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VEGETATION, MICROCLIMATE AND SOIL, AS INFLUENCED BY SLOPE AND EXPOSURE, GRIZZLY CREEK, ST. ELIAS MT. RANGE, YUKON TERRITORY.

By

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Submitted to the School of Graduate Studies
in fulfillment of the requirements of the
M.A. program of Geography

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1980

Increased interest in the recreational resource base of Canada's northern national park system (i.e. Kluane), has forced park planners to pay greater attention to the delicate balance of Arctic and Alpine ecosystems. Plant production, the basis of the ecosystems, is in a form of dynamic equilibrium with the surrounding physical environment. Interference in these fragile ecosystems by man, without a comprehensive understanding of their degree of sensitivity, will result in irreparable damage.

D. Leverton (1980)

ABSTRACT

The vegetation, soils and microclimates of 3 different exposures along a transect in a small valley on Grizzly Creek in the Donjek Range of the St. Elias Mountains were examined. Seventeen regularly spaced vegetation quadrats were sampled and soils and microclimatic data were obtained from the midpoints of each slope. A total of 54 plant species were found and estimates were made of the frequency of occurrence and the percent cover of each plant species. Direct amounts of incoming solar radiation, mean soil, soil subsurface and air temperatures, relative humidity, precipitation and wind direction were measured daily between June 9, 1979 and July 13, 1979. The microclimates of the north-, south-and east-facing slopes were found to be different and this was reflected in the soil properties and rates of soil development. The availability of essential macronutrients P^+, K^+, Ca^{++}, Mg^{++} and N were also examined between sites. Major differences occurred in the concentrations of availiable and exchangeable cations and the depth of distribution of the various macronutrients. Only 33 percent of the total number of plant species were common to all 3 study areas. The species present and the relative dominance of the various species was found to be related to the aforementioned biotic and abiotic controls. For example, mosses were the most abundant form of vegetation on the nutrient-poor north-facing slope whereas grasses tended to dominate the nutrient-rich south-facing slope. The intervening east-facing slope had the highest species diversity of the 3 sites.

PREFACE

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CHAPTER 1

INTRODUCTION

Alpine regions, because they occur over such a wide range of latitude (from the Arctic to the high mountains of equatorial regions) provide a unique opportunity to observe the relative effects of latitude versus elevation on microclimates, plant growth and resultant vegetational structure. Prior to 1955 the bulk of research into the relationships of these biotic and abiotic parameters was carried out in the middle and southern latitudes. Technological advancements since that time (i.e. helicopter), have made it increasingly easier to pursue such studies in Arctic and alpine areas.

Alpine environments exist wherever mountains are higher than the regional timberline (Billings and Mooney, 1968). Subarctic-alpine environments exist wherever mountains are higher than the natural polar tree limit which more or less follows the 10°C mean daily isotherm for the warmest month of the year. The major difference between subarctic-alpine environments and tropical-alpine environments is the length of the growing season. In the equatorial mountains it remains continuous while in subarctic-alpine regions it lasts only 4-10 weeks (Bliss, 1974).

Variations in slope and aspect, resulting from topographic differences, are reflected in soil and air temperatures, snow cover duration, soil nutrient and moisture contents and consequently in the distribution of vegetation (Ives and Barry, 1974). In regions of rugged topography, such as those occurring in the St. Elias Mountain Range, Yukon Territory, differences in slope and aspect result in dissimilarities in both the physical and biological environment.

In the summer of 1979, a study of micro-climate, vegetation cover and soil development was undertaken on north-, south-, and east-facing slopes in the St. Elias Mountains, Yukon Territory. The primary objective of this study, was to investigate dissimilarities in soil development and vegetation over select sites and attempt to establish the major physical controls which are responsible for these differences. In order to explain the dissimilarities, a number of physical and climatic parameters were examined:

1) Soil Temperature and Air Temperature:

Temperature is the most important environmental factor affecting plant distribution and growth (Wilson, 1957). Air temperature and soil temperature will usually be higher on south-facing slopes. In conjunction, maximum air and soil temperatures will show a greater difference than minima with differences in slope exposure. In general, this will result in a competitive advantage for southern environs, providing an extra 2-4 weeks of growing time over their counterparts on north-facing slopes (Hoefs, 1975).

2) Relative Humidity:

The relative humidity of a given microclimate is related directly to surface and subsurface temperature, the moisture content of the subsurface and the vegetation inhabitating the given site. Geiger (1950) reports that the humidity gradient tends to increase near the ground surface in a way similar to temperature. Although relative humidity values are not a direct measure of evapotranspiration losses, they are an indicator of the moisture holding capacity of the soil surface, especially on days of direct insolation. Relative humidity values will be dependent on the precipitation values, temperature and moisture holding capacities of the given sites.

3) Precipitation:

Dissimilarities over selected sites will be affected primarily by the topographic gradient and prevailing winds. Variations in precipitation will have a major effect on the nutrient regimes of the given sites (i.e. leaching; ion exchange, hydrolysis, adsorption, swelling, oxidation and reduction).

4) Albedo Rates:

Variations in albedo between the north- and south-facing slopes provide a quantitative measure of the amount of short wave radiation absorbed at the soil surface and the amount of long wave radiation reradiated back into the atmosphere (Geiger, 1950). Regions of limited vegetational development such as the north-facing slope will be expected to yield higher absorbance values during the day and higher reflectance values during the night, than south-facing slopes, due to differences in the thermal properties of the soil and parent material of the different sites.

5) Wind Direction:

The interaction between wind and topography can result in uneven distributions of precipitation. Wind can also have an abrasive effect on developing ridge-top communities and exposed slopes (Wilson, 1959). Furthermore, wind can have a moderating effect on temperature thereby retarding plant development.

6) Soil Development:

Subarctic-alpine soils are weakly developed, primarily because of the recent age of the parent materials, the cold climate of the region and the sparse vegetation cover (Douglas and Knapik, 1974). The nature and rates of weathering and soil formation are greatly influenced by precipitation, temperature and their effects on plant growth and decomposition. Dissimilarity within the particle size distribution within a given pedon, indirectly affects the nutrient status, the moisture holding capacity and the thermal properties of that soil. This in turn directly affects plant root growth and seed germination within the plant species.

7) Nutrient Characteristics:

An important trend in the successional development of plant vegetation, is the tightening of the biogeochemical cycle (Odum, 1969). An important measure of a developing system is its ability to entrap and hold nutrients. Knowledge of the availability of various macronutrients over the selected sites may help to indicate their level of maturity (Odum, 1969). Other characteristics such as the organic matter content affect the moisture retaining capacity of the soil and thus the nutrient holding characteristics of a given area (Brady 1974).

8) Vegetation:

Biological dissimilarity over the selected sites is due primarily to differences within the physical environment. These variations, modified through time (i.e. evolution) have resulted in a variety of morphologic and physiologic plant characteristics within the individual species. This has provided some plants (i.e. Dryas, Salix) with an ability to competitively exclude their neighbors, thereby eliminating them from select sites. Many of these differences are explored in the literature review as well as within the vegetative study.

Vegetation occurring on the south-facing slope will be expected to develop much more rapidly than the vegetation on the north-facing slope. This is due primarily to the much more ameniable physical conditions occurring on the south-facing slope.

In summation, the primary objective of this study is to investigate dissimilarities in soil development and vegetation over three select sites and to attempt to establish the major physical controls which are responsible for these differences. At present, very little is known about the functioning of Subarctic-alpine ecosystems. Although only an independent case study, results from this investigation will provide information into the physical variability and the biological heterogeneity of these isolated environments.

CHAPTER 2

A REVIEW OF THE MAJOR BIOTIC AND ABIOTIC COMPONENTS AFFECTING THE DISTRIBUTION OF ARCTIC AND ALPINE VEGETATION

With the exception of the equatorial mountains, vegetational mosaics of arctic and alpine areas show many resemblances to each other (Billings, 1974). Ecotypic differences which exist between the groups, is due primarily to isolation and evolution during the glacial phases of the Pleistocene (Hultèn, 1968). Isolation has also resulted in the total alpine flora of the Northern Hemisphere being many times richer than the arctic flora (Billings, 1974). In alpine environments, very little information is available which examines variations between soil, microclimate and vegetation relative to differences in slope and aspect. The following then, is a comprehensive summary of all material which is directly or indirectly related to this thesis topic. The scope of the review, being to familiarize the reader with all the published information which deals with this somewhat obscure topic.

Cody (1971) acknowledges the presence of some 1,105 taxa in the Yukon out of which approximately 28% are circumpolar; 22% are Amphi-Beringian in decent; 20% are broad-ranging North American species; 9% are Cordilleran and 8% are alien species introduced by man. Only 9% of the total taxa are endemic to parts of boreal and Arctic North America (Cody, 1971). According to Hultèn (1968) a large proportion of the southwest Yukon remained unglaciated during the Pleistocene, thereby serving as a refugium for many of these endemic arctic-alpine plant species.

Subarctic-alpine ecosystems may be referred to as "habitat islands" because of their deviation from the normal pattern of mainland biota. This degree of deviation from the surrounding environment, Brinck (1974) refers to as the "degree of insularity". The degree of insularity in alpine ecosystems is directly related to biological age. In both Arctic and equatorial alpine regions, ecological and geographical insulation increases with the age of the ecosystem (Brinck, 1974). The degree of insularity is therefore much lower in the subarctic-alpine regions than in the equatorial alpine zones.

In all environments, physical gradients result in biological gradients (Billings, 1974). In other words it is impossible to understand subarctic-alpine dynamics or vegetation associations, without a parallel examination of topographic microrelief, soils and thaw depths which collectively constitute the substrate for plant life (Johnson, 1969). In subarctic-alpine environments there are two major types of physical macrogradients: latitude and altitude.

Latitudinal environmental gradients are affected mainly by differences in the solar radiation regimes. In arctic and alpine environments, three of the most important elements of this regime are light intensity, duration and quality. In mid-summer, light intensity at noon is usually greater in the subarctic-alpine zone than in the arctic tundra, primarily because of the thinner alpine atmosphere (Bliss, 1962; Caldwell, 1968). Mooney and Billings (1961) indicate that many populations of arctic plant species are physiologically adapted to a 24-hour photoperiod. Because of latitude, subarctic-alpine vegetation remains exposed to a 24-hour photoperiod for a much shorter length of time. In relation to light intensity, the shorter the photoperiod, the greater the solar angle at mid-day. This, in turn, increases the rate of solar radiation entering the subarctic-alpine ecosystem (Billings, 1974). Therefore, a reduction in light duration in subarctic-alpine regions does not retard growth, but may actually encourage it, depending on exposure and altitude.

Altitudinal macrogradients in the subarctic-alpine region reflect the general environmental character of the latitudinal gradient at any given point from the equator (Billings, 1974). For example, in clear weather at high altitudes, there is an upward increase in solar radiation intensity resulting in a greater ultraviolet component (Caldwell, 1968). This physical gradient in turn affects the biological gradient. Caldwell (1968) found that the red leaves of Oxyria digyna and Geum rosii had reduced ultraviolet transmission while the green leaves of Sedum rosea transmitted almost three times as much. Caldwell believed this difference to be related to the amount of anthocyanins within the epidermal layers of the plant species. The anthocyanins apparently act as an excellent filter of ultraviolet radiation.

Temperature is the most important environmental factor affecting plant distribution and growth. According to Wilson (1957) the physiological explanation for the critical temperature effect is two-fold. First, the mean summer air temperatures are fluctuating around 0°C, which is the lower cardinal point for many metabolic processes. For example, translocation, though not markedly affected by temperature under normal temperate conditions, receives a marked check when plants are chilled to 0 to 5°C. Secondly, certain physiologic processes are accelerated by temperature increases at low temperatures. Data quoted by Wilson (1956), suggests that a 50 per cent increase in photosynthetic rate may be produced by a rise of 1°C at 0°C, but only by a 10°C rise at 20°C.

Other information on temperatures in tundra and alpine environments is contained in papers by Sørensen (1941), Bliss (1956), Wilson (1957), Billings and Bliss (1959), Johnson (1970), Price (1971) and Bliss (1976). Unfortunately, no seasonal temperature data is available for subarctic-alpine regions. In the arctic however, although temperatures are relatively low, they do show normal day-time temperature gradients in the microenvironments with temperature inversions typical at "night" (Bliss, 1962). Bliss explains that where day-time temperatures at .7 metres rarely exceed 13°C to 18°C, soil-surface temperatures are sometimes recorded as high as 38°C. (Nighttime soil-surface temperatures were 4°C to 7°C for the same period). Bliss therefore concluded that temperature regimes in the microenvironment on north- and south-facing slopes, are markedly different helping to explain the heterogeneous nature of plant distribution.

Topographic variation is the most important mesogradient affecting microclimate, plant community structure and soil development in subarctic-alpine environments. In the south-central Yukon, the length of the growing season is approximately 10 weeks (Hoefs, 1975). In the alpine areas Hoefs stresses the importance of aspect, indicating that the vegetation on south-facing slopes have much more time to complete their life cycles, while the habitats on northern exposures, may be restricted to a growing season of only 4-6 weeks. Smith (1974) expands further on these microclimate differences which may exist between north- and south-facing slopes. At latitude 41°N mid-day insolation on a 20° slope is on the average, 40% greater on south-facing slopes than on north-facing slopes during all seasons. This will therefore have a stronger affect on the moisture and heat budgets of southern exposures in subarctic-alpine environments.

Chang (1958), reported that as radiation intensities decline with increasing latitude, the extent to which subsurface temperatures are influenced by slope and aspect diminshes. Hannell (1972) tested Chang's hypothesis on Devon Island in the Canadian Arctic. Hannell measured subsurface temperatures of a deep narrow valley with north- and south-facing slopes at an angle of 29°. Under dry conditions the top 20 cm. of the active layer on the south-facing slope was always warmer, by up to 11°C through the late morning and early afternoon. Hannell's study clearly indicates that slope and aspect are important microclimatic variables, even at high latitudes.

