cochrane, S. A. Morain and D. S. Simonett. 1969. A multi-sensor study of plant communities at Horsefly Mountain, Oregon. p. 63-94. In P. L. Johnson (ed.) Remote sensing in ecology. University of Georgia Press. Athens.

Pojar, J. 1977. Vegetation and some plant-animal relationships of Ecological Reserve #68, Gladys Lake. Unpublished report of Ecological Reserves Unit, Land Management Branch, Department of Environment, Victoria, B. C.

Poore, M. E. D. 1955. The use of phytosociological methods in ecological investigations. I. The Braun-Blanquet system. II. Practical issues involved in an attempt to apply the Braun-Blanquet system. III. Practical applications. J. Ecol. 43: 226-244, 245-269, 606-651.

__________. 1956. The use of phytosociological methods in ecological investigations. IV. General discussion of phytosociological problems. J. Ecol. 44: 28-50.

__________. 1962. The method of successive approximation in descriptive ecology. Adv. Ecol. Res. 1: 35-68.

Poore, M. E. D. 1964. Integration in the plant community. J. Ecol. 52 (suppl.): 213-226.

Poulton, C. E. 1972. A comprehensive remote sensing legend for the ecological characterization and annotation of natural and altered landscapes. p. 393-408. In Proc. Eighth Internat. Symp. Remote Sens. Environ.

Price, L. W. 1972a. The periglacial environment, permafrost, and man. Commission on College Geography, Resource Paper No. 14. Association of American Geographers, Washington, D. C.

__________. 1972b. Vegetation, microtopography, and depth of active layer on different exposures in subarctic alpine tundra. p. 211-220. In V. C. Bushnell and R. H. Ragle (eds.) Icefield Ranges Research Project, Scientific Results. Vol. 3. American Geographical Society, N. Y. and Arctic Institute of North America, Montreal.

Reed, J. C. 1968. Remote sensing of the polar regions. p. 479-481. In Proceedings of the Fifth Symposium on Remote Sensing of Environment. Univ. of Michigan, Ann Arbor.

Retzer, J. L. 1956. Alpine soils of the Rocky Mountains. J. Soil Sci. 7(1): 22-32.

__________. 1965. Present soil-forming factors and processes in arctic and alpine regions. Soil Science 99: 38-44.

__________. 1974. Alpine soils. p. 771-801. In J. D. Ives and R. G. Barry (eds.) Arctic and alpine environments. Methuen, London.

Sanderson, M. 1948. The climates of Canada according to the new Thornthwaite classification. Sci. Agri. 28: 501-517.

Savile, D. B. O. 1972. Arctic adaptations in plants. Monograph No. 6. Research Branch, Canada Department of Agriculture.

Schurholz, G. and J. Larsson. 1973. Falschfarbenbilder für die Vegetationskartierung. Allgemeine Forst und Jagdzeitung. 144. Jg. 5/6: 111-117.

Scott, R. W. 1974a. Alpine plant communities of the southeastern Wrangell Mountains, Alaska. p. 283-306. In V. C. Bushnell and R. H. Ragle (eds.) Icefield Ranges Research Project, Scientific Results. Vol. 4. American Geographical Society. N. Y. and Arctic Institute of North America, Montreal.

__________. 1974b. The effect of snow duration on alpine plant community composition and distribution. p. 307-318. In V. C. Bushnell and R. H. Ragle (eds.) Icefield Ranges Research Project, Scientific Results. Vol. 4. American Geographical Society, N. Y. and Arctic Institute of North America, Montreal.

Scott, R. W. 1974c. The vegetation of Chitistone, Skolai and Frederika valleys, Alaska. p. 331-337. In V. C. Bushnell and R. H. Ragel (eds.) Icefield Ranges Research Project, Scientific Results. Vol. 4. American Geographical Society, N. Y. and Arctic Institute of North America, Montreal.

Sigafoos, R. S. 1951. Some botanical problems in the interpretation of aerial photographs of tundra areas. Photogr. Engr. 16:429-431.

Sneddon, J. I., L. M. Lavkulich, and L. Farstad. 1972. Morphology and Genesis of some alpine soils in British Columbia, Canada. I. Morphology, classification and genesis. Soil Sci. Amer. Proc. 36: 100-104.

Stephens, P. R. 1976. Comparison of color, color infrared, and panchromatic aerial photography. Photogrammetric Engineering and Remote Sensing. 42(10): 1273-1277.

Tarnocai, C. 1972. The use of remote sensing techniques to study peatland and vegetation types, organic soils and permafrost in the boreal region of Manitoba. p. 323-335. In Proceedings of the First Canadian Symposium on Remote Sensing. Ottawa.

Taylor, R. L. and B. MacBryde. 1977. Vascular plants of British Columbia -- A descriptive resource inventory. Tech. Bull. No. 4. U.B.C. Botanical Garden. University of British Columbia Press, Vancouver.

Thie, J. 1972. Application of remote sensing techniques for description and mapping of forest ecosystems. p. 149-169. In Proc. First Can. Symp. Remote Sens. Ottawa.

Thomson, J. W. 1967. The lichen genus Cladonia in North America. University of Toronto Press, Toronto.

van Ryswyk, A. L. 1969. Forest and alpine soils of south-central British Columbia. Unpublished Ph.D. thesis. Washington State University.

Viereck, L. A. and E. L. Little, Jr. 1972. Alaska trees and shrubs. Agricultural handbook no. 410. Forest Service, United States Department of Agriculture. Washington, D. C.

Washburn, A. L. 1956. Classification of patterned ground and review of suggested origins. Geol. Soc. America Bull. 67: 823-865.

______________. 1973. Periglacial processes and environments. Edward Arnold Ltd., London.

Watson, E. K. 1977. A remote sensing based multilevel rangeland classification for the Lac-du-bois rangelands, Kamloops, British Columbia. Unpublished M.Sc. thesis. University of British Columbia, Vancouver.

Welsh, S. L. 1974. Anderson's flora of Alaska and adjacent parts of Canada. Brigham Young University Press, Provo, Utah.

Welsh, S. L. and J. K. Rigby. 1971. Botanical and physiographic reconnaissance of northern British Columbia. Brigham Young Univ. Sci. Bull. Biol. Ser. 14(4): 1-49.

Whittaker, R. H. 1956. Vegetation of the Great Smoky Mountains. Ecol. Monogr. 26: 1-80.

______________. 1962. Classification of natural communities. Bot. Rev. 28: 1-239.

Willard, B. and J. Marr. 1970. Effects of human activities on alpine tundra ecosystems in Rocky Mountain National Park, Colorado. Biological Conservation 2: 257-265.

______________________. 1971. Recovery of alpine tundra under protection after damage by human activity in the Rocky Mountains of Colorado. Biological Conservation 3: 181-190.

Wilson, J. W. 1958. Dirt on snow patches. J. Ecol. 46: 191-198.

___________. 1959. Notes on wind and its effects in arctic-alpine vegetation. J. Ecol. 45: 415-427.

Worsfold, R. D. 1976. Color compensating filters with infrared film. Photogrammetric Engineering and Remote Sensing. 42(11): 1385-1398.

Young, G. K. and N. F. Alley. The northern and central plateaus and mountains. In K. W. G. Valentine, P. N. Sprout, T. E. Baker and L. M. Lavkulich (eds.) The soil landscapes of British Columbia. Resource Analysis Branch, Ministry of Environment, Victoria, British Columbia. (In press).

Zwinger, A. H. and B. E. Willard. 1972. Land above the trees: a guide to American alpine tundra. Harper and Row, New York.