Mesotopography in conjunction with wind can have a marked effect on plant distribution and growth. Windswept ridges provide one of the most severe environments in terms of temperature, drought stress, soil frost action and wind abrasion (Billings, 1974). In these environments vascular plants such as Saxifraga oppositifolia, Dryas integrifolia, Saxifraga tricuspidata and Draba bellii, survive at their limit of tolerance (Polunin, 1951; Savile, 1964).

Certain morphological adaptations have enabled these plant species to survive under such harsh conditions.

Wilson (1959) for example~~; not~~ed that wind speed is greatly reduced within clumps of tundra plants during the summer period. Wilson discovered that near the tips of the more exposed leaves the wind speed was approximately 50 cm./sec., falling to 10 cm./sec. on the lee side. Wilson concluded that the potent affect of wind on tundra vegetation is a result of the sensitivity of plant growth to wind. This sensitivity is due less to excessive transpiration and more to temperature conditions, as they affect net assimilation and shoot growth rates (Wilson, 1959).

Mesotopography also influences the distribution of precipitation over a given area. In subarctic-alpine environments snow distribution is not very uniform, due to the interaction between wind and topography. As a result, snowbank vegetation occurs in those areas where large snow drifts have accumulated. These plant species are adapted to shorter growing seasons and colder temperatures. Some species can even begin growth under as much as 50 cm. of snow (i.e. Deschampsia caespitosa and Carex elynoides) (Billings and Bliss, 1959; Mooney and Billings, 1961).

Plants which are buried under the snow are protected during periods of high wind and low temperatures (Bliss, 1961). During the summer, the meltwater also ensures that the existing vegetation will not suffer drought (Billings and Bliss, 1959). Saxifraga punctata, on the one hand, is an example of a plant of moist environments, which is usually deeply snowcovered. Salix tricuspidata on the other hand, is found on the more exposed ridges where rapid winter dissemination is likely to occur (Calder and Savile, 1960). In the Arctic tundra, shrubs are found only where winter snowcover prevails. Shrub height appears then, to be related directly to mean winter snow depth (Wilson, 1958).

Nutrient input and output are directly related to amounts of water moving into and out of the subarctic-alpine ecosystem, as emphasized by the "leaching" and "flushing" concepts of Ratcliffe (1959). The nature and rate of weathering and soil formation are also influenced by precipitation inputs, since water is essential to the major weathering processes (i.e. ion exchange, hydrolysis, solution, diffusion, oxidation and reduction and adsorption and swelling) (Brady, 1974).

Edaphic factors affect to a certain extent, the distribution of vegetation in subarctic-alpine environments, because of their effect on water transport and the nutrient regime. In alpine environments, soil formation results from pedologic as well as cryopedologic processes. In Canada, alpine regions have been little studied from the standpoint of pedology. The first comprehensive study of soils of the southwestern Yukon was not completed until Day (1964). He described the development of Orthic Brown Wooded (Orthic Dystric Brunisols), Orthic Regosols and Gleyed Orthic Regosols.

In 1974, Douglas and Knapik described the development of twenty-seven pedons in Kluane National Park, Canada. They found that the pattern of montane soil types is directly related to the developing plant communities. For example, herb and shrub vegetation is usually associated with Regosolic soils. These soils are weakly developed because of the recent age of the parent materials, the cold climate of the region and the sometimes sparse vegetation cover (Douglas and Knapik, 1974).

Prior to this paper, little, if any, emphasis had been placed on trying to analyze the nutrient regime of these weakly developed soils. Accompanying this lack of information, is an inadequate understanding of the mineral requirements of individual plant species and the rates and seasonality of uptake of the various macro- and micronutrients.

Bormann (1967) suggests four major compartments in the terrestrial ecosystem where nutrients are found; in the atmosphere; in organic materials; in soil and rock and in the pool of available nutrients in the soil. The available nutrients in soil, consists of all ions adsorbed on the clay-humus complex or dissolved in the soil solution (Bormann, 1967). An important trend in successional development, is the closing or tightening of the biogeochemical cycling of these available major nutrients such as potassium, nitrogen and calcium (Odum, 1969). Mature systems, as compared to developing ones, have a greater capacity to entrap and hold nutrients for cycling. On southern exposures in subarctic-alpine environments, one would expect to find a higher percentage of available nutrients due to a larger volume of vegetative cover. Reductions in the volume of vegetation due to exposure on north-facing slopes would result in increased water yields causing greater outflow accompanied by greater nutrient losses (Odum, 1969).

Early research by Crocker and Major (1955) showed evidence of how soil changes (i.e. nutrient availability) are affected by the earlier pioneer vegetation on newly deglaciated terrain similar to the study area in Grizzly Creek. Dryas species were found to rapidly stabilize the soil surface against erosion, as well as increase the amount of soil nitrogen as a result of nitrogen fixation in its root nodules. This, in turn, aided the survival and growth of woody plants such as a number of Salix species that have no symbiotic nitrogen-fixing micro-organisms. Eventually a humic layer developed which increased the ability of the soil to entrap nutrients. These earlier results of Crocker and Major (1955) were later reconfirmed by Lawrence (1967).

Organic matter decomposition rates have been investigated in northern Alaska by Douglas and Tedrow (1959). Decomposition rates were found to be dependent on both soil temperature and soil moisture content. Soil moisture content had the greatest affect on decomposition during periods of high temperature. At 19.5°C the rate of organic matter decomposition was about seven times as great as at 7°C. In areas such as the southwestern Yukon, where the mean annual air temperature is less than 0°C (Weber, 1974), the rate of organic decomposition will be extremely low. In the summer months, however, slope and exposure will have a strong influence on the rates of organic matter breakdown, especially on southerly exposures.

Cryopedologic phenomena greatly affect community dynamics in subarctic-alpine regions. These frost-action processes are responsible for the creation of many micro-topographical features which affect the location of certain plant species. Price (1971) describes how there was an increase in the number of available microhabitats on the south-east-facing slope because of the presence of solifluction lobes. On the southwest- and north-facing slopes, the absence of solifluction lobes reduced the availability of microhabitats for many plant species.

Prior to Price (1971), Johnson and Billings (1962) discussed the impact of cryopedogenic processes on alpine vegetation in the Beartooth Plateau, Wyoming, Montana. On the basis of this study, four major vegetation types were interpreted as being in dynamic equilibrium with cryoplanation processes. This continuum was controlled by snow cover and topographic site, which, in turn, interacted with the wind. Within each vegetative type, smaller vegetative patterns developed in response to local disturbance by small mammals and frost-action. Inactive patterned ground created micro-habitats which were again important in the development of plant communities (Johnson and Billings, 1962). Solifluction terraces also create a topography which is favourable to snow accumulation, eventually resulting in snowbed zonation of plant communities (Price, 1971).

Plant distribution is often affected by factors other than just the physical environment. In the preceding sections we have examined the effects of latitude, altitude, microclimate, topography, soil development and nutrient status on developing Arctic and alpine plant communities. The last major topic of discussion will be a review of the morphological and physiological adaptations which enable many of these plant species to survive in such an unforgiving environment.

Natural selection operates on the phenotypes in plant populations at four major levels: morphological, physiological, reproductive and ecological (Billings, 1974). The net results are adaptations at each level, which, in turn, contribute to the survival of the whole plant and thus of the local population of plant species (Billings, 1974).

Morphologically, the typical alpine plant is a small, even dwarf angiosperm. Almost one hundred per cent of these angiosperms are perennial plants which take a long period of time to establish (Billings, 1974). In the subarctic-alpine zone perennial herbs are by far the most common both floristically and vegetationally.

Most of the perennial herbs have large underground roots and/or rhizome systems which store carbohydrates throughout the winter (Mooney and Billings, 1960). The following summer, the stored carbohydrates are used in the regrowth of shoots and leaves after snowmelt (Mooney and Billings, 1960). Scott and Billings (1964) noted that the root:shoot ratios in perennial herbs was much larger in the moist regions than in the dry regions. Hoch (1941) a much earlier researcher, described root habits of certain plants of the foothills and alpine belts of Rocky Mountain National Park. In the alpine belt, there is a great reduction in the size of the plants; the shoot being reduced even more than the roots.

The majority of alpine plants are less than 6 to 8 cm. in height (Wilson, 1957b). The above-ground parts are in the lower part of the microenvironment where higher temperatures occur. This morphological characteristic permits metabolic processes to proceed much more rapidly (Wilson 1957b). Daubenmire (1941) concluded that as plants increase in size there is a tendency to proliferate near the ground line in order to minimize wind abrasion and heat loss.

Photosynthesis and respiration are the main physiologic factors responsible for the characteristic dwarf nature of tundra plants and their slow rates of growth. The ability to metabolize rapidly at low temperatures however, is the key to survival in short, cold growing seasons (Bliss, 1956; Billings, 1974). Mooney and Billings (1961) demonstrated in the field that arctic and alpine ecotypes of Oxyria digyna differ from each other in these rates. This was later confirmed by Billings, et. al. (1971) under controlled conditions. Billings (1971) also found that low and high temperature acclimation regimes have very marked effects on mitochondrial activity as well as photosynthesis and respiration.

Early researchers suggested a number of other variables to explain the dwarf nature and slower rates of growth in arctic and alpine plant species. Wager (1938) believed that low temperatures and low carbohydrate synthesis were more limiting than the small supply of nitrogen, soil nutrients and water. Sørenson (1941) concluded that there must be root competition for a limited supply of water and nutrients, especially nitrogen and the inherent development morphology of the plants. Russell (1940a) believed nitrogen deficiency was the limiting factor in determining the distribution and development of many plant communities. Polunin (1955) believed slow growth rates were due to a number of different factors: protein synthesis occurs at a much slower rate; cell elongation is reduced at low temperature and soil and climatic conditions are usually unfavourable for high rates of growth.

Dormancy is another extremely important physiologic adaptation in alpine environments. Without dormancy or hardening, alpine plants would be in no condition to withstand the rigors of an alpine winter. Billings (1974a) found that arctic ecotypes of *Oxyria digyna*, begin to form perennating buds at photoperiods as long as 14 to 15 hrs. Alpine ecotypes under the same temperature conditions do not do this until the photoperiod is down to 12 to 13 hrs. This implies that the alpine ecotype is able to continue metabolizing for a much longer time period and has a greater chance of producing seed.

In alpine plant communities, at least 60 to 70 per cent have no intrinsic dormancy (Billings, 1974). Mooney and Billings (1961) found that seeds of four different populations of *Oxyria digyna* germinated poorly at constant temperatures below 10°C, but rather well at higher temperatures. In addition, most alpine seeds do not germinate when the soil surface is dry, thereby acting as a safeguard against seed germination late in the season.

In any viable, but dormant seed, biotic order and the potential for the proliferation of order (morphogenesis), are preserved in an apparently lifeless position (Amen, 1966). Porsild (1967) gives a detailed account of seed longevity in the growth of six arctic lupine plants (Lupinus arcticus) over 10,000 years old. The seeds were found in lemming burrows deeply buried in permanently frozen silt of Pleistocene age in the unglaciated central Yukon. Cryptobiotic states (viable, but seemingly lifeless) then, serve as adaptive mechanisms of growth cessation and often give some species a selective advantage in distribution (Amen, 1966).

Reproduction in alpine plant species is carried out in two ways; sexually by flower and seeds or vegetatively by rhizomes (Billings, 1974). Reproduction by seed is much more common in southern alpine plants than in arctic or subarctic alpine plants where seed-set is rare. For example, alpine plants of Oxyria in the western American mountains, reproduce entirely from seed, while those of Alaska reproduce largely by rhizomes and only occasionally by seed (Billings, 1974a).

Almost all North American and European alpine flora (as with arctic ones) produce flower primordia at least the year before flowering (Bliss, 1971). These preformed flower buds help to ensure flowering immediately after snowmelt, thereby allowing enough time for seed-set the following fall. Mark (1970) has found this trait to be universal. In the alpine plants of New Zealand (which have evolved from an entirely different flora) the preformed bud is ubiquitous.

Flowering in most alpine plants occurs 10-20 days after snowmelt (Bliss, 1971). The speed and time of flowering depends especially on the time of snowmelt and the corresponding temperature regime. Porsild (1951) examined the ability of arctic plants to grow and flower when the air temperature was only slightly above freezing. Porsild concluded that this was due primarily to increased insolation at the plant surface. Investigations by Krog (1955) support Porsild's theory. Krog found that the radiation from the sun had its greatest intensity in the yellow part of the spectrum. Krog observed on one occasion in Anaktuvik Pass, Alaska, that the spikelets of the arctic cottongrass Eriophorum, were yellow with pollen on the side turned toward the sun, while the opposite side remained black and undeveloped. The air temperature at the time of Krog's observation was well below 0°C.

In the subarctic-alpine regions, sexual reproduction by pollination is either by insect or wind. Graminoids for example are pollinated only by wind (Billings, et. al., 1973), while many of the more attractive alpine flowers are pollinated by insects. Macor (1975) studied the pollination ecology of six native species of Pedicularis in the Kluane Range of the

St. Elias Mountains, Yukon. Macor found that seed production in all species was dependent upon pollination by bumblebees. This coadaptive process between bumblebees and plant species is a good illustrator of how plant distribution is often affected by factors other than just the physical environment.

From this synopsis, it is apparent that the amount of consideration given to the major climatic, edaphic and biological factors concerning the distribution and growth of arctic and alpine vegetation, is limited in subarctic-alpine regions. Extrapolation from research in both arctic tundra and southern alpine environments has helped provide a much broader insight into the physical and biological concerns of these isolated regions.

CHAPTER 3

THE STUDY AREA

3.1 General Description of the Study Area:

The study area was located at Grizzly Creek, approximately 32 km. northwest of mile post 1070 of the Alaska Highway, in the Donjek Range of the St. Elias Mountains (see Plate 1). The actual work site was situated in a small depression (between two north- and south-facing ridges of glacial till) on the west side of Grizzly Creek, roughly 4 km. from the present day glacier at an elevation of approximately 1524 m.

Vegetation cover consisted mainly of herbacious plant species with the exception of the valley bottom where there were a number of shrub willows. Mosses tended to dominate the north-facing slope. Lichens were more prevalent along the tops of the ridge where the percentage of exposed rock surface increased.

Soil development reached a maximum depth of 57.0 cm. on the south-facing slope, 16 cm. on the north-facing slope and 23.5 cm. in the valley bottom. The underlying till consisted of unconsolidated rock material ranging from .5 cm. to 40 cm. in diameter. Visual analysis of the unconsolidated materials indicated a dominance of sedimentary rock types, primarily calcareous shale and limestone.

Overlying permafrost at the base of the depression, were a series of solifluction lobes. Depth of the active layer there, varied from 18 cm. to 80 cm. at the end of the field season in mid-July. Two meltwater streams flowed through this central area (at the base of the north- and south-facing slopes) becoming more ramified toward the mid-section of the hollow. By late June the two streams had dried up, becoming active only during periods of heavy precipitation.

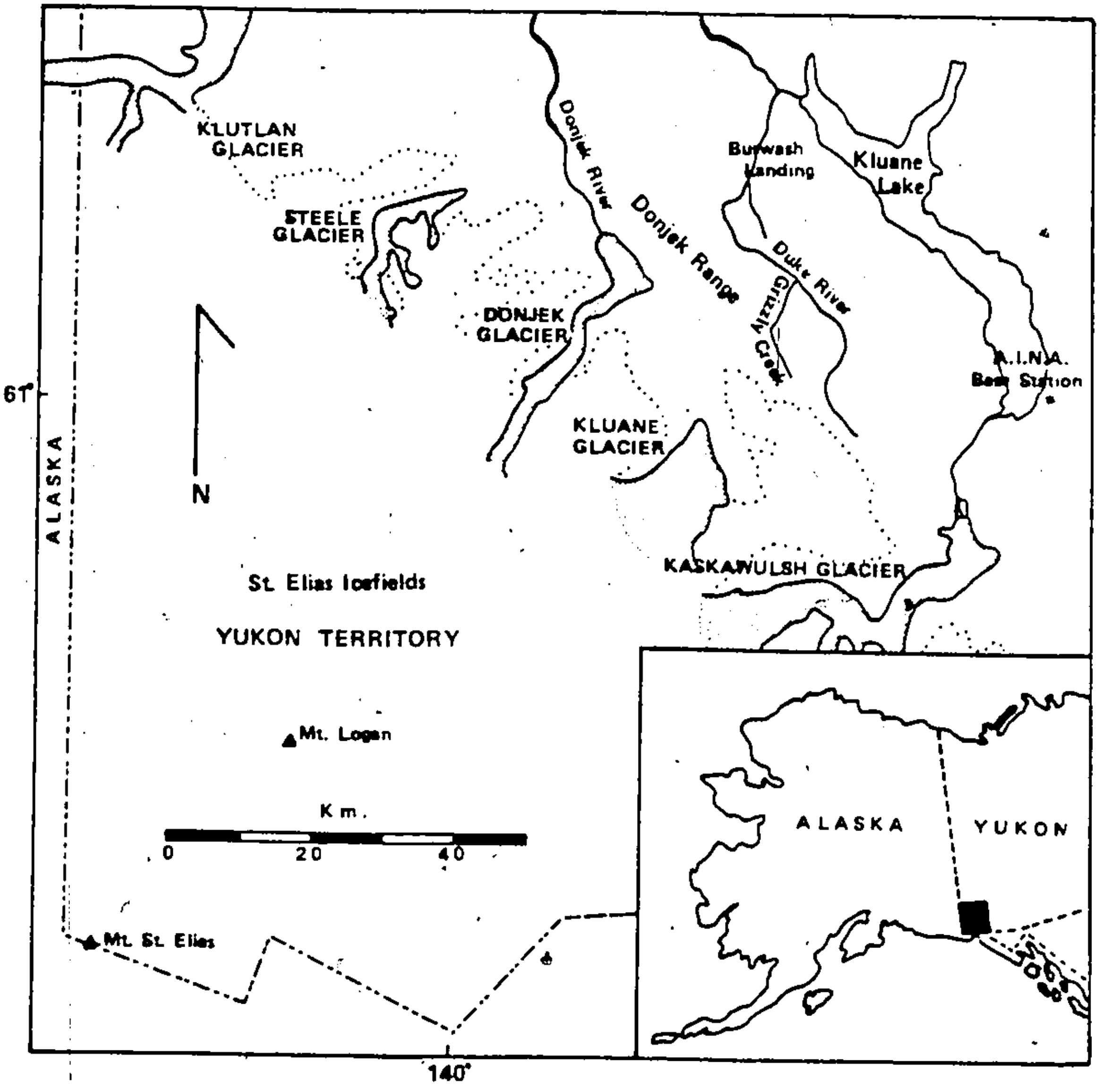


PLATE 1

Location of Grizzly Creek in Yukon Territory

1 40,000

Km

0 1 2

PLATE 2

Location of Study Site

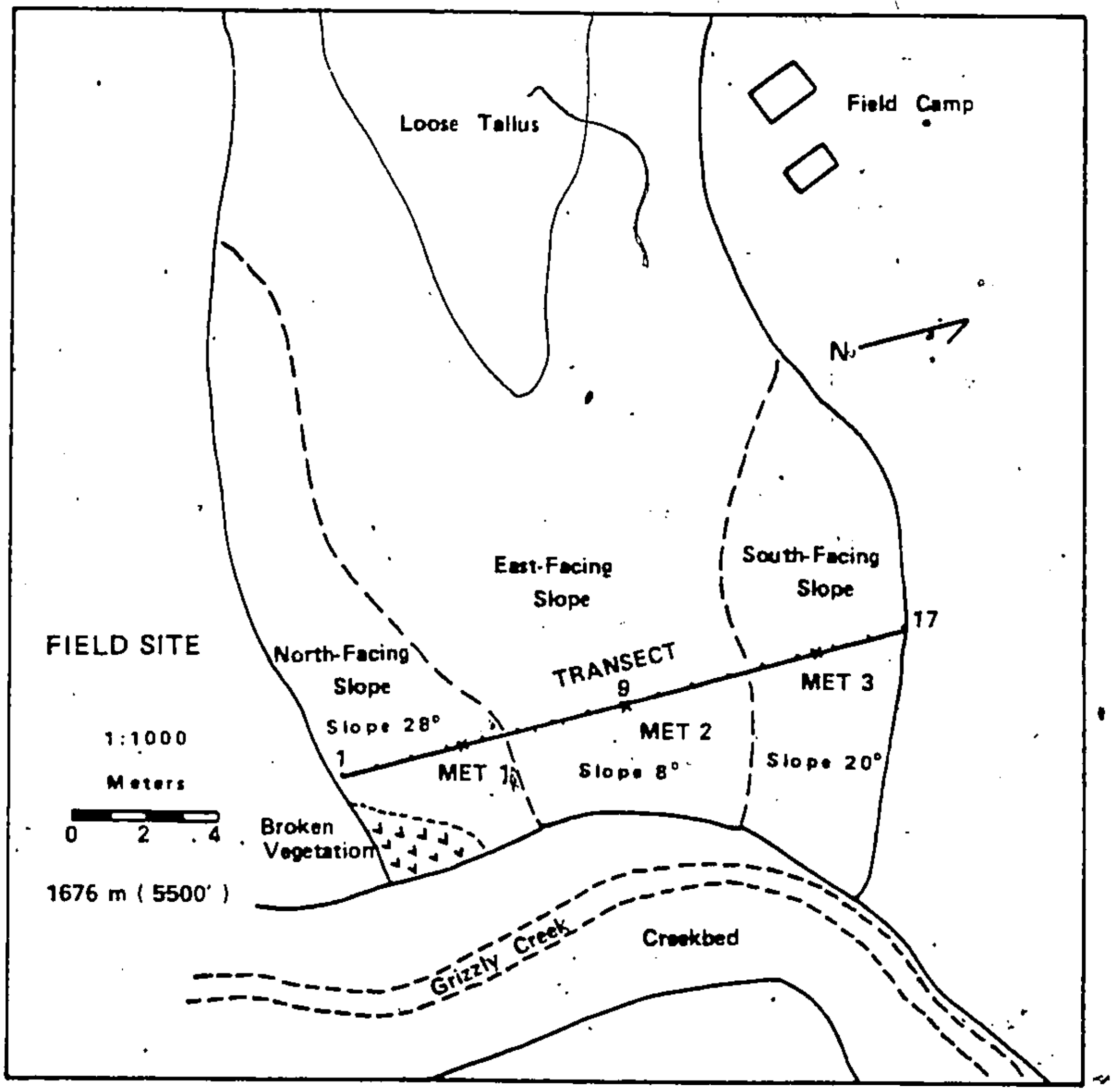


PLATE 3

Study Site - Yukon Territory

Figure 3.1 Overview of Study Site

CHAPTER 4

FIELD AND LABORATORY INVESTIGATIONS

4.1 Field Procedure:

The following data was collected between June 9, 1979 and July 12, 1979.

4.1.1 Vegetative Analysis:

With increasing knowledge of plant population distributions, it has been found that truly random dispersal is hardly, if ever, found in nature (Dombois-Ellenberg, 1974). Instead, plant communities tend to be more clumped or contiguously distributed (Ashby, 1948; Greig-Smith, 1964). Therefore, unless the clumps themselves are randomly distributed, a grid of regularly placed samples along a vegetation transect will give a better coverage of the range of variation than a randomly distributed sample. Consequently, sampling at the study site was systematic. Sampling procedure was as follows:

1) A north-south transect crossing from the north-facing to the south-facing slope was established and sampling was conducted at 10 metre intervals. The total transect was 160 metres so 17 sites were investigated (see Plate 2).

2) At each site sampling was conducted using the standard quadrat method (Greg-Smith, 1964). Each quadrat was 1 m^2 and was subdivided into four equal sections each .25 m^2. This meant that 68 samples each of .25 m^2 were investigated.

3) The plant species growing in each .25 m^2 quadrat were identified as well as the per cent cover attributable to each plant species. Plant specimens were also collected for further study.

4) At each site sampling was conducted between two periods, June 10-24 and July 5-11, 1979 to allow assessment of changes in vegetation patterns during the growing season. A list of the identified plant species is presented in Appendix A.

4.1.2 Microclimatic Measurements:

Meteorological stations were established at 3 sites along the transect: 35 metres, 80 metres, and 125 metres from the southern end (see Plate 3). These three points represented the mid-points of the north-facing slope, valley bottom and the south-facing slope. Shelter boxes oriented in a north-south direction were placed at the 3 sites at approximately 40 cm. above the ground surface. Observations and daily readings were recorded in the following manner:

1) Maximum and minimum daily air temperatures were taken at a height of approximately 40 cm. above the ground surface.

Figure 4.1 Meterological Station established at midpoint of south-facing slope

Daily readings were taken at 10:30 a.m. Pacific Standard Time.

2) Soil surface temperature was observed daily between June 25th and July 2nd. Readings were at two hour intervals commencing at 6:30 a.m. and ending at 8:30 p.m..

3) Subsurface soil temperatures were also observed daily between June 25th and July 2nd on the north-, south- and east-facing midslopes. Readings were taken from thermocouples using a type 1221 microvoltmeter at depths of 1, 3, 5, 10, 15, 20 and 30 cm. on the north and south slopes and at 10, 13.5 and 17.5 cm. on the east-facing slope. Measurements were taken at two hour intervals commencing at 6:30 a.m. and ending at 8:30 p.m. P.S.T..

4) Wet and dry bulb thermometers were placed approximately 40 cm. above the ground surface at each site. Daily readings were taken at two hour intervals commencing at 10:30 a.m. and ending at 4:30 p.m. P.S.T..

5) Precipitation measurements were taken on both the north- and south-facing slopes using continuously recording rain gauges. Horizontal wind direction was estimated from a continuously recording anemometer situated on the top of the moraine rock glacier .5 km. up valley.

6) Net radiation measurements were taken using a Swissteco Net Radiometer at a height of 1 metre above the ground surface on the north-facing slope. Continuous readings

were taken on the north-facing slope, using a battery powered (12 volt) Rustrac Recorder. Equipment failures on the south-facing slope resulted in net radiation measurements being taken daily with a microvoltmeter at two hour intervals, commencing at 8:30 a.m. and ending at 8:30 p.m. P.S.T..

7) Solar radiation measurements were taken at the soil surface of both the north- and south-facing slopes, using Kipp CR5 Solarimeters. Continuous readings were taken on the north-facing slope, using a battery powered (12 volt) Rustrac Recorder. Equipment failures on the south-facing slope resulted in solar radiation measurements being taken daily with a microvoltmeter at two hour intervals commencing at 8:30 am and ending at 8:30 p.m. P.S.T..

4.1.3 Soil Analysis:

Soil samples were collected from selected points along the transect. The sampling procedure was as follows:

1) Five pits were dug; at the top of the north-facing slope (0 m.), in the middle of the north-facing slope (40 m.), in the middle of the valley bottom (east-facing slope)(80 m.), in the middle of the south-facing slope (120 m.) and at the top of the south-facing slope (160 m.). On one side of each pit a clean vertical face was exposed.

2) The general appearance, colour (Munsell Colour Charts were employed), texture, and depth of each horizon was recorded and photographs of each pit were taken.

3) Two soil samples were taken from each soil horizon in the five pits. One complete set was placed in metal containers, weighed (in order that moisture content could later be determined), sealed and stored for transport to Ottawa for future in-lab analysis. The second set of samples were placed in plastic bags, brought back to the field camp work tent and tested for pH. These latter samples were also transported to Ottawa.

4) Soil monoliths were also collected from the five sample sites. These were wrapped in newspaper (in order to absorb moisture) and protected in an outer layer of plastic, for shipment to Ottawa.

4.2 Laboratory Investigation:

Each of the soil samples were analyzed for the following information:

1) Per Cent Moisture Content: The sealed soil samples (which were weighed in the field with their natural water content) were opened and placed in an oven at 110°C for 24 hours. The water content of the soil was expressed as a per cent dry weight of the soil samples.

2) Particle Size Distribution Analysis: This was determined for all samples using the falling drop method (Nickling, W.G., 1972).