APPENDIX A

Vascular Plants Occurring in the Alpine Zone of Teresa Island

A total of 161 taxa of vascular plants were identified from collections made in 1971, 1974, 1975 and 1976. Thirty-eight families are represented. In the following list, the habitat type for each species is recorded. Relative abundance within a habitat type is indicated by: 'a', abundant; 'c', common; 'o', occasional; 'r', rare; and '-', absent. Nomenclature is according to Taylor and MacBryde (1977). Identification was facilitated by reference to Hultén (1968) and Welsh (1974): I, fellfields and blockfields; II, snowbeds; III, drainage areas; IV, meadows and shrubfields. Asterisks signify an SFUV specimen with no recorded habitat data.

Taxa	Habitat types			
	I	II	III	IV
LYCOPODIACEAE				
Lycopodium alpinum L.	r	c	-	r
L. clavatum L.	-	-	r	-
L. complanatum L.	-	-	r	-
Huperzia selago (L.) Bernh.	-	c	o	o
SELAGINELLACEAE				
Selaginella sibirica (Milde) Hieron.	-	-	-	o
EQUISETACEAE				
Equisetum palustre L.	-	c	c	-
E. scirpoides Michx.	-	o	o	-
ASPLENIACEAE				
Cystopteris fragilis (L.) Bernh.	o	-	-	-
Dryopteris fragrans (L.) Schott	r	-	-	-
OPHIOGLOSSACEAE				
Botrychium lunaria (L.) Sw.	r	-	-	-
CUPRESSACEAE				
Juniperus communis L. ssp. *alpina* (Neilr.) Celakov.	-	r	-	-
PINACEAE				
Abies lasiocarpa (Hook.) Nutt. ssp. *lasiocarpa*	-	o	-	-
Pinus contorta Dougl. var. *latifolia* Engelm.	-	o	-	-
ASTERACEAE				
Agoseris aurantiaca (Hook.) Greene var. *aurantiaca*	-	-	-	o
Antennaria alpina (L.) Gaertn. var. *media*	c	o	-	r
A. microphylla Rydb.	-	-	-	r
A. monocephala DC.	a	c	-	-
Arnica alpina (L.) Olin ssp. *attenuata* (Greene) Maguire	o	-	-	-
A. cordifolia Hook.	-	-	-	c

Taxa	Habitat Types I	II	III	IV
A. latifolia Bong. var. latifolia	-	-	r	-
A. louiseana Farr. ssp. frigida (C.A. Mey.) Welsh	r	-	-	-
Artemisia arctica Less. ssp. arctica	c	c	a	a
*A. michauxiana Bess.				
Erigeron acris L. ssp. debilis (Gray) Piper	r	-	-	-
E. humilis Graham	-	c	-	-
Hieracium gracile Hook.	-	c	-	-
Petasites frigidus (L.) Fries var. frigidus	-	-	o	-
P. nivalis Greene	-	-	c	-
Senecio lugens Richards.	-	-	o	o
S. sheldonensis Pors.	-	-	-	o
S. triangularis Hook	-	-	c	o
S. yukonensis Pors.	o	-	c	-
Solidago multiradiata Ait. var. multiradiata	c	-	o	o
Taraxacum lyratum (Ledeb.)DC.	o	o	-	r
BETULACEAE				
Betula glandulosa Michx. var. glandulosa	c	c	o	o
BORAGINACEAE				
Mertensia paniculata (Ait.) G. Don	-	-	-	c
Myosotis asiatica (Vestergr.) Schischk.	o	-	-	-
BRASSICACEAE				
Cardamine bellidifolia L.	-	c	-	r
Draba alpina L.	-	o	-	-
D. borealis DC.	-	-	-	o
D. crassifolia Graham	-	o	-	o
D. densifolia Nutt.	o	-	-	-
D. incerta Payson	o	-	-	r
D. lactea Adams	-	-	r	-
D. nivalis Lilj.	c	-	-	-
D. stenoloba Ledeb.	-	-	-	o
CAMPANULACEAE				
Campanula lasiocarpa Cham. ssp. lasiocarpa	c	o	-	o
CARYOPHYLLACEAE				
Cerastium beeringianum Cham. & Schlecht. ssp. beeringianum	r	-	-	r
Minuartia obtusiloba (Rydb.) House	-	o	-	o
M. rubella (Wahl.) Hiern	r	-	-	r
Silene acaulis (L.) N. J. Jacquin ssp. acaulis	c	o	-	o
Stellaria longipes Goldie var. edwardsii (R. Br.) Gray	a	o	-	c
CRASSULACEAE				
Sedum lanceolatum Torr. var. lanceolatum	r	-	-	-
S. rosea (L.) Scop. ssp. integrifolium (Raf.) Hult.	o	-	c	o
EMPETRACEAE				
Empetrum nigrum L. ssp. hermaphroditum (Hagerup) Bocher	c	o	c	o
ERICACEAE				
Arctostaphylos rubra (Rehd. & Wilson) Fern.	r	-	-	-
A. uva-ursi (L.) Spreng.	r	-	-	-
Cassiope mertensiana (Bong.) D. Don var. mertensiana	-	o	o	o
C. stelleriana (Pall.) DC.	-	c	c	-
C. tetragona (L.) D. Don var. tetragona	r	a	-	a
Kalmia microphylla (Hook.) Heller ssp. microphylla	-	o	o	-
Ledum palustre L. ssp. decumbens (Ait.) Hult.	o	-	-	o
Loiseleuria procumbens (L.) Desv.	o	-	-	o

Taxa	Habitat Types			
	I	II	III	IV
Phyllodoce empetriformis (Sm.) D. Don	-	c	-	-
Vaccinium uliginosum L. ssp. *microphyllum* Lange	a	-	-	o
V. vitis -idaea L. ssp. *minus* (Lodd.) Hult.	c	-	-	o
FABACEAE				
Lupinus arcticus Wats. ssp. *arcticus*	a	-	-	-
L. kuschei Eastw.	r	-	-	-
Oxytropis huddelsonii Pors.	o	-	-	-
GENTIANACEAE				
Gentiana glauca Pall.	o	c	c	c
GERANIACEAE				
Geranium erianthum DC.	-	-	-	c
GROSSULARIACEAE				
Ribes triste Pall.	r	-	-	-
ONAGRACEAE				
Epilobium anagallidifolium Lamarck	-	c	c	o
E. angustifolium L.	-	c	-	-
E. lactiflorum Hausskn.	-	r	-	-
E. latifolium L.	-	r	-	o
PAPAVERACEAE				
Papaver kluanense Love	r	-	-	-
PARNASSIACEAE				
Parnassia fimbriata Konig	-	-	r	-
POLEMONIACEAE				
Polemonium pulcherrimum Hook.	-	-	-	o
POLYGONACEAE				
Bistorta vivipara (L.) Gray	o	-	a	c
Oxyria digyna (L.) Hill	-	c	-	-
PORTULACACEAE				
Claytonia sarmentosa C. A. Mey.	-	-	c	-
PRIMULACEAE				
Androsace septentrionalis L.	r	-	-	-
PYROLACEAE				
Pyrola asarifolia Michx. var. *purpurea* (Bunge) Fern.	-	-	-	r
P. grandiflora Radium	o	-	-	o
RANUNCULACEAE				
Aconitum delphinifolium DC. ssp. *delphinifolium*	-	o	c	c
Anemone richardsonii Hook.	-	o	-	r
Caltha leptosepala DC.	-	-	o	-
Pulsatilla patens (L.) Miller ssp. *multifida* (Pritzel) Zamels	o	-	-	-
Ranunculus eschscholtzii Schlecht. var. *eschscholtzii*	-	o	a	o
R. nivalis L.	-	-	c	-
R. pygmaeus Wahl.	-	c	-	-
ROSACEAE				
Dryas integrifolia M. Vahl. ssp. *integrifolia*	o	-	-	-
D. octopetala L. ssp. *octopetala*	a	-	-	o
Luetkea pectinata (Pursh) Kuntze	-	c	c	o
Potentilla diversifolia Lehm. var. *diversifolia*	-	-	c	c
**P. hookeriana* Lehm.				
P. hyparctica Malte	c	-	-	o
P. uniflora Ledeb.	o	-	-	r
Rosa acicularis Lindl. ssp. *sayi* (Schwein.) Lewis	-	r	-	-
Rubus arcticus L. ssp. *acaulis* (Michx.) Focke	-	-	-	r