3) Soil pH was determined in the field laboratory using a Lamotte Chemicals pH meter, model TRL 5. The soil

samples were mixed with distilled water in a ratio of approximately 1 ml. of water per gm. of soil.

4) Organic matter content was determined by ashing at 450^{o}C for 3 hours.

5) <u>Extraction of Soil for Cation Analysis</u>: This was carried out on all samples for the following elements: Ca, Mg, K, and Na; using the methods described by McKeague (1978) (see Appendix B).

6) <u>Total Nitrogen Content</u>: The per cent nitrogen available in each sample was determined using the modified Macro-Kjeldahl Method (Jackson, 1958) (see Appendix B).

7) <u>Extractable Phosphorous</u>: This was determined for all samples using the method outlined by Olsen and Dean (1976) (see Appendix B).

8) <u>Cation Exchange Capacities</u>: These were calculated for all the metallic cations and are expressed in terms of meq./100 gm. soil. Sample calculations are provided in Appendix C.

CHAPTER 5

RESULTS AND DISCUSSION OF RESULTS

5.1.1 General Discussion:

Subarctic-alpine environments have been little studied from the standpoint of pedology (Tedrow, 1977). Day (1964), the first researcher to provide a comprehensive study of a subarctic-alpine environment, described the development of Orthic Regosols and Gleyed Orthic Regosols in the southwest Yukon. Douglas and Knapik (1974) found that the vegetation usually associated with these regosolic soils consisted mainly of herbs and shrubs. The general hypothesis for the lack of development of these soils, is the recent age of the parent materials, the cold climate and the sometimes sparse vegetation cover.

Northern soils which develop on glacial till deposits are usually quite similar (Douglas, 1974). The moderately well drained soils often lack either organic horizons or Ah horizons. When present, organic and Ah horizons have a depth of 1 to 9 cm (Douglas, 1974). In Grizzly Creek, all the soil profiles contained either an Ah or an organic horizon less than 8 cm in depth (Figures 5.1.1-5.5.5).

Pedon Description: Site #1

Location : Yukon Territory-Grizzly Creek
60° 06'N, 135° 08'E
Parent Material: glacial till
Landform : ridge of glacial till
Slope : 0°
Aspect : --
Elevation : 1692 m (5550 ft.)
Drainage Class : well drained
Vegetation : *Dryas octopetalia*, Mosses, Graminae, *Salix stolonifera*, *Polygonum bistorta*, *Cardamine purpurea*, *Astragalus umbellatus*, *Artemisia globularia*, *Anemone multivida*, *Anemone drummondii*.

Horizon	Depth (cm)	Description
L	2-1	Fresh litter
H	1-0	Decomposed organic matter
Ah	0-6	Very dark greyish brown (2.5Y 3/2) silt loam; granular; friable; smooth boundary; pH 5.75
B	6.16	Very dark greyish brown (2.5Y 3/2) silt loam; granular; friable; wavy boundary; pH 5.9
C	16.21+	Dark greyish brown (2.5Y 4/2) loam; blocky; 25-50% gravel to cobble-sized coarse rocks pH -

Figure 5.1.1

Figure 5.1.1.1 Sampling Location 1

Pedon Description: Site #5

Location	Yukon Territory-Grizzly Creek 60° 06'N, 135° 08'E
Parent Material	glacial till
Landform	steeply sloping ridge
Slope	28°
Aspect	N
Elevation	1,584 m (5525 ft.)
Drainage Class	moderate to well drained
Vegetation	Mosses, *Salix reticulata*, Lichen, *Anemone drummondii*, *Anemone multivida*, *Anemone parviflora*, *Antennaria monocephala*, *Artemisia arctica*, *Cardamine purpurea*, *Claytonia sarmentosa*, *Dryas octopetala*, Grominae, Liverwort, *Oxyria digynia*, *Parrya naudicaulis*, *Pedicularis lanata*, *Polemonium boreale*, *Polygonum bistorta*, *Saxifraga davurica*.

Horizon	Depth (cm)	Description
L	3-1	Fresh litter
H	1-0	Decomposed litter
Ah	0-6	Black (2.5Y 2/0) friable very fine to fine; pH 5.65
Bg	6.0-16	Very dark greyish brown (2.5Y 3/2) silt loam; crumb; friable; smooth boundary; pH 5.8
C	16-27+	Dark greyish brown (2.5Y 4/2), blocky; 25-50% gravel to cobble-sized coarse; pH 6.25

Figure 5.1.2

Figure 5.1.2.1 Sampling Location 2

Pedon Description: Site #9

Location : Yukon Territory-Grizzly Creek
60° 06'N, 135° 08'E
Parent Material: glacial till
Landform : tallus slope
Slope : 8°
Aspect : E
Elevation : 1676 m (5500 ft.)
Drainage Class : moderate
Vegetation : Graminae, Mosses, *Salix stolonifera*, *Aconitum delphinifolium*, *Anemone drummondii*, *Anemone multivida*, *Anemone parviflora*, *Artemisia arctica*, *Astragalus umbellatus*, *Cardamine purpurea*, *Claytonia sarmentosa*, *Erigeron* sp., *Corudalis* sp., *Draba* sp., *Lloydia serotina*, *Mertensia paniculata*, *Oxyria digynia*, *Oxytropis nigreseens*, *Parrya naudicaulis*, *Polemonium boreale*, *Polygonum bistorta*, *Ranunculus pedatifidus*, *Salix reticulata*, *Salix stolonifera*, *Stellaria* sp., *Valerian capitate*.

Horizon	Depth (cm)	Description
L	7-2	Fresh litter
H	2-0	Decomposed organic matter
Ah	0-8	Black (2.5Y $^{2}/_{0}$) sandy loam; very fine to fine; horizontal roots; wavy boundary; pH 6.6
C	8-18	Dark greyish brown (2.5Y $^{4}/_{2}$) silt loam; medium; wavy boundary; pH 6.9
Of	18-23.5	Black (2.5Y $^{2}/_{0}$) loam; fine to medium; decomposed and undecomposed litter; wavy boundary; pH 6.9
C	23.5-46 Permafrost	Dark greyish brown (2.5Y $^{4}/_{2}$) loam; medium; wavy boundary; pH 7.1

Figure 5.1.3

Figure 5.1.3.1 Sampling Location 3

Pedon Description: Site #13

Location : Yukon Territory-Grizzly Creek
60° 06'N, 135° 08'E
Parent Material : glacial till
Landform : moderately sloping ridge
Slope : 20°
Aspect : S
Elevation : 1684 m (5525 ft.)
Drainage Class : moderately drained
Vegetation : *Graminae*, *Anemone drummondii*, *Anemone multivida*, *Anemone parviflora*, *Erigeron* sp., *Corydalis* sp., *Draba* sp., Lichen, *Lupinus arcticus*, *Mertensia paniculata*, Mosses, *Myosotis alpestrix*, *Polemonium boreale*, *Potentilla* sp., *Saxifrage reflexa*, *Stellaria* sp., *Zygodenus elegans*.

Horizon	Depth (cm)	Description
L	6-1	Fresh Litter
H	2-0	Decomposed organic matter
Ah	0-7	Black (2.5Y $^{2}/_{0}$) sandy loam; granular; medium; oblique to horizontal roots; smooth boundary; pH 6.9
B	7-27	Very dark greyish brown (2.5Y $^{3}/_{2}$) silt loam; crumb; fine; smooth boundary; pH 6.8
C	27-76+	Dark greyish brown (2.5Y $^{4}/_{2}$) blocky; friable; 25-40% gravel to cobble-sized coarse; pH 6.9

Figure 5.1.4

Figure 5.1.4.1 Sampling Location 4

Pedon Description: Site #17

Location : Yukon Territory-Grizzly Creek
60° 06'N, 135° 08'E
Parent Material: glacial till
Landform : ridge of glacial till
Slope : 0°
Aspect : --
Elevation : 1692 (5550 ft.)
Drainage Class : moderate to well drained
Vegetation : Dryas octopetala, Mosses, Lichen, Anemone multivida, Anemone parviflora, Arnica frigida, Erigeron sp., Graminae, Liverwort, Lloydia serotina, Lupinus arcticus, Mushroom sp., Myosotis alpestris, Oxytropis nigrescens, Pedicularis lanata, Polygonum bistorta, Potentilla sp., Saxifraga davurica, Saxifraga reflexa, Saxifraga tricuspidata, Stellaria sp.

Horizon	Depth (cm)	Description
L	3-1	Fresh litter
H	1-0	Decomposed organic matter
Ah	0-5	Black (2.5Y $^{2}/0$) sandy clay loam; granular; very fine to medium; oblique to horizontal roots; wavy boundary; pH 6.8
ASH Layer	5.0-5.5	White (5Y $^{8}/1$) tephra layer; wavy boundary; pH 7.15
B	5.5-10	Very dark greyish brown (2.5Y $^{3}/2$) loam; blocky; friable; wavy boundary; pH 6.4
C	10-16+	Dark greyish brown (2.5Y $^{4}/2$); blocky, friable; 25% gravel to cobble-sized coarse; pH 6.8

Figure 5.1.5

Figure 5.1.5.1 Sampling Location 5

Table 5.1.1 - Analysis of Subarctic-alpine Soils Grizzly Creek, Yukon Territory

Station Number	Location	Depth (cm.)	Mechanical Analysis Total Sand %	Mechanical Analysis Silt %	Mechanical Analysis Clay %	Soil Texture	Organic Matter Content %	pH	Moisture Content %
1	Ridge of	0-6	8.5	78.1	14.4	silt loam	15	5.75	55.84
	North-facing	6-16	38.5	58.7	10.8	silt loam	-	5.9	42.75
	Slope	16-21+	32.6	33.1	34.3	loam	-	-	28.03
5	North-facing	0-6	-	-	-		22	5.65	193.5
	Slope	6-16	26.0	62.3	11.7	silt loam	-	5.8	25.45
		16-27+	-	-	-		-	6.25	-
9	Central	0.8	52.8	26.4	20.8	sandy loam	44.5	6.6	226.0
	East-facing	8-18	12.1	76.4	11.6	silt loam	-	6.9	67.89
	slope	18-23.6	39.2	42.0	18.8	loam	-	6.9	109.59
		23.5-46+	50.0	40.1	9.9	loam	-	7.1	67.4
13	South-facing	0-7	58.8	29.7	11.5	sandy loam	42.5	6.9	163.0
	Slope	7-27	21.5	72.2	6.3	silt loam	-	6.8	25.0
		27-76+	-	-	-		-	6.9	-
17	Ridge of South-facing	0-5	59.5	20	20.5	sandy clay loam	47.5	6.8	149.0
	slope	5-5.5	ASH	ASH	ASH		ASH	7.15	-
		5.5-10	52.0	39.4	9.6	loam	-	6.4	18.0
		10-16+	-	-	-		-	6.8	-

The physical properties of soil - texture, structure, temperature, chemistry and colour - are all dominant factors affecting vegetational development. Organic matter, a biological component, undergoes a number of important interactions with all the aforementioned physical properties. In any given environment, organic matter has a positive effect on soil structure and soil porosity as well as helping to reduce erosion by wind and moisture (Donahue, et. al., 1977). Chemically, organic matter is the source of nearly all nitrogen and up to 60 per cent of all available phosphorus (Brady, 1974).

Decomposition rates of organic matter were found to be dependent on both soil temperature and soil moisture content. Early research by Tedrow (1959) reported that soil moisture content tended to have its greatest effect on decomposition during periods of high temperature. At 19.5°C the rate of organic matter decomposition was approximately seven times as great as at 7°C. In sub-arctic alpine regions of the Yukon, such as Grizzly Creek, where the mean annual air temperature is less than 0°C, the rate of organic matter decomposition is extremely low.

The organic matter content of a sample taken from the upper 5 cm of each profile, is presented in Table 5.1.1. Along the transect, organic matter content tends to be lower on the north-facing ridge and slope than on the south-facing slope and ridge. The north-facing slope for example contained only 22% organic matter in the Ah horizon compared with 42.5% organic matter content in the Ah horizon on the south-facing slope. Similarly, the ridge on the north-facing slope only contained 15% organic matter in the Ah horizon compared with 47.5% organic matter content on the south-facing ridge. At the base of the central east-facing slope organic matter content also tended to increase. Overall, organic matter content tends to increase on the slopes better exposed to solar radiation.

Texture, one of the most important physical properties of soil, affects the moisture holding capacity of the soil, water absorption, the amount of aeration (vital to root growth) as well as soil fertility. In Grizzly Creek, soil texture varied considerably along the transect (Table 5.1.1). The north-facing slope had, in general, a high silt content in the Ah and B horizons whereas the south-facing slope had a high sand content in the Ah and B horizons. The mid-slope locations followed a similar pattern with the exception that the B horizon on the south-facing slope was dominated by silt. Solifluction lobes on the central east-facing slope are responsible for the soil texture profile observed. The Ah has a high proportion of sand-sized particles, while the C horizon directly below it has a high silt content. The sandier Ofb horizon underlying the C represents the upper horizon of a buried paleosol (Figure 5.2.3).

Water content in soil has an effect on soil formation, erosion structure stability and plant growth. Water serves four functions in plants: it is the major constituent of plant protoplasm (85-95 percent); it is essential for photosynthesis and the conversion of starches to sugars; it is the solvent in which nutrients move into and through plant parts; and it provides plant turgidity, which maintains the proper form and position of plant parts to capture sunlight (Donahue, et. al., 1977).

Vegetation absorbs some water through leaf stomata, but most of the water used by plants is absorbed by the roots from the soil. For optimum water use, it is vital to know how water moves into and through the soil, how the soil stores water, how the plant absorbs it, how nutrients are lost from the soil by percolation and how to measure soil water content and losses.

Soil texture and organic matter content are important in determining the amount of water soils can retain. Increases in clay and organic matter content increase total wa[illegible] retention and the extremely large total surface areas of clay particles and organic materials cause a large amount of water to be held tightly close to the surface by adhesion.

In less clayey soils with less surface area or in soils with less organic matter, more of the total water will be held less strongly (Donahue, et. al., 1977).

Soil moisture content varied considerably from site to site, as did soil texture and organic matter content. The north-facing ridge had a low moisture content in the Ah horizon and a high moisture content in the B horizon (55% and 43%) whereas the south-facing ridge had a high moisture content in the Ah horizon and a low moisture content in the B horizon (149% and 18%). In contrast, the mid-slope locations had quite similar moisture contents. On the south-facing slope the Ah horizon had a 163% moisture content and the B horizon had a 25% moisture content. On the north-facing slope the Ah horizon had a 193.5% moisture content and the B horizon a similar 25% moisture content. Meltwater from the underlying permafrost in the valley bottom, flowed through the soil profile increasing moisture contents considerably. The Ah horizon had a moisture content of 226%, the C horizon directly below it had a 68% moisture content and the Ofb horizon underlying the C horizon a 109% moisture content.

These differences in moisture contents across the transect are related to a number of important variables. While soil texture plays a significant role in lower latitudes, it appears to have a marginal affect in subarctic-alpine environments. Slope exposure, organic matter content and microtopography seem to be much more important factors. For example, prevailing northwest winds result in a much higher distribution of moisture on the leeward, south-facing, slope thereby greatly affecting the soil moisture regime.

Soil pH is easily determined and provides clues about other soil properties such as nutrient status. There appears to be a trend towards lower, much more acidic, pH values on the northern exposures than on the south- and east-facing slopes (Table 5.1.1). For example, the soil pH of the Ah and B horizons (5.79-5.9) on the north-facing ridge was much lower than the pH of the Ah and B horizons (6.8-6.4) on the south-facing ridge. Similar conditions existed between the north- and south-facing slopes. The soil pH was 5.65 in the Ah horizon and 5.8 in the B horizon of the north-facing slope compared with 6.9 in the Ah horizon and 6.8 in the B horizon of the south-facing slope. The soil pH was also higher in the valley bottom than on the northern slope, where values of 6.6 in the Ah horizon and 6.9 in the C horizon were recorded.

Increased acidity along the northerly exposed surface is probably due mainly to the leaching away of the basic cations (Ca^{++}, Mg^{++}, K^+, Na^+) and replacement of many of them by H^+ cations from carbonic acid (H_2CO_3) formed from dissolved carbonates from dissolved Al hydrozyl ions. This appears to be a result of poor soil texture and low organic matter content.

5.1.2 Nutrient Variability Along Select Sites:

As previously mentioned, an important trend in successional development is the closing or tightening of the biogeochemical cycling of major nutrients such as nitrogen, phosphorus, and calcium. Mature systems, as compared to developing ones, have a greater capacity to entrap and hold nutrients for cycling within the system (Odum, 1969). Reductions in the volume of vegetation or degree of development such as on the north-facing slope, results in increased water yield causing greater outflow accompanied by greater nutrient losses.

In Grizzly Creek, concentrations of P^+, K^+, Ca^{++}, Mg^{++} and N were examined in relation to plant succession on north-, south- and east-facing slopes. Concentrations of most of the available P^+, K^+, Ca^{++}, Mg^{++} and N and exchangeable cations$^+$ (see Tables 5.1.2, 5.1.3) decrease significantly as one progresses from the south to the north-facing slope. Increased concentrations of some nutrients in the valley bottom appears to be related to meltwater leaching along the valley slopes.

Table 5.1.2

Site Specific
Concentration of Macronutrients

mgm/gm

Location	Sample #	Depth(cm)	N	Ca	Mg	P	K
Ridge	1-1	0-5	11.5	8.4	.109	3.31	.484
of	1-2	5-10	1.43	1.5	.032	1.08	.098
S-facing	1-3	10-16+	1.18	1.9	.035	1.795	.094
Mid-Slope	2-1	0-7	9.485	6.4	.132	1.176	.374
S-facing	2-2	7-27	1.51	2.5	.070	1.12	.099
	2-3	27-76+	.619	1.5	.036	1.74	.080
Midpoint	3-1	0-8	10.15	6.2	.073	1.572	.581
E-facing	3-2	8-18	3.849	3.7	.033	1.08	.109
	3-3	18-23.6	3.6	3.9	.040	1.512	.106
	3-4	23.6-54.6+	.96	2.0	.026	1.356	.077
Mid-Slope	4-1	0-6	3.844	2.0	.061	1.176	.179
N-facing	4-2	6-16	.772	2.5	.036	1.056	.060
	4-3	16-17+	.97	1.7	.039	.912	.039
Ridge	5-1	0-6	3.813	1.6	.063	.912	.093
of	5-2	6-16	2.784	1.9	.058	.624	.035
N-facing	5-3	16-21+	2.739	1.9	.051	.732	.034

Table 5.1.3– Concentration of Macronutrients in Soil Horizons

Station Number	Location	Depth (cm)	Kjeldahl nitrogen (mg/gm)	Available P(mg/gm)	Available Metallic Cations meq/100gms			C.E.C. of Major Metallic Macronutrients
					K	Ca	Mg	
1	Ridge of North-facing Slope	0-6	3.813	.912	.242	9.5	.523	10.39
		6-16	2.784	.624	.09	9.5	.48	10.19
		16-21+	2.739	.732	.088	8.5	.42	9.12
5	North-facing Slope	0-6	3.844	1.176	.456	12.5	.506	13.74
		6-16	.772	1.056	.156	8.5	.298	9.2
		16-27+	.97	.912	.101	8.0	.324	8.68
9	Central East-facing Slope	0-8	10.15	1.572	1.51	31.0	.61	33.49
		8-18	3.849	1.08	.28	18.5	.278	19.39
		18-23.6	3.6	1.512	.276	19.5	.332	20.34
		23.6-54.6+	.96	1.356	.20	10.0	.216	10.66
13	South-facing Slope	0-7	9.485	1.176	.972	32.0	1.09	34.37
		7-27	1.51	1.116	.257	12.5	.581	13.56
		27-76+	.619	1.74	.208	7.5	.298	8.24
17	Ridge of South-facing Slope	0-5	11.5	3.312	1.26	42.5	.904	44.88
		5-10	1.43	1.08	.25	7.5	.266	8.29
		10-16+	1.18	1.795	.24	9.5	.291	10.3

Total quantities of P^+, K^+, Ca^{++}, Mg^{++} and N in available and exchangeable forms are consistently lower in the sphagnum soils on the north-facing slope (see Table 5.1.3). The depth distribution of these nutrients on a volume basis also differs. In the sphagnum soils, their distribution is much more even while on the south- and east-facing slopes the nutrients are concentrated in the organically rich Ah horizons (see Table 5.1.3). Results from this set of data clearly indicates that declining availability of nutrients is a primary factor in reducing plant productivity on the north-facing slope.

5.2.1 Discussion: Solar Radiation:

The effect of rugged topography is to create what have been referred to, as countless topoclimates (Thornthwaite, 1954; Geiger, 1950) which differ greatly from one another in response to slope and aspect effects. Consequently, the amount of solar radiation, precipitation and wind speed is extremely variable, and bears little resemblance to the given or expected values at high altitudes (Barry & Van Wie, 1971). Mountain areas, then, usually present such a mosaic of heterogeneous facets that standard climatological analysis is usually quite misleading.

In the alpine regions, climatic conditions at or near the ground surface have an important effect on the distribution of plant species (Geiger, 1950). These small-scale climates result from the interaction of local surface features with the prevailing regional meterogical controls (Barry & Van Wie, 1971). In Grizzly Creek slope angle and aspect were major determinants of topo- and microclimates. Differences in radiation receipts resulting from topographic factors were reflected in soil and air temperatures, relative humidities and soil moisture contents and consequently in the distribution of vegetation. Similarly, variations in wind, resulting from topographic differences, were reflected in the pattern of distribution of precipitation thereby indirectly affecting nutrient status and plant location.

In any given environment microclimatic differences are largely the result of the balance of direct insolation, diffuse sky radiation and terrestrial radiation. Geiger (1965) estimated the distribution of incoming radiation during a summer day to be as follows: (1) global radiation, which is the sum of the direct beam penetration to the earth's surface (19 percent) and the diffuse sky radiation (26 percent); (2) scattered radiation returned to outer space (11 percent); (3) reflected by clouds (28 percent); and (4) absorbed by the atmosphere (16 percent). Thus, the short-wave radiation reaching the ground represents 45 percent of the incoming energy.

In mountainous regions direct insolation plays a very important role in determining the thermal regime of the soil and the growth of plants. In rugged environments such as Grizzly Creek direct beam solar radiation is influenced greatly by slope and the angle of incidence. Figure 5.2. demonstrates that at Grizzly Creek at midday on June 25, 1979, the decrease in the angle of incidence from the north-, east- and south-facing slopes is 62.5°, 36° and 17.5° respectively. On the same day, approximately 562 cal cm^{-2} were received on the south-facing slope compared to only 418 cal cm^{-2} on the north-facing slope. Consequently, in the former case the amount of heat received per unit area decreases as the area covered increases.

Unlike direct insolation, sky radiation has a tendency to moderate differences of exposure, since all slopes receive roughly the same amount of heat energy from this source. Geiger (1950) points out that in the Arctic where the ratio of direct to diffuse radiation is relatively small, exposure usually is not quite as significant a factor as in the middle latitudes. Terrestrial radiation in comparison, is easily absorbed by the atmosphere because it consists largely of very long wavelengths (4 to 30 microns) in contrast to the visible light rays (0.4 to 0.7 microns) and shorter infrared rays (0.7 to 3.0 microns) which make

Angle of Incidence
for North- South-
and East-Facing Slopes
at Noon on June 25, 1979

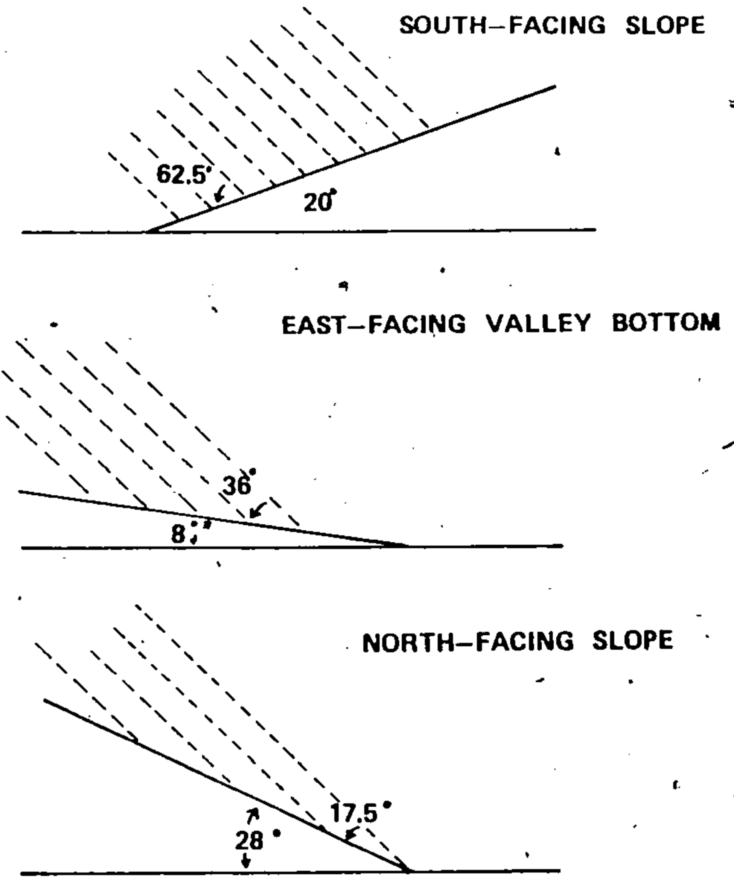


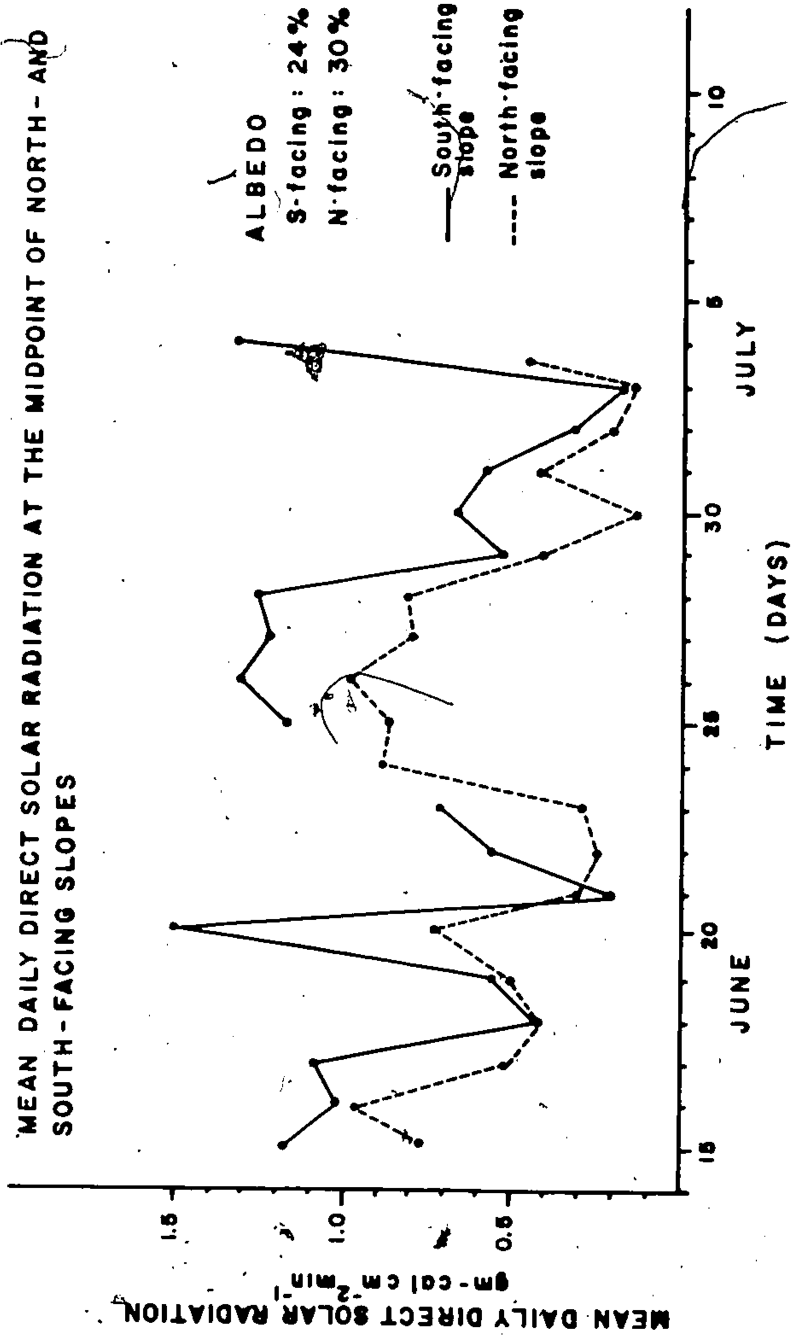
Figure 5.2.1

up almost all of the diffuse and direct incoming solar radiation (Strahler, 1975).