Taxa	Habitat Types I	II	III	IV
Sanguisorba canadensis L. ssp. latifolia (Hook.) Calder & Taylor	-	-	o	-
Sibbaldia procumbens L.	-	a	c	-
Sorbus sitchensis L.	-	-	-	r
SALICACEAE				
Salix arctica Pall.	-	o	-	o
S. barrattiana Hook.	-	-	-	o
S. brachycarpa Nutt. ssp. niphoclada (Rydb.) Argus	-	c	-	c
S. planifolia Pursh ssp. pulchra (Cham.) Argus	o	c	a	c
S. polaris Wahl.	a	a	a	a
S. reticulata L.	o	c	c	c
SAXIFRAGACEAE				
Leptarrhena pyrolifolia (D. Don) R. Br.	-	-	r	-
Saxifraga bronchialis L. ssp. funstonii (Small) Hult.	a	-	-	-
S. cernua L.	o	-	-	r
S. cespitosa L. ssp. sileneflora (Sternb.) Hult.	o	-	-	-
S. ferruginea Grah.	-	c	o	o
S. lyallii Engler ssp. hultenii (Calder & Savile) Calder & Savile	-	-	o	-
S. nelsoniana D. Don ssp. porsildiana (Calder & Savile) Hult.	-	-	a	-
S. nivalis L.	-	o	-	-
S. oppositifolia L.	o	r	-	-
S. rivularis L. var. flexuosa (Sternb.) Eng. & Irmsch.	c	o	-	c
S. tricuspidata Rottb.	a	-	-	o
SCROPHULARIACEAE				
Castilleja unalaschcensis (Cham. & Schlecht.) Malt.	-	c	-	c
Pedicularis capitata Adams	o	o	c	c
P. labradorica Wirsing	r	-	-	r
P. langsorfii Fisch. ssp. arctica (R. Br.) Pennell	c	-	o	c
Veronica wormskjoldii Roem. & Schult. var. wormskjoldii	-	c	c	c
VALERIANACEAE				
Valeriana sitchensis Bong. ssp. sitchensis	-	-	-	r
VIOLACEAE				
Viola epipsila Ledeb. ssp. repens (Turcz.) Becker	-	-	-	r
CYPERACEAE				
Carex albonigra Mack.	o	-	-	-
C. bipartita All.	o	c	c	-
C. capitata L.	-	-	-	o
C. microchaeta Holm	c	c	c	c
C. nardina Fries	r	-	-	-
C. nigricans C. A. Mey.	-	o	-	-
C. phaeocephala Piper	-	-	-	o
C. podocarpa R. Br.	-	o	a	o
C. pyrenaica Wahl. ssp. micropoda (C. A. Mey.) Hult.	-	c	-	o
*C. spectabilis Dewey				
Eriophorum scheuchzeri Hoppe	-	-	o	-
Kobresia myosuroides (Vill.) Fiori & Paol.	-	r	-	-
POACEAE				
Calamagrostis canadensis (Michx.) Beav. ssp. canadensis var. canadensis	-	-	c	-
C. lapponica (Wah.) Hertm. var. nearctica Pors.	-	-	-	o

Taxa	Habitat Types I	II	III	IV
*C. purpurascens R. Br. ssp. purpurascens				
Festuca altaica Trin.	a	o	o	a
F. brachyphylla Schult.	a	-	-	c
Hierochloe alpina (Swartz) Roem. & Schult. ssp. alpina	c	c	-	o
Phleum alpinum L. var. commutatum (Gaudin) Grisebach	-	-	-	o
Poa arctica R. Br.	c	o	o	-
P. glauca Vahl	o	-	-	-
P. leptocoma Trin. var. paucispicula (Scribn. & Merr.) Hitchc.	-	c	a	-
P. lettermanii Vasey	o	-	-	-
Trisetum spicatum (L.) Richter	c	o	-	r
*Vahlodea atropurpurea (Wahl.) Fries ssp. paramushirensis (Kudo) Hult.				
JUNCACEAE				
Juncus biglumis L.	-	-	o	o
*J. castaneus J. E. Smith var. castaneus				
J. drummondii E. Meyer	-	c	-	-
Luzula arcuata (Wahl.) Swartz ssp. unalaskensis (Buch.) Hult.	-	-	c	o
L. confusa Lindeb.	c	-	-	o
L. multiflora (Retz.) Lej. var. frigida (Buch.) Sam.	-	o	o	-
L. multiflora (Retz.) Lej. ssp. multiflora var. multiflora	-	-	o	-
L. spicata (L.) DC.	c	-	-	c
L. wahlenbergii Rupr.	-	-	o	r

Checklist of cryptogams occurring in the alpine zone of Teresa Island

Musci

Andreaea rupestris var. alpestris (Thed.) Sharp
Aulacomnium palustre (Hedw.) Schwaegr.
A. turgidum (Wg.) Schwaegr.
Bartramia ithyphylla Brid.
Brachythecium sp.
Brachythecium albicans (Hedw.) B.S.G.
B. campestre (C.Muell.) B.S.G.
B. salebrosum (Web.+ Mohr) B.S.G.
Bryum sp.
Bryum creberrimum Tayl.
B. cryophilum Mart.
Calliergon sarmentosum (Wahlenb.) Kindb.
C. stramineum (Dicks.) Kindb.
Ceratodon purpureus (Dedw.) Brid.
Cnestrum shistii (Wg.) Hag.
Cynodontium strumiferum (Hedw.) Lindb.
Desmadodon latifolius (Hedw.) Lindb.
Dicranoweisia crispula (Hedw.) Lindb.
Dicranum elongatum Schleich. ex Schwaegr.
D. fuscescens Turn.
D. muhlenbeckii B.S.G.
D. pallidisetum (Bail. ex Holz.) Irel.
D. scoparium Hedw.
Distichium capillaceum (Hedw.) B.S.G.
Drepanocladus exannulatus (B.S.G.) Warnst.
D. uncinatus (Hedw.) Warnst.
Encalyptra rhabdocarpa Schwaegr.
Eurhynchium pulchellum (Hedw.) Jenn.
Grimmia apocarpa (L.) Hedw.
Hygrohypnum luridum (Hedw.) Jenn.
H. styriacum Broth.
Hylocomium alaskanum Lesq.+ Jam.
Kiaria blyttii (Schimp.) Broth.
K. falcata (Hedw.) Hag.
K. starkei (Web. ex Mohr) Hag.
Paludella squarrosa (Hedw.) Brid.
Paraleucobryum enerve (Thed. ex C.J.Hartm.) Loeske
Philonotis fontana var. pumila (Turn.) Brid.
Plagiomnium ellipticum (Brid.) Kop.
P. rostratum (Schrad.) Kop.
Plagiothecium denticulatum (Hedw.) B.S.G.
Pleurozium schreberi (Brid.) Mitt.
Pohlia cruda (Hedw.) Lindl.
P. nutans (Hedw.) Lindl.
P. proligera (Kindb. ex Limpr.) Lindb.
P. wahlenbergii (Web.+ Mohr) Andr.
Polytrichum alpestre Hoppe + Hornsch.

Polytrichum alpinum (Hedw.) Roehl.
P. piliferum Hedw.
Rhacomitrium canescens (Hedw.) Brid.
R. lanuginosum (Hedw.) Brid.
R. sudeticum (Funck) B.S.G.
Sphagnum girgensohnii Russ.
S. nemoreum Scop.
Splachnum ovatum Hedw.
Stegonia latifolia (Schwaegr. ex Schultes) Vent ex Broth.
Tomenthypnum nitens (Hedw.) Loeske.
Tortula ruralis (Hedw.) Gaertn.