Cloud cover is also important in subarctic-alpine environments because of the moderating affect it can have on temperature. Temperatures are lower and much more uniform on the three slopes, when direct insulation has been screened out by cloud cover. During the night cloud cover acts as a blanket, reflecting long-wave radiation back to the earth increasing surface temperature. During the summer months of June to August, average cloud cover for Whitehorse, southwestern Yukon is about 60% (Webber, 1974). Over a 31-day period (June 10-July 9, 1979) at Grizzly Creek, total cloud cover averaged approximately 66%.

In Grizzly Creek, the major climatic variations experienced between north-, south- and east-facing slopes is a result of differences in the amounts of direct beam solar radiation received. Although no quantitative figures concerning direct radiation are available for the east-facing slope, considerable information is available for the north- and south-facing mid-slopes.

During a 20-day period (June 15-July 4, 1979) the mean daily amount of direct solar radiation received on the south-facing slope was consistently higher than the amount received on the north-facing slope (see Figure 5.2.2). Over the 20-day



MEAN DAILY DIRECT SOLAR RADIATION AT THE MIDPOINT OF NORTH- AND SOUTH-FACING SLOPES

Figure 5.2.2

period a mean average of 404 cal cm^{-2} day^{-1} were received on the south-facing slope, compared to only 262 cal cm^{-2} day^{-1} on the north-facing slope. These aforementioned mean variations in receipt of incoming direct solar radiation occurred during the period surrounding summer solstice (June 22, 1979). It is therefore reasonable to assume that the preceding values approximate the peak amounts of direct radiant energy received at these sites for 1979.

The percentage reflection, or albedo, (the ratio of the reflected to the incident radiation) is dependent upon the nature of the surface, the angle of the sun, and the solar elevation. In Grizzly Creek between June 15-July 4, 1979, albedo rates were considerably higher on the north-facing slope (30 percent) compared to only 24 percent on the south-facing slope. Hypothetically, higher reflectance values were anticipated on the south-facing as opposed to the north-facing slope. This hypothetical difference was based on extreme variations in vegetation cover (the predominance of light brown graminoid species and much dryer conditions on the south-facing slope opposed to moss-dominated wetter conditions on the north-facing slope). The difference however, appears to be due mainly to variations in the angle of incidence at the 3 sites. Other climatic parameters such as prevailing wind may affect albedo rates to a certain extent. Unfortunately the importance of convective air flow at the study sites was not quantified.

5.2.2 Temperature:

Temperature was the most carefully monitored micro-climatic factor at Grizzly Creek. Daily air, soil surface and soil subsurface temperatures were measured at the middle of the north-, south-, and east-facing slopes. Between June 9 and July 12, 1979, the temperature at screen height on the south-facing slope was higher than the air temperature at screen height, on the north-facing slope, 84 percent of the time. The temperature on the east-facing slope was higher than the temperature on the north-facing slope 66 percent of the time (Figure 5.2.3, 5.2.5, 5.2.7).

Comparisons of the mean minimum and maximum air and soil surface temperatures at the 3 sites (Figure 5.24 and Figure 5.2.6) illustrate the extreme diurnal variations in temperature that occur in these subarctic-alpine environments. The greater difference between the minimum and maximum soil surface temperatures than air temperatures is a result of variations in convective transfers between the 3 sites.

Subsurface soil temperatures decrease daily with depth (Figure 5.2.7). Similar to air temperatures, subsurface soil temperatures tend to show a decrease in diurnal variation. Overall differences in subsurface temperature are directly related to slope, aspect and vegetative cover.

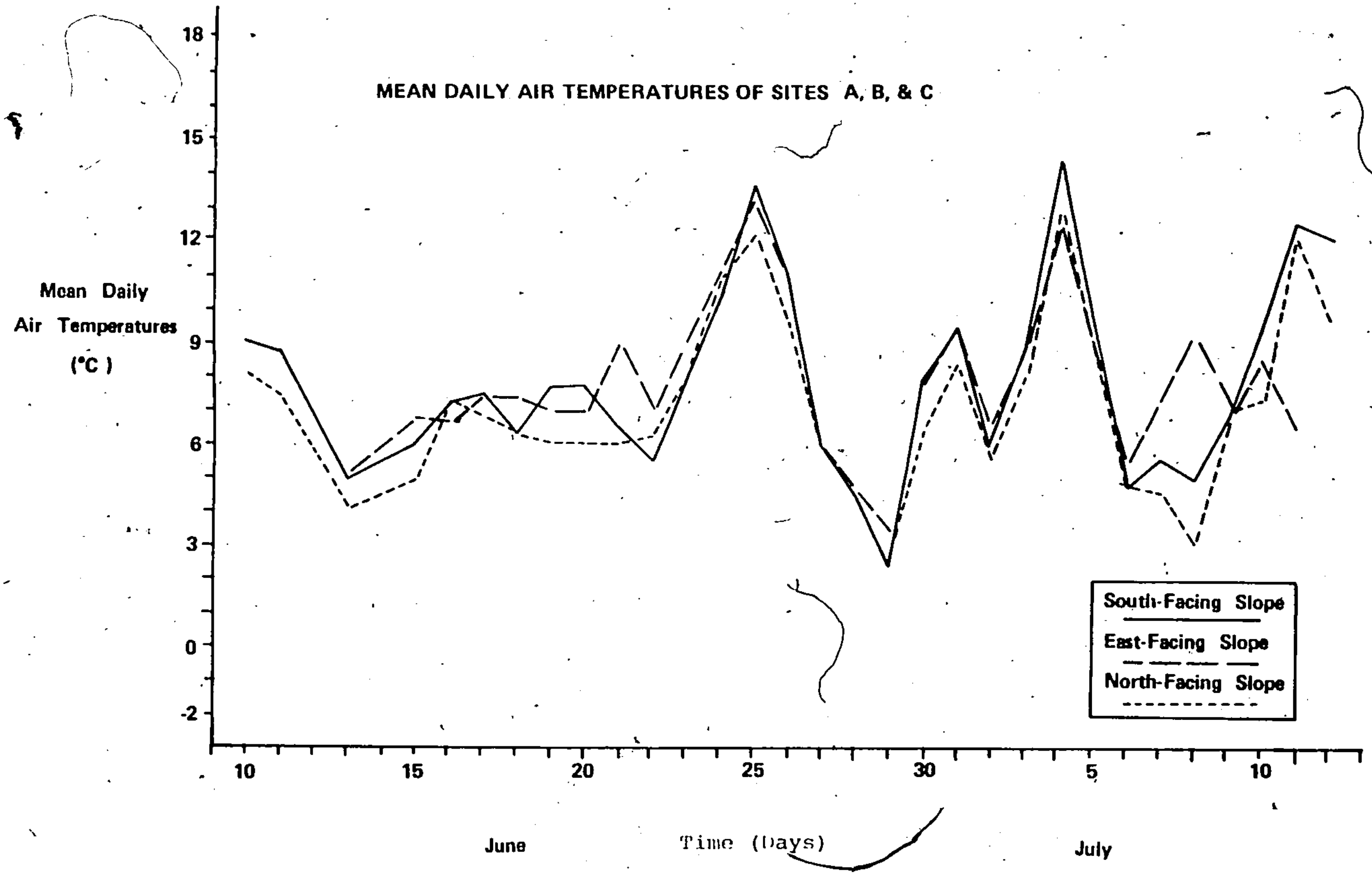

MEAN DAILY AIR TEMPERATURES OF SITES A, B, & C
Mean Daily
Air Temperatures
(°C)
18
15
12
9
6
3
0
-2
10
15
20
25
30
5
10
June
Time (Days)
July
South-Facing Slope
East-Facing Slope
North-Facing Slope

Figure 5.2.3

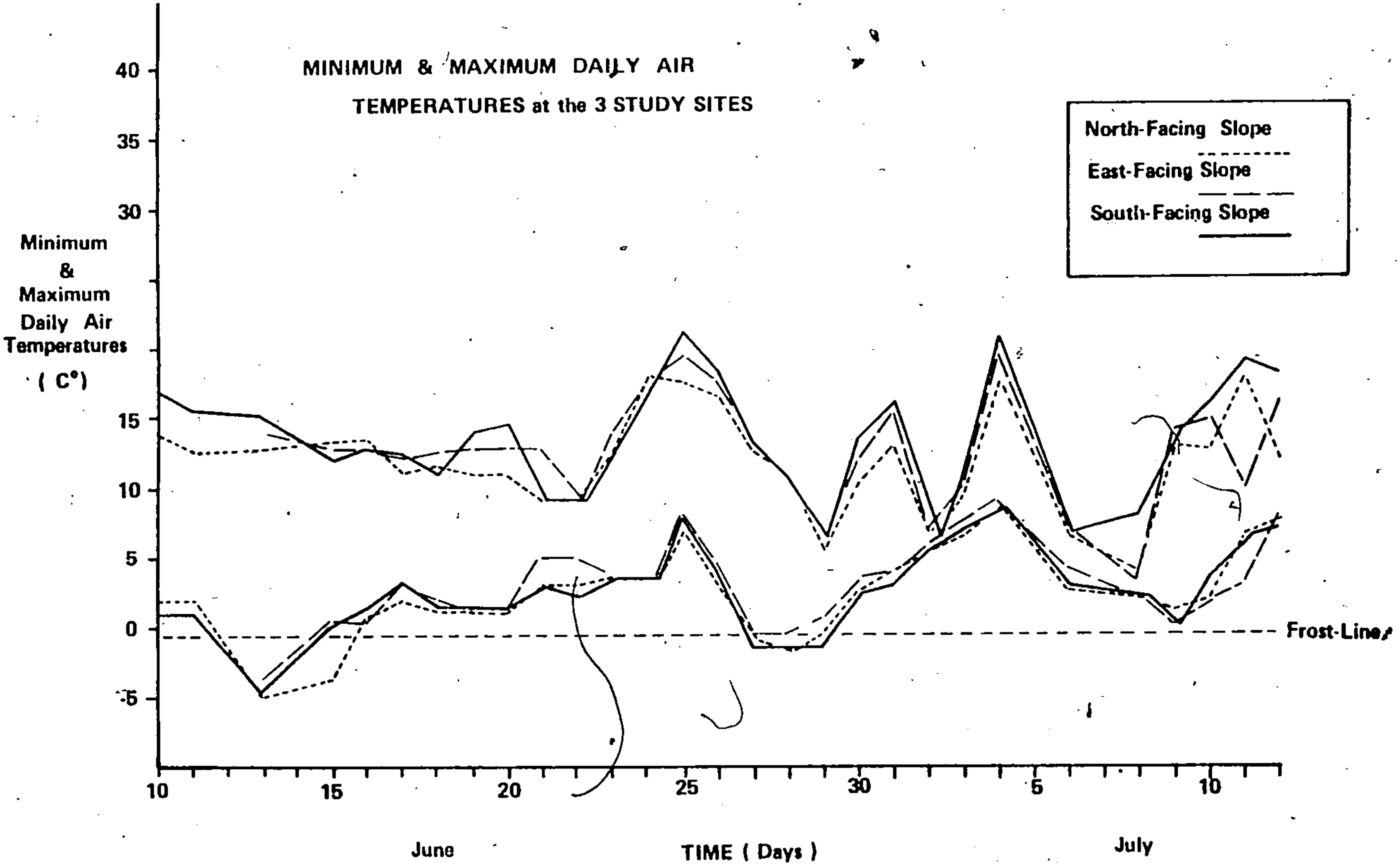

MINIMUM & MAXIMUM DAILY AIR
TEMPERATURES at the 3 STUDY SITES
North-Facing Slope
East-Facing Slope
South-Facing Slope
Minimum & Maximum Daily Air Temperatures (C°)
40
35
30
15
10
5
0
-5
Frost-Line
10
15
20
25
30
5
10
June
TIME (Days)
July