Hepaticae
Anastrophyllum minutum (Schreb. ex Cranz) Schust.
Anthelia juratzkana (Limpr.) Trev.
Asterella ludwigii (Schwaegr.) Und.
Barbilophozia hatcheri Loeske
B. lycopodioides Loeske
Blepharostoma trichophyllum (L.) Dum.
Cephalozia sp.
Chandonanthus setiformis (Ehrh.) Lindb.
Diplophyllum taxifolium (Wahlenb.) Dum.
Gymnomitrion corallioides Nees
Lophocolea minor Nees
Lophozia longidens (Lindb.) Mac.
L. opacifolia Culmann
L. ventricosa (Dicks.) Dum.
L. wenzelii (Nees) Steph.
Marsupella sp.
Orthocaulis kunzeanus Buch
Pleuroclada albescens (Hook.) Spruce
Ptlidium ciliare (L.) Hampe
Scapania sp.
Tritomaria quinquedentata (Huds.) Buch
T. scitula (Tayl.) Joerg.

Lichens
Alectoria minuscula (Nyl. ex Arnold) Degel
A. nigricans (Ach.) Ny.
A. ochroleuca (Hoffm.) Mass.
Cetraria commixta (Nyl.) Th.Fr.
C. cucullata (Bell.) Ach.
C. delisei (Bory) Th.Fr.
C. ericetorum Opiz.
C. hepatizon (Ach.) Vain.
C. islandica (L.) Ach.
C. laevigata (Sm.) Ach.
C. nivalis (L.) Ach.
C. pinastri (Scop.) S.Gray
C. richardsonii Hook.
C. tilesii Ach.
Cladina arbuscula (Wallr.) Rabenh.
C. mitis Sandst.
C. rangiferina (L.) Wigg.
C. tenuis (Flörke) Harm.

Cladonia amaurocraea (Flörke) Schaer.
C. bellidifolia (Ach.) Schaer.
C. carneola (Fr.) Fr.
C. cenotea (Ach.) Schaer.
C. chlorophaea (Flörke ex Somm.) Spreng. ex Asah.
C. coccifera (L.) Willd.
C. crispata (Ach.) Flot.
C. ecmocyna (Ach.) Nyl.
C. fimbriata (L.) Fr.
C. gonecha (Ach.) Asah.
C. gracilis (L.) Willd.
C. lepidota Nyl.
C. macrophylla (Schaer.) Stenham.
C. pocillum (Ach.) O.Rich.
C. pyxidata (L.) Hoffm.
C. uncialis (L.) Wigg.
C. verticillata (Hoffm.) Schaer.
Cornicularia aculeata (Schreb.) Ach.
C. muricata (Ach.) Ach.
Dactylina arctica (Hook.) Nyl.
D. ramulosa (Hook.) Tuck.
Dermatocarpon rivulorum (Arnold) D.T.+ Sarnth.
Hypogymnia oroarctica Krog
Lobaria linita (Ach.) Rabenh.
Nephroma arcticum (L.) Torss.
N. expallidum (Nyl.) Nyl.
Ochrolechia frigida (Sw.) Lynge
Parmelia centrifuga (L.) Ach.
P. stygia (L.) Ach.
Parmeliopsis hyperopta (Ach.) Arn.
Peltigera aphthosa (L.) Willd.
P. canina (L.) Willd.
Pertusaria dactylina (Ach.) Nyl.
Rhizocarpon geographicum (L.) DC.
Solorina crocea (L.) Ach.
Stereocaulon arcticum Lynge
S. botryosum Ach.
S. paschale (L.) Hoffm.
S. tomentosum Fr.
Thamnolia vermicularis (Sw.) Ach.
T. subuliformis (Ehrb.) Culb.
Umbilicaria cylindrica (L.) Del.
U. deusta (L.) Baumg.
U. hyperborea (Ach.) Ach.
U. proboscoidea (L.) Schrad.

Appendix B

Symbolic and Technical Legend Classes (After Legge, *et. al.*, 1974)

EARTH SURFACE AND LAND-USE FEATURES

PRIMARY CLASSES

100 - BARREN LAND
200 - WATER RESOURCES
300 - NATURAL VEGETATION
400 - CULTURAL VEGETATION
500 - AGRICULTURAL PRODUCTION
600 - URBAN, INDUSTRIAL, TRANSPORTATION
700 - EXTRACTIVE INDUSTRY, NATURAL DISASTERS
800 - RECREATION AND OPEN SPACE-RELATED
900 - OBSCURED LAND

PRIMARY CLASSES

- SECONDARY CLASSES
  - TERTIARY CLASSES
    - QUATERNARY CLASSES

100 - BARREN LAND
- 110 - Playas, dry, or intermittent lake basins
- 120 - Aeolian barrens (other than beaches and beach sand)
  - 121 - Dunes
  - 122 - Sandplains
  - 123 - Blowouts
- 130 - Rocklands
  - 131 - Bedrock outcrops (intrusive & erosion-bared strata)
  - 132 - Extrusive igneous (lava flows, pumice, cinder and ash)
  - 133 - Gravels, stones, cobbles & boulders (usually transported)
  - 134 - Scarps, talus and/or colluvium (system of outcropping strata)
  - 135 - Patterned rockland (nets or stripes)
- 140 - Shorelines, beaches, tide flats, and river banks
- 150 - Badlands (barren silts and clays, related metamorphic rocks and erosional wastes)
- 160 - Slicks (saline, alkali, soil structural, non-playa barrens)
- 170 - Mass movement
- 190 - Undifferentiated complexes of barren lands

200 - WATER RESOURCES
- 210 - Ponds, lakes, and reservoirs
  - 211 - Natural lakes and ponds
  - 212 - Man-made reservoirs and ponds
- 220 - Water courses
  - 221 - Natural water courses
  - 222 - Man-made water courses

PRIMARY CLASSES

SECONDARY CLASSES

TERTIARY CLASSES

QUATERNARY CLASSES

- 230 - Seeps, springs and wells
  - 231 - Seeps and springs
  - 232 - Wells
- 240 - Lagoons and bayous
- 250 - Estuaries
- 260 - Bays and coves
- 270 - Oceans, seas, and gulfs
- 280 - Snow and Ice
  - 281 - Seasonal snow cover
  - 282 - Permanent snow fields and glaciers
- 290 - Undifferentiated water resources

300 - NATURAL VEGETATION
- 310 - Herbaceous types
  - 311 - Lichen, cryptogam, and related communities
  - 312 - Prominently annuals
  - 313 - Forb types
  - 314 - Grassland, steppe, and prairie
  - 315 - Meadows
  - 316 - Marshes
  - 317 - Bogs and muskegs
  - 319 - Undifferentiated complexes of herbaceous types
- 320 - Shrub/Scrub Types
  - 321 - Microphyllous, non-thorny scrub
  - 322 - Microphyllous thorn scrub
  - 323 - Succulent and cactus scrub
  - 324 - Halophytic shrub
  - 325 - Shrub steppe
  - 326 - Sclerophyllous shrub
  - 327 - Macrophyllous shrub
    - 327.1 - Willow (Salix) Predominant Vegetation
    - 327.2 - Birch (Betula) Predominant Vegetation
    - 327.3 - Alder (Alnus)Predominant Vegetation
    - 327.4 - Mixed Shrub (Prunus/Symphoricarpos/Crataegus)
    - 327.9 - Undifferentiated Shrub-Types
  - 328 - Microphyllous dwarf shrub
    - 328.1 - Spruce-Fir (Picea-Abies) Krummholz Types
    - 328.2 - Mountain Heath Types (Vaccinium/Cassiope/Phyllodoce)
    - 328.3 - Mountain Avens Types (Dryas)
    - 328.4 - Juniper (Juniperus)-Bearberry (Arctostaphylos) Types
    - 328.9 - Undifferentiated
  - 329 - Undifferentiated complexes of shrub/scrub types
- 330 - Savanna-like Types
  - 331 - Tall shrub/scrub over herb layer
  - 332 - Broad-leaved tree over herb layer
  - 333 - Coniferous tree over herb layer

PRIMARY CLASSES

SECONDARY CLASSES

TERTIARY CLASSES

QUATERNARY CLASSES

- 334 - Mixed tree over herb layer
- 335 - Broad-leaved tree over low shrub layer
- 336 - Coniferous tree over low shrub layer
- 337 - Mixed tree over low shrub layer
- 339 - Undifferentiated complexes of savanna-like types

340 - Forest and Woodland Types
- 341 - Conifer forests
  - 341.1 - Pine (*Pinus*) Prominent Vegetation
  - 341.2 - Douglas Fir (*Pseudotsuga*) Prominent
  - 341.3 - Pine/Spruce (*Pinus*/*Picea*)
  - 341.4 - Spruce (*Picea*) Prominent
  - 341.5 - Spruce/Fir (*Picea*/*Abies*)
  - 341.6 - Fir/Larch (*Abies*/*Larix*)
  - 341.9 - Undifferentiated
- 342 - Broadleaf Forests
  - 342.1 - Poplar (*Populus*) Prominent Vegetation
  - 342.2 - Birch (*Betula*) Prominent Vegetation
- 343 - Conifer-broadleaf mixed forests and woodlands
  - 343.1 - Pine/Poplar (*Pinus*/*Populus*)
  - 343.2 - Spruce/Poplar (*Picea*/*Populus*)
  - 343.3 - Douglas Fir/Poplar (*Pseudotsuga*/*Populus*)
- 344 - Broadleaf-conifer mixed forests and woodlands
  - 344.1 - Poplar/Pine (*Populus*/*Pinus*)
  - 344.2 - Poplar/Spruce (*Populus*/*Picea*)
  - 344.2 - Poplar/Douglas Fir (*Populus*/*Pseudotsuga*)
- 349 - Undifferentiated complexes of forest and woodland types

390 - Undifferentiated Natural Vegetation

400 - CULTURAL VEGETATION
- 410 - Cultural herbaceous types
  - 411-419 - Tertiary levels duplicate those of Natural Vegetation (300)
- 420 - Cultural shrub/scrub types
  - 421-429 - Tertiary levels duplicate those of Natural Vegetation (300)
- 430 - Cultural savanna-like types
  - 431-437, 439 - Tertiary levels duplicate those of Natural Vegetation (300)
- 440 - Cultural forest and woodland types
  - 441-443, 449 - Tertiary levels duplicate those of Natural Vegetation (300)
- 490 - Undifferentiated cultural vegetation types

500 - AGRICULTURAL PRODUCTION
- 510 - Field crops
- 520 - Vegetable and truck crops
- 530 - Tree, shrub, and vine crops

PRIMARY CLASSES

SECONDARY CLASSES

TERTIARY CLASSES

QUATERNARY CLASSES

- 540 - Pasture
- 550 - Horticultural specialties
- 560 - Non-producing fallow, transitional, or idle land
- 570 - Agricultural production facilities
- 580 - Aquaculture
- 590 - Undifferentiated agricultural production

600 - URBAN, INDUSTRIAL, AND TRANSPORTATION
- 610 - Residential
- 620 - Commercial and services
- 630 - Institutional
- 640 - Industrial
- 650 - Transportation, communications, and utilities
  - 651 - Man and Material Transport
    - 651.1 - Rail
    - 651.2 - Motor Vehicle
    - 651.3 - Water
    - 651.4 - Air
    - 651.5 - Trails, foot and animal
    - 651.9 - Undifferentiated
  - 652 - Utilities distribution
  - 653 - Power production
  - 654 - Communication
  - 655 - Sewer and solid waste
  - 659 - Undifferentiated
- 670 - Vacant plots and lots
- 690 - Undifferentiated urban

700 - EXTRACTIVE INDUSTRY AND NATURAL DISASTERS
- 710 - Non-Renewable Resource Extraction
  - 711 - Sand and Gravel
  - 712 - Rock quarrie
  - 713 - Petroleum Extraction - Gas and oil fields
  - 714 - Oil shale and sand extraction
  - 715 - Coal/peat
  - 716 - Non-metalic, chemical, fertilizer, etc.
  - 717 - Metalic
  - 719 - Undifferentiated
- 720 - Renewable resource extraction
  - 721 - Forest harvest
    - 721.1 - Clearcut Forest
    - 721.2 - Selective Forest Cut
  - 722 - Fisheries
  - 729 - Undifferentiated
- 730 - Natural disasters
  - 731 - Earth
  - 732 - Air

PRIMARY CLASSES

SECONDARY CLASSES

TERTIARY CLASSES

QUATERNARY CLASSES

733 - Fire
734 - Water
735 - Disease
739 - Undifferentiated

800 - RECREATION AND OPEN SPACE RELATED
810 - Natural greenways, open space and buffer zones
820 - Preservation areas and natural museums
830 - Improved and developed open space
840 - Historical and archeological sites
850 - Scenic views
860 - Rock hounding, paleontological sites
870 - Recreation facilities
880 - Designated destructive use areas
890 - Undifferentiated

900 - OBSCURED LAND
910 - Clouds and fog
920 - Smoke and haze
930 - Dust and sand storms
940 - Smog
990 - Undifferentiated obscured land

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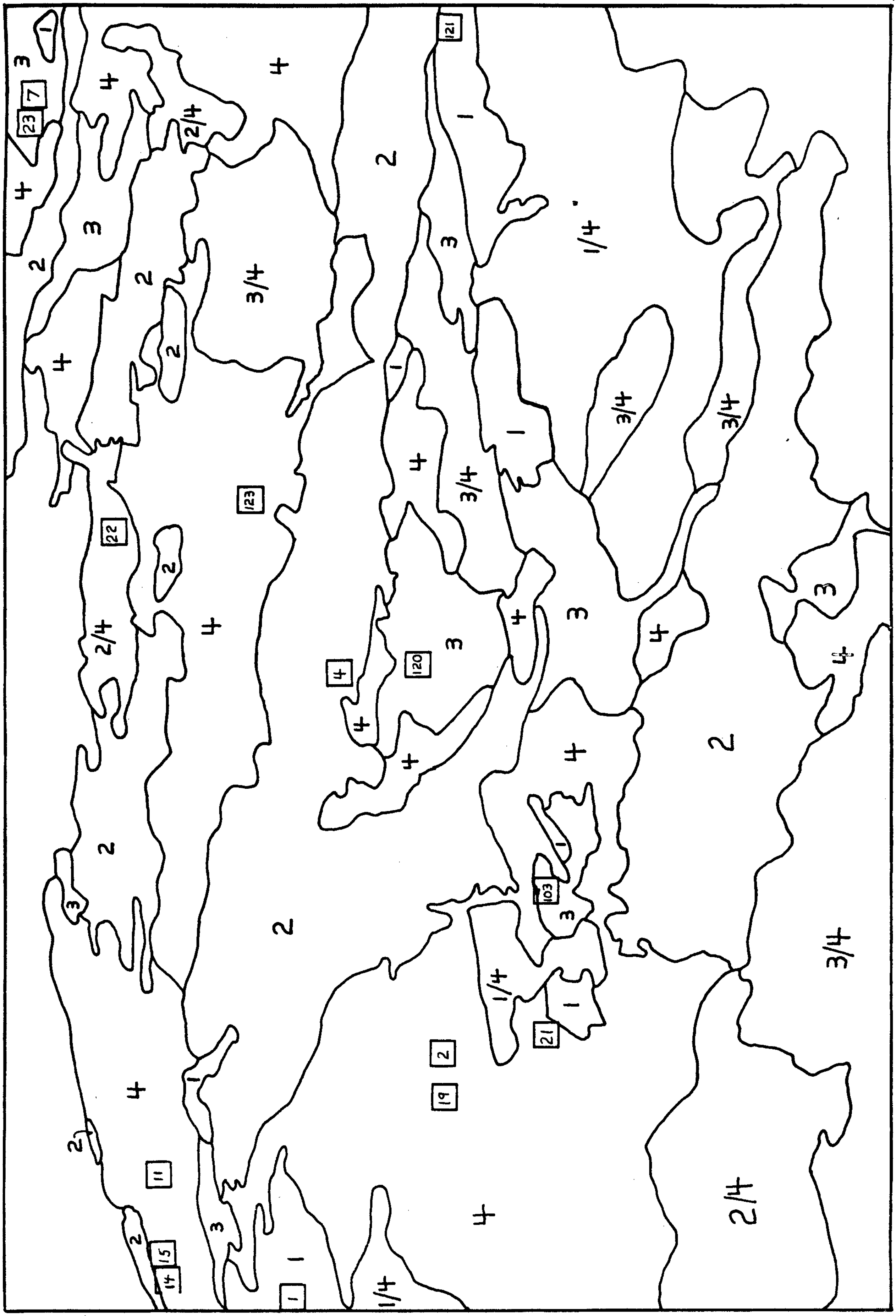