Figure 5.2.4

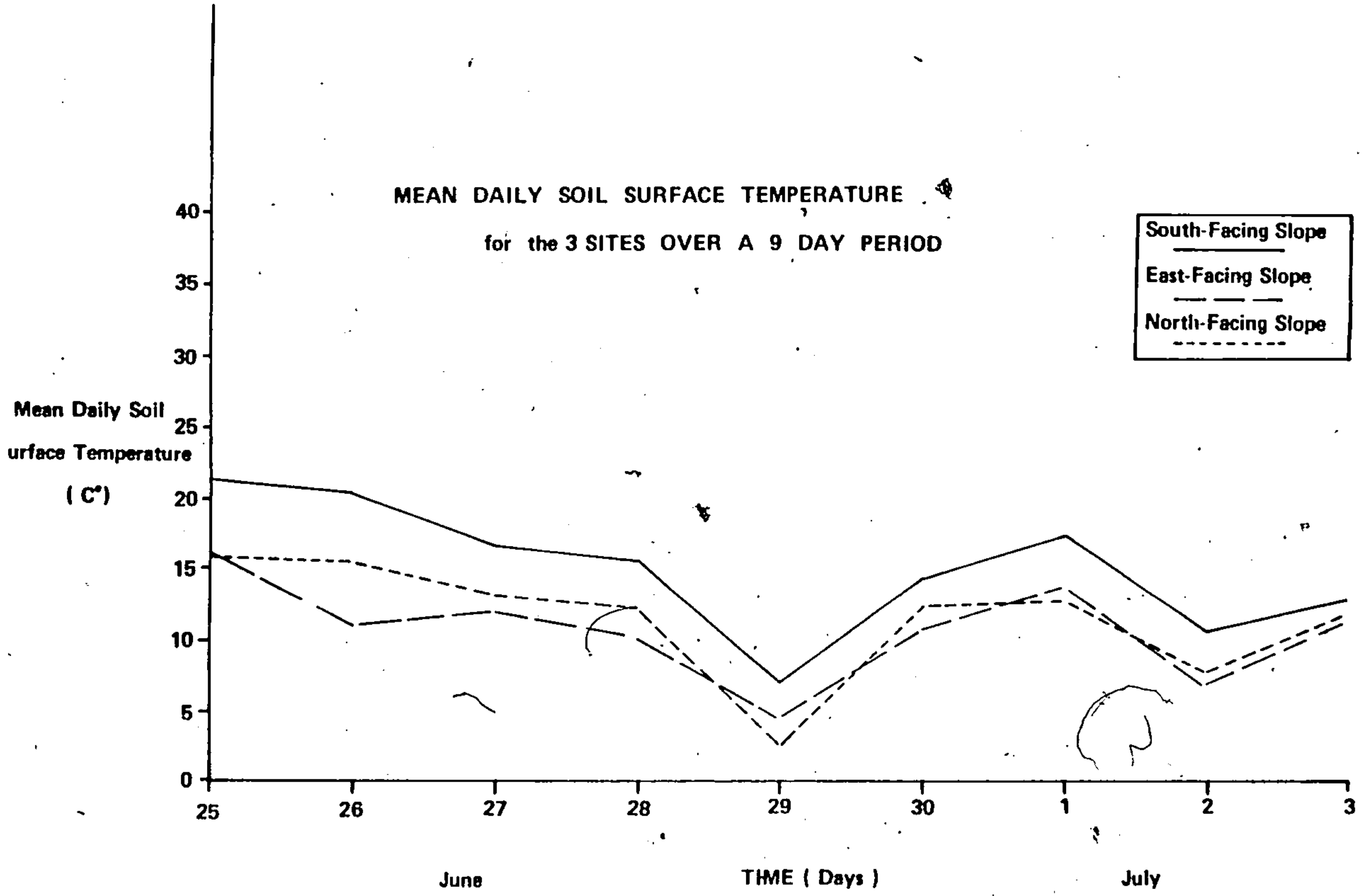

MEAN DAILY SOIL SURFACE TEMPERATURE
for the 3 SITES OVER A 9 DAY PERIOD
South-Facing Slope
East-Facing Slope
North-Facing Slope
Mean Daily Soil
urface Temperature
(C°)
40
35
30
25
20
15
10
5
0
25
26
27
28
29
30
1
2
3
June
TIME (Days)
July

Figure 5.2.5

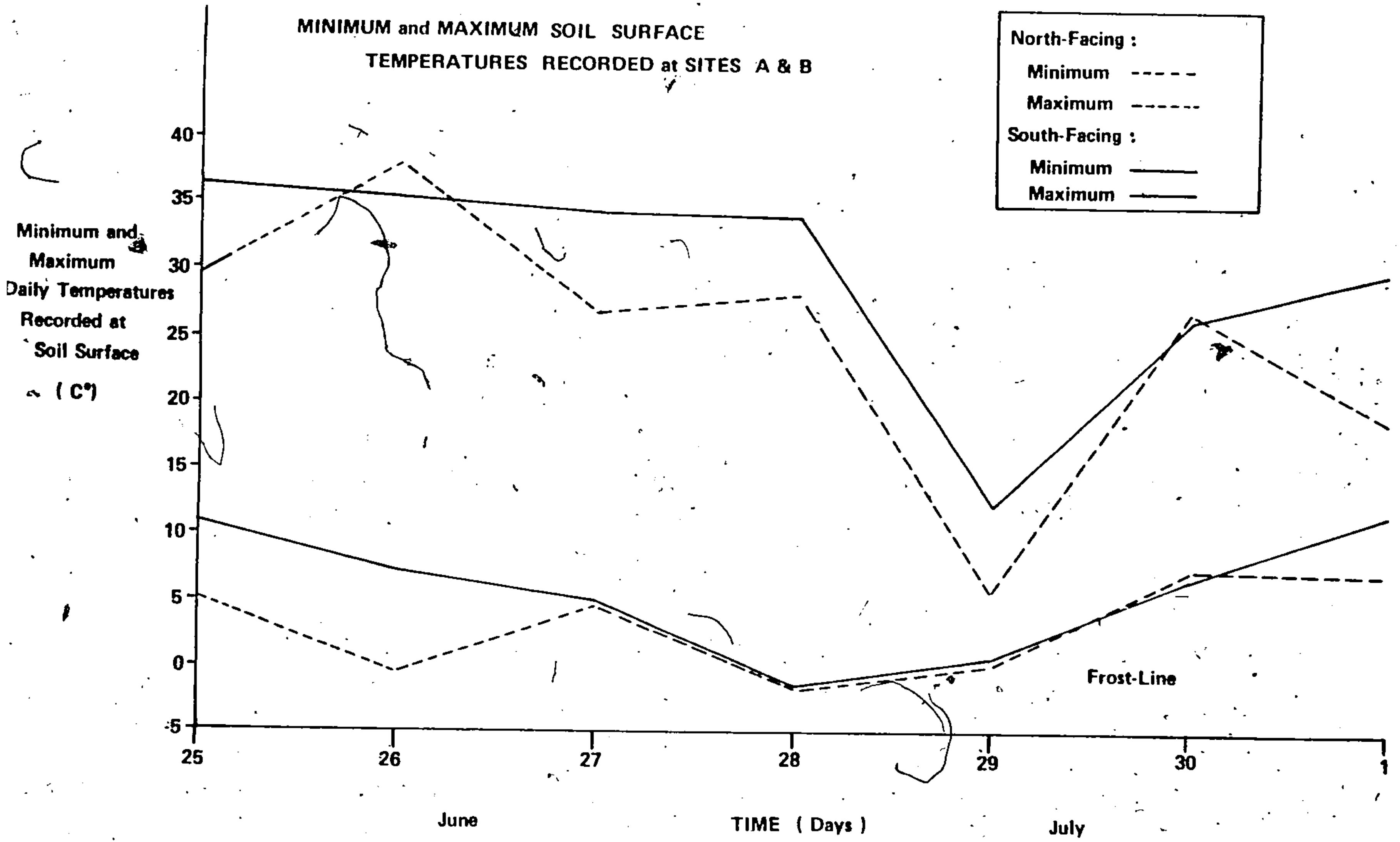

MINIMUM and MAXIMUM SOIL SURFACE
TEMPERATURES RECORDED at SITES A & B
North-Facing :
Minimum
Maximum
South-Facing :
Minimum
Maximum
Minimum and Maximum Daily Temperatures Recorded at Soil Surface (C°)
40
35
30
25
20
15
10
5
0
-5
25
26
27
28
29
30
1
June
TIME (Days)
July
Frost-Line

Figure 5.2.6

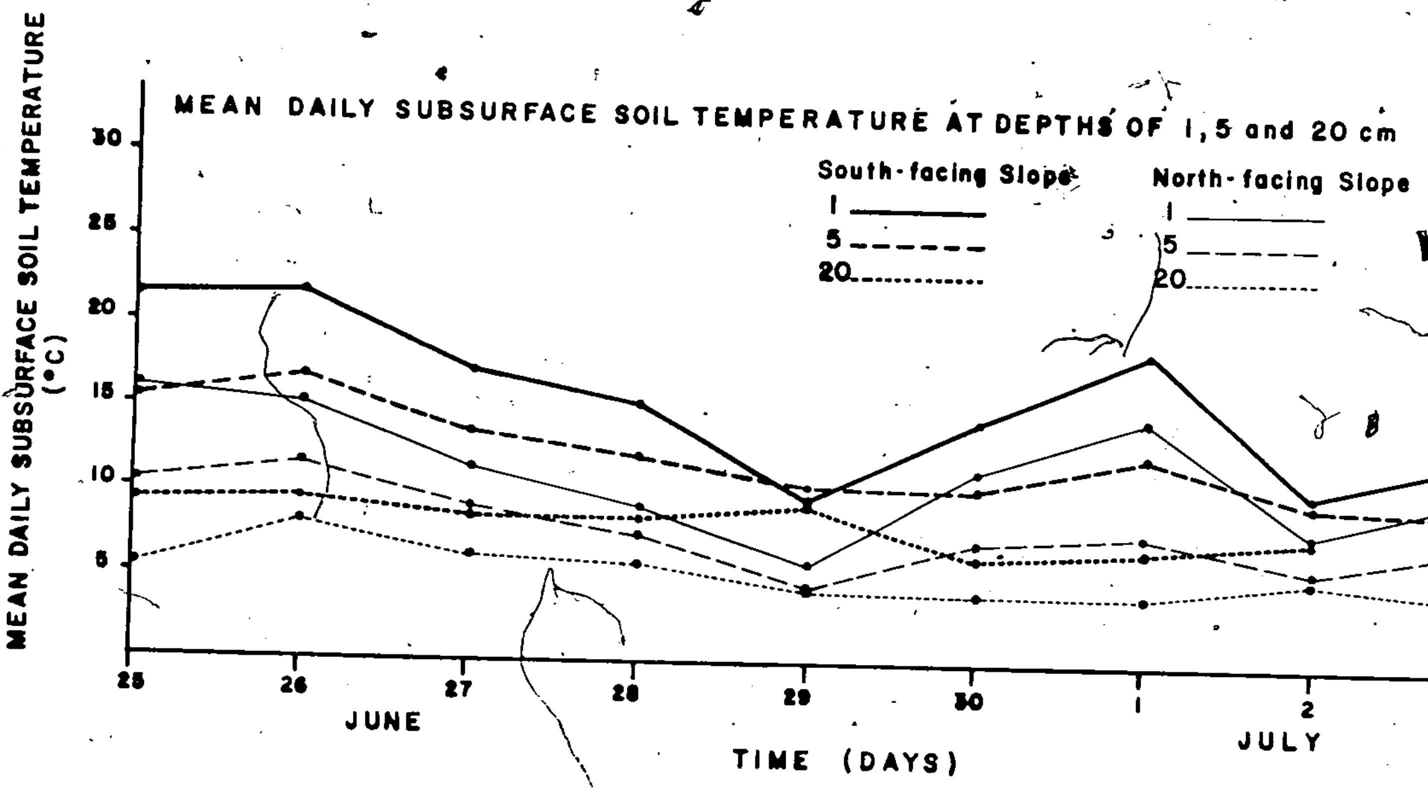

MEAN DAILY SUBSURFACE SOIL TEMPERATURE AT DEPTHS OF 1,5 and 20 cm
South-facing Slope
1
5
20
North-facing Slope
1
5
20
MEAN DAILY SUBSURFACE SOIL TEMPERATURE (°C)
30
25
20
15
10
5
25
26
27
28
29
30
1
2
3
JUNE
JULY
TIME (DAYS)

Figure 5.2.7

Vegetation plays a significant role on soil temperature because of the insulating properties of plant cover. The major impacts of vegetation are associated with (1) the albedo effect, (2) decreasing the depth of penetration of radiation through the canopy (Chang, et. al., 1965), (3) increasing the latent heat in evapotranspiration and (4) decreasing the rate of heat loss from the soil through its insulating effect. The temperature gradient depicted in Figure 5.2.8, graphically illustrates the mean temperature gradient between June 25-July 3, 1979. Differences between the north- and south-facing slopes are primarily related to major differences in absorption of direct insulation. Over a 20-day period (June 15-July 4, 1979), a mean total of 308 cal cm^{-2} day^{-1} were absorbed on the south-facing slope compared to only 184 cal cm^{-2} day^{-1} on the north-facing slope. The exact importance of vegetation cover in influencing soil temperature is not known, but it will be qualitatively assessed during the general discussion. It is however important to point out that it does appear to play a significant role.