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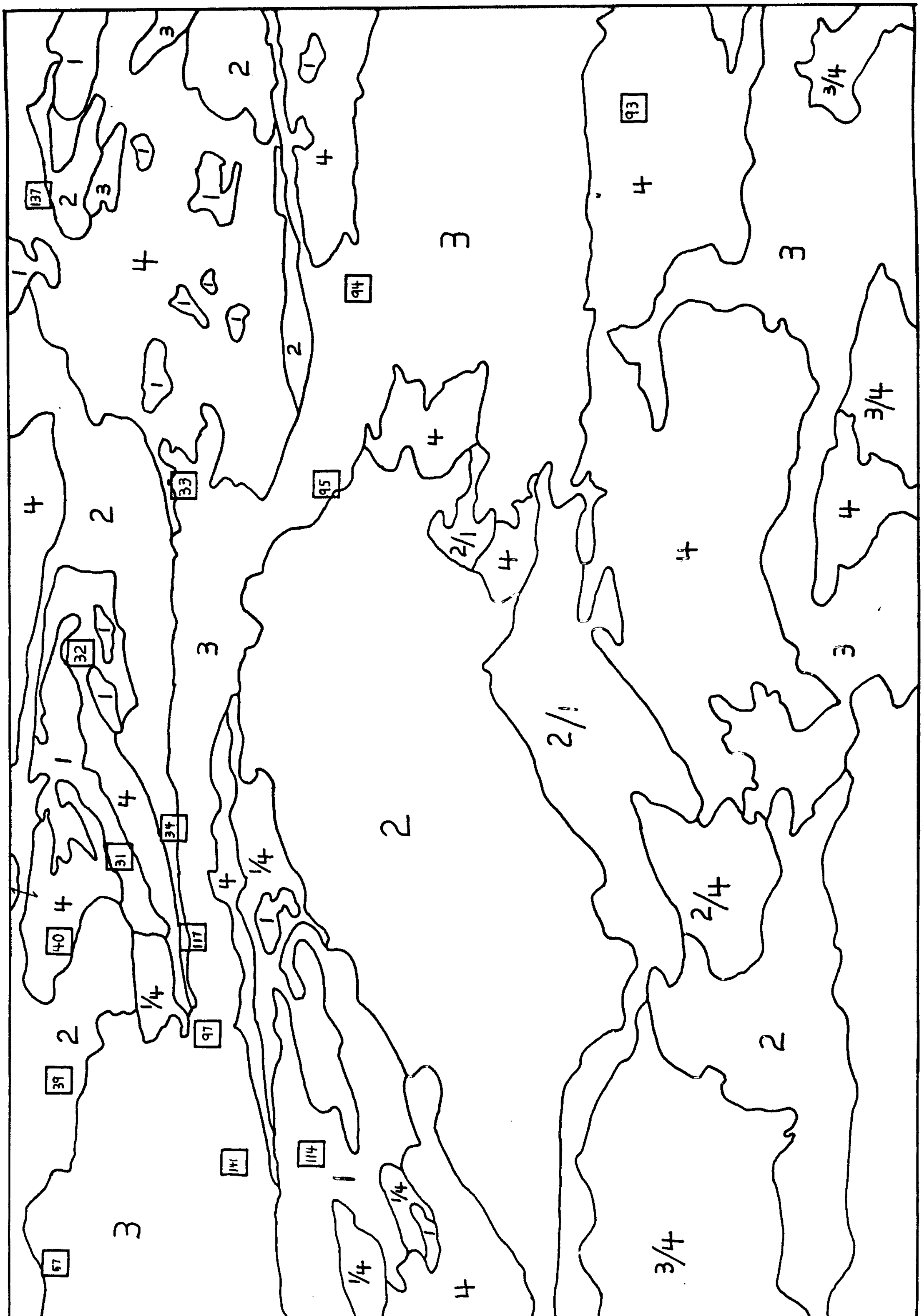

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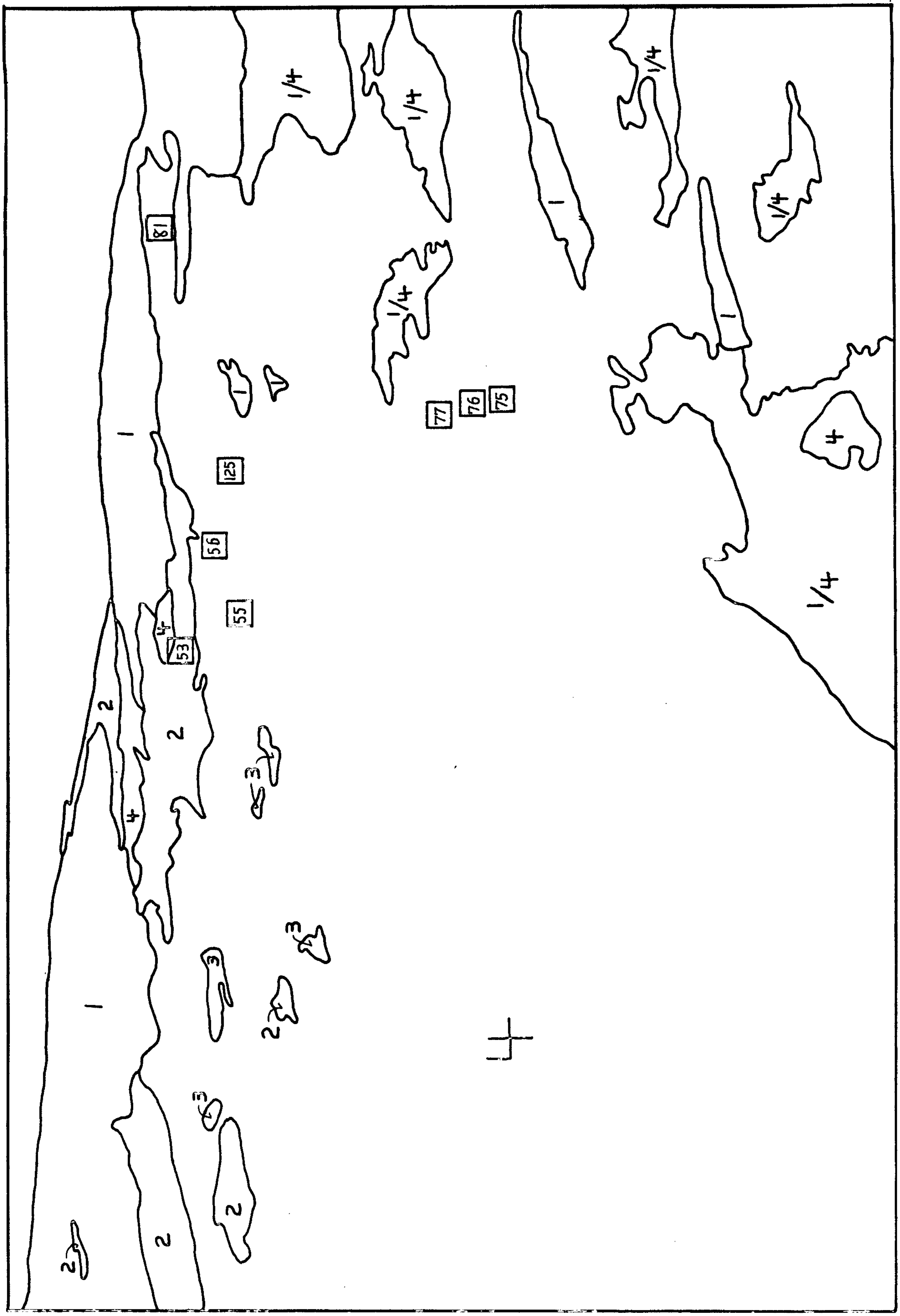