Subsurface permafrost also plays an important role in affecting soil temperature. Permafrost, located at a depth of 80 cm below the soil surface at the midpoint of the east-facing slope, had a moderating affect on soil temperature (Figure 5.2.8). Over a 20-day period, the mean temperature

SOIL MEAN TEMPERATURE GRADIENT FOR PERIOD JUNE 25 - JULY 3, 1979

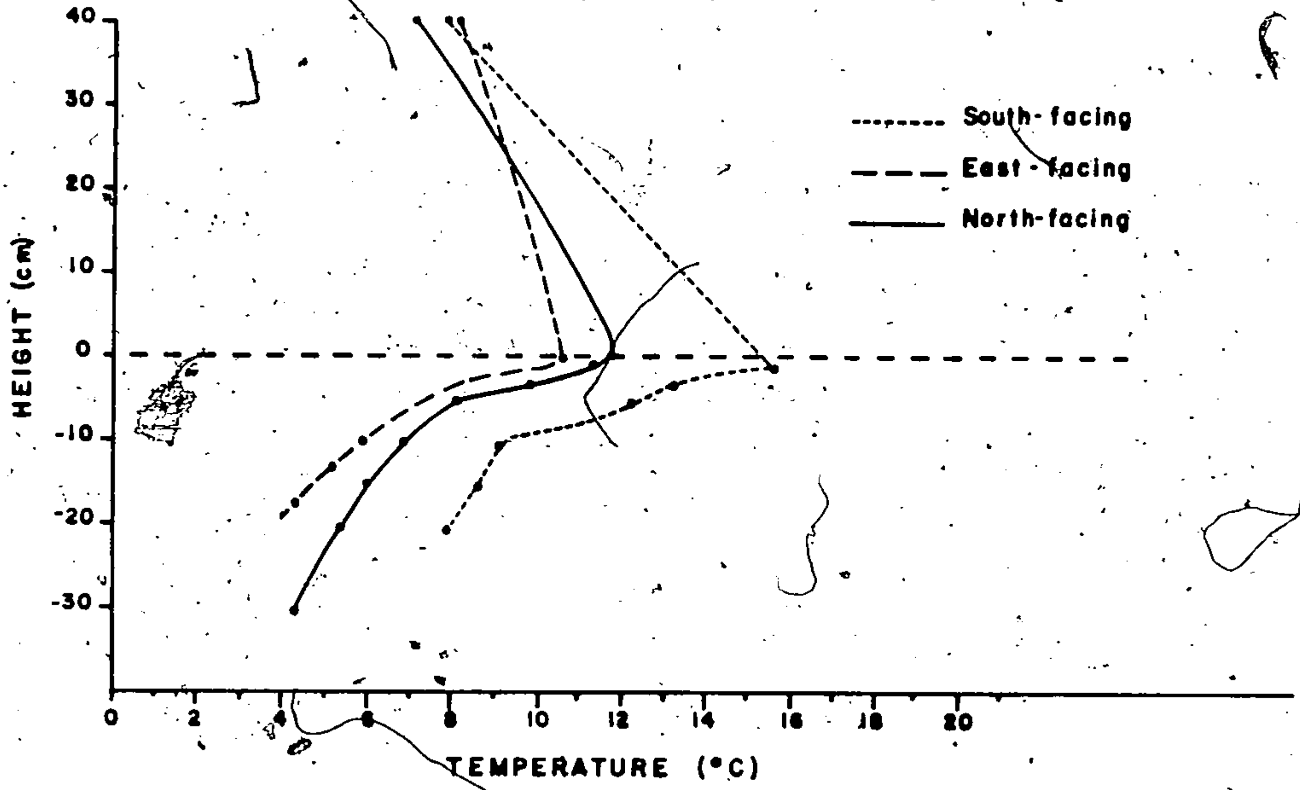


Figure 5.2.8

at screen height on the east-facing slope remained approximately 1°C warmer than air temperatures on the north-facing slope. In contrast, soil surface temperatures remained consistently colder (1.5°C) on the east-facing slope. The affect of this temperature difference on root development and the germination of seedlings cannot be overlooked, and will be evaluated in our final analysis of vegetation distribution.

5.2.3 <u>Precipitation</u>:

Large differences existed between the precipitation received by the north- and south-facing slopes. Between June 9 and July 15, 1979 a total of 95 mm fell on the south-facing slope and only 54 mm fell on the north-facing slope. The major differences occurred on days of heavy snowfall (Figure 5.2.9). The explanation for this probably is associated with the northwest winds which predominated during the storm periods and indeed most of the time (Figures 5.2.9- 5.2.12). A decrease in wind velocity over the south-facing slope results in the deposition of much larger volumes of snow (Figure 5.2.9), than on the north-facing slope. The increase in precipitation on the north-facing slope on July 17, 1979 was probably due to unstable wind conditions; unfortunately, however, no wind data exists to support this conclusion.

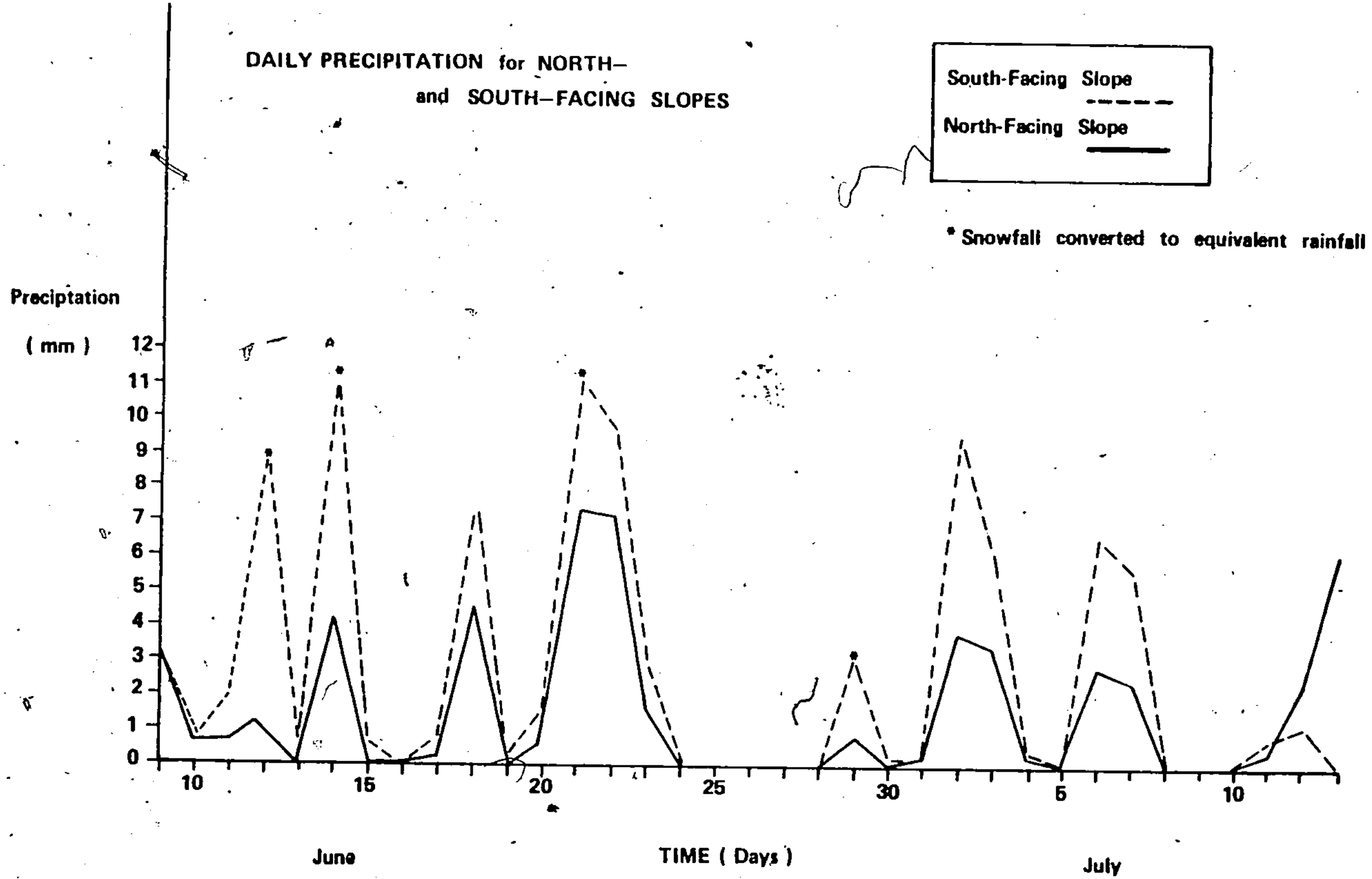

DAILY PRECIPITATION for NORTH- and SOUTH-FACING SLOPES
South-Facing Slope
North-Facing Slope
* Snowfall converted to equivalent rainfall
Preciptation (mm)
12
11
10
9
8
7
6
5
4
3
2
1
0
10
15
20
25
30
5
10
June
TIME (Days)
July

Figure 5:2.9

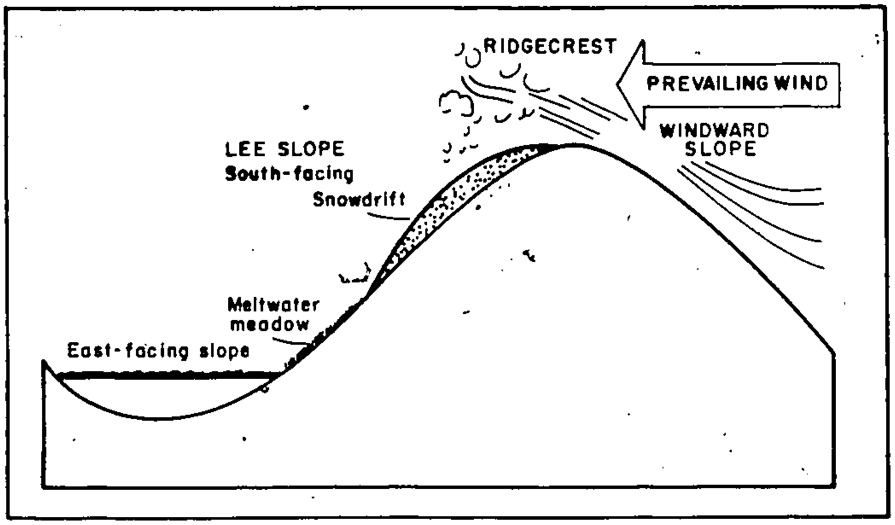


Figure 5.2.10

Diagram of a typical alpine mesotopographic gradient. (Modified from Tranquillini Physiological Ecology of the Alpine Timberline edited by W.D. Billings, Springer-Verlag, New York, 1979).

5.2.4 Relative Humidity:

Geiger (1950) reports that the humidity gradient tends to increase near the ground surface in a way similar to that of the temperature gradient. Thus, the values obtained at 40 cm above the ground will not be as high as those obtained if measurements are taken at the ground surface. Between June 25 and July 3, 1979 (Figure 5.2.11) the soil surface temperature was consistently warmer on the south-facing slope. Similarly, during this period direct solar radiation (Figure 5.2.2) inputs were consistently higher.

In response to these differences, during periods of precipitation, relative humidity values were higher on the south-facing slope - this being directly related to higher evapotranspiration rates as a result of higher temperatures. Conversely, on clear days higher direct insulation values on the south-facing slope resulted in faster drying rates causing a rapid decrease in relative humidity. Therefore this seems to indicate that the diurnal fluctuation in relative humidity is much more extreme on the south-facing slope than on the north-facing slope.

5.2.5 Wind:

Mean wind direction and the percentage frequency of wind direction are presented in Figure 5.2.12 and Figure 5.2.13, respectively. Between the period June 11-July 13, 1979, winds prevailed from the northwest 45 percent of the time. Extended periods of stratus and nimbostratus cloud cover were usually associated with the upvalley winds. Downvalley winds from the southeast, occurred 14 percent of the time. These winds were usually associated with periods of clear sky and high receipts of direct solar radiation. Unstable periods accounted for approximately 40% of the time. During these time periods weather patterns were unpredictable.

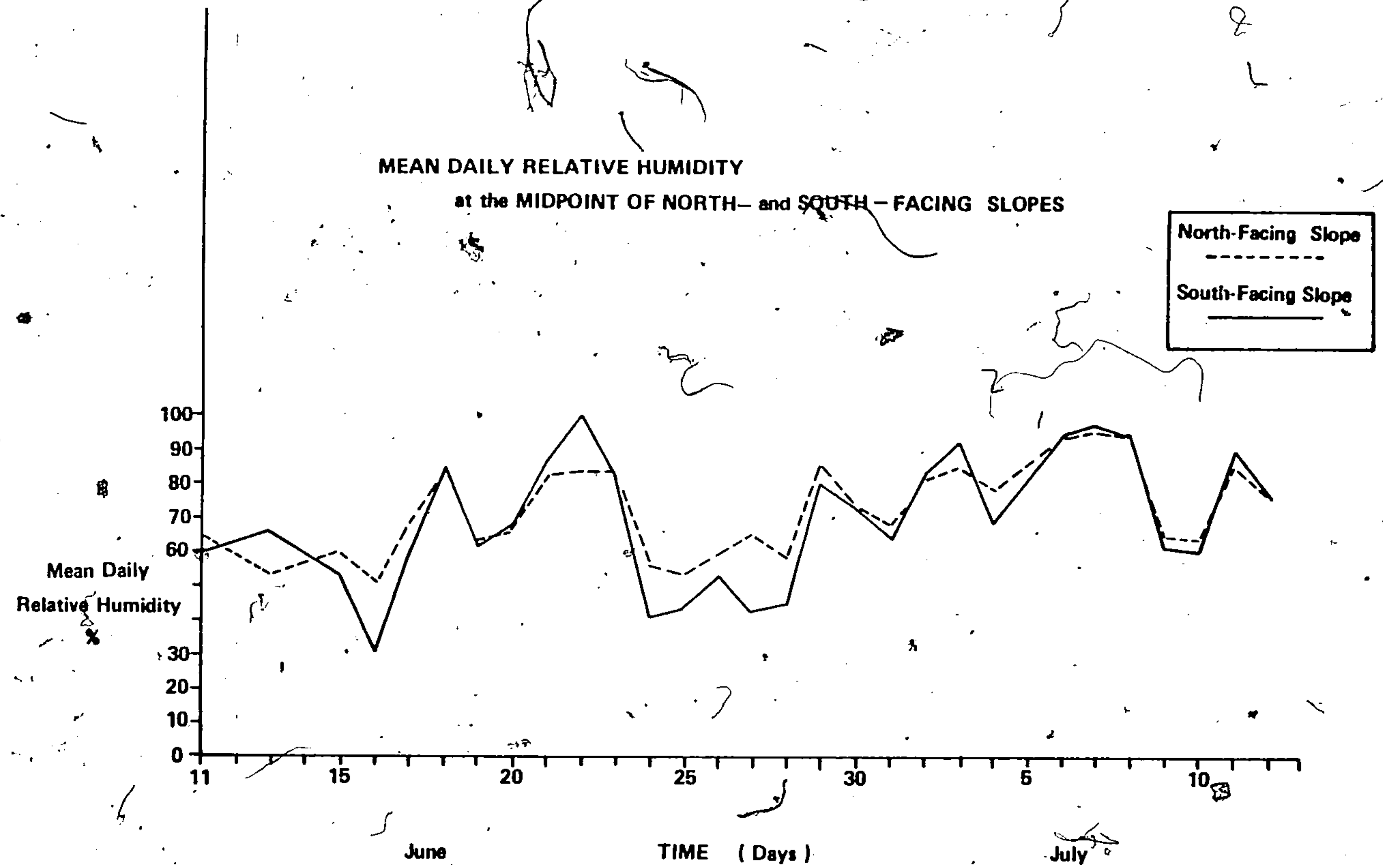