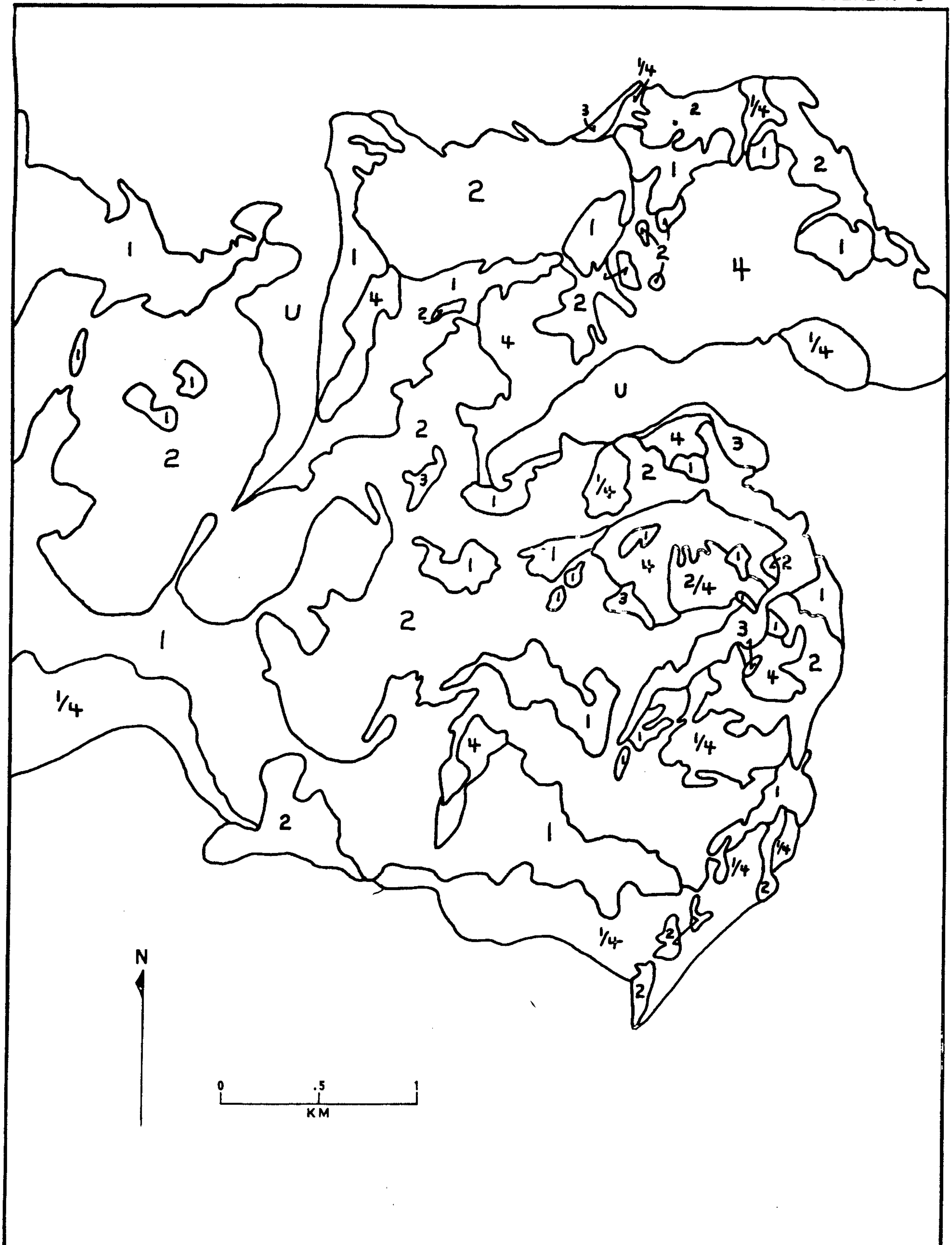

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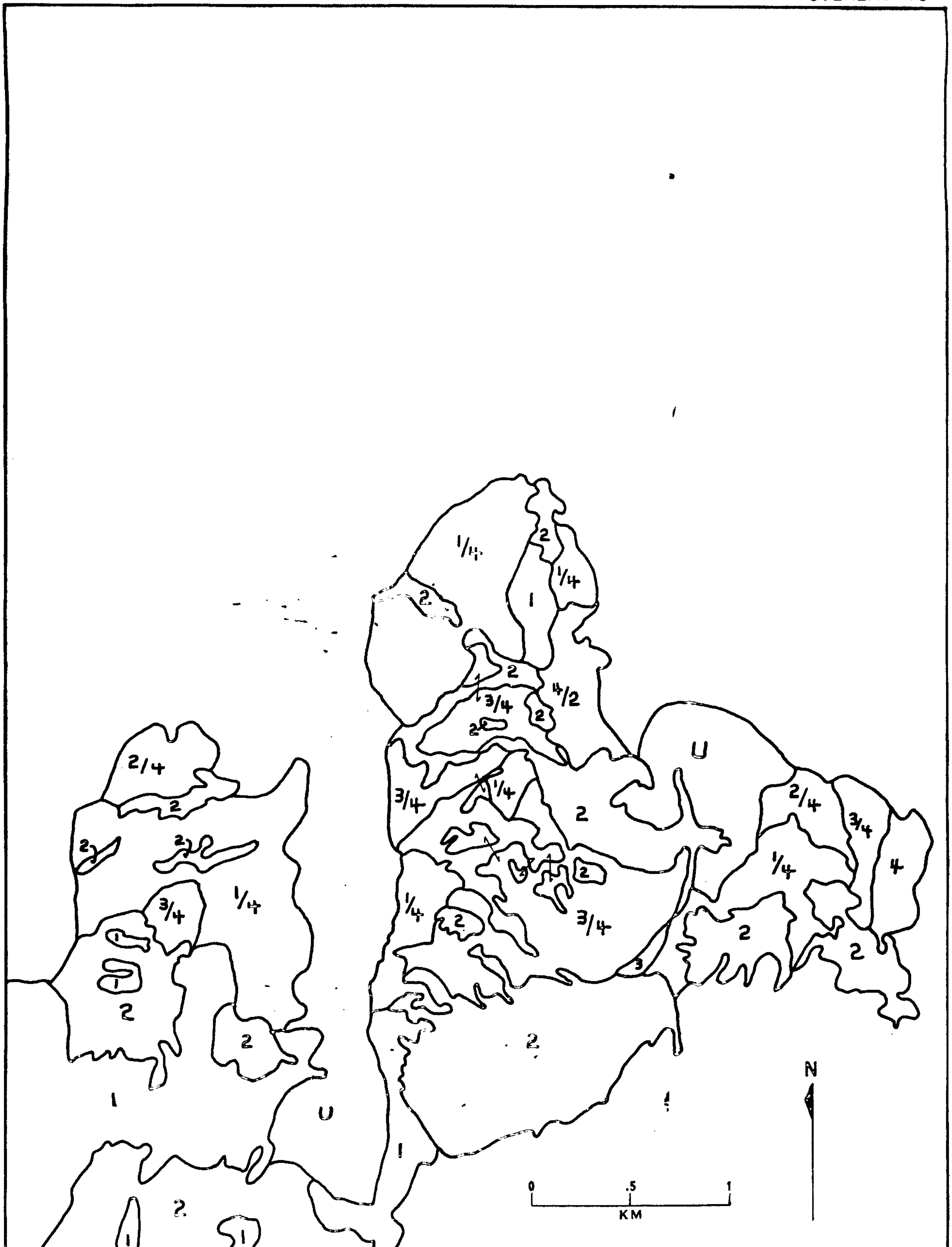

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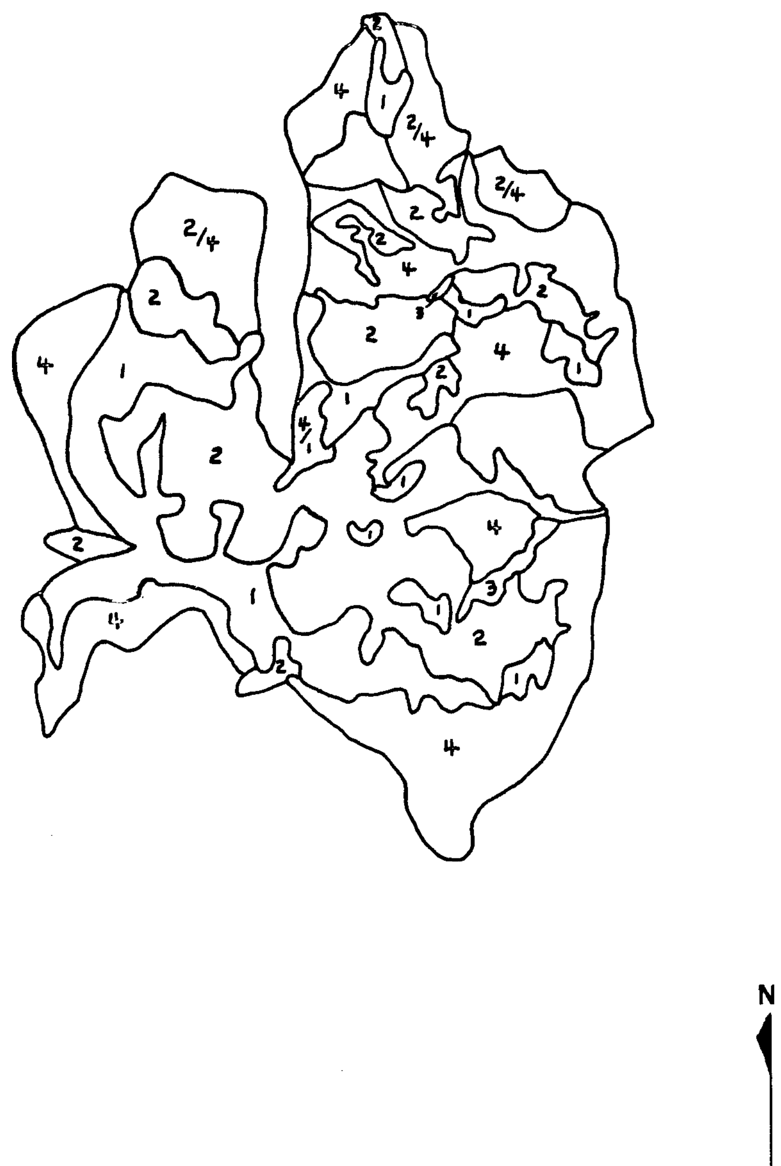
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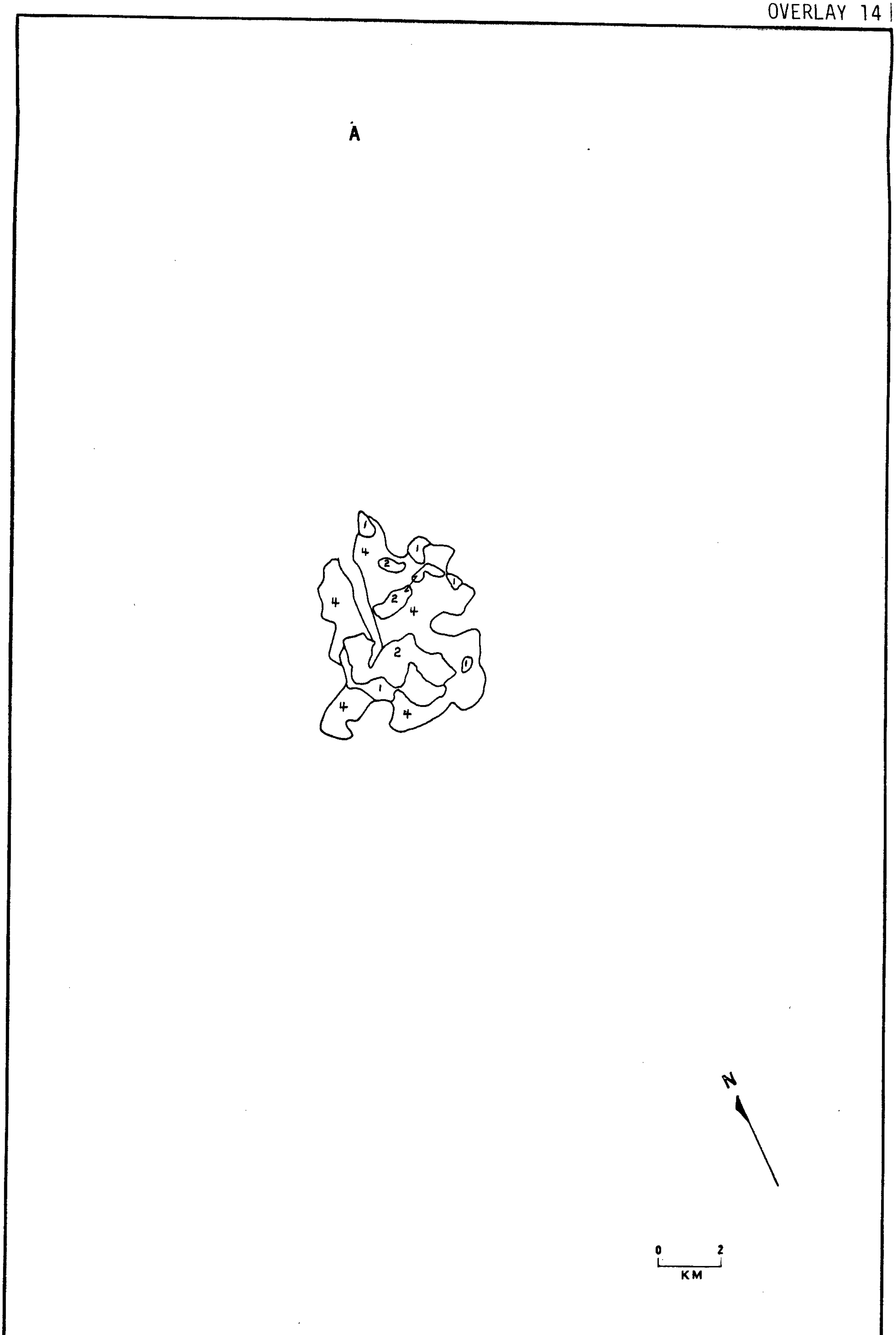
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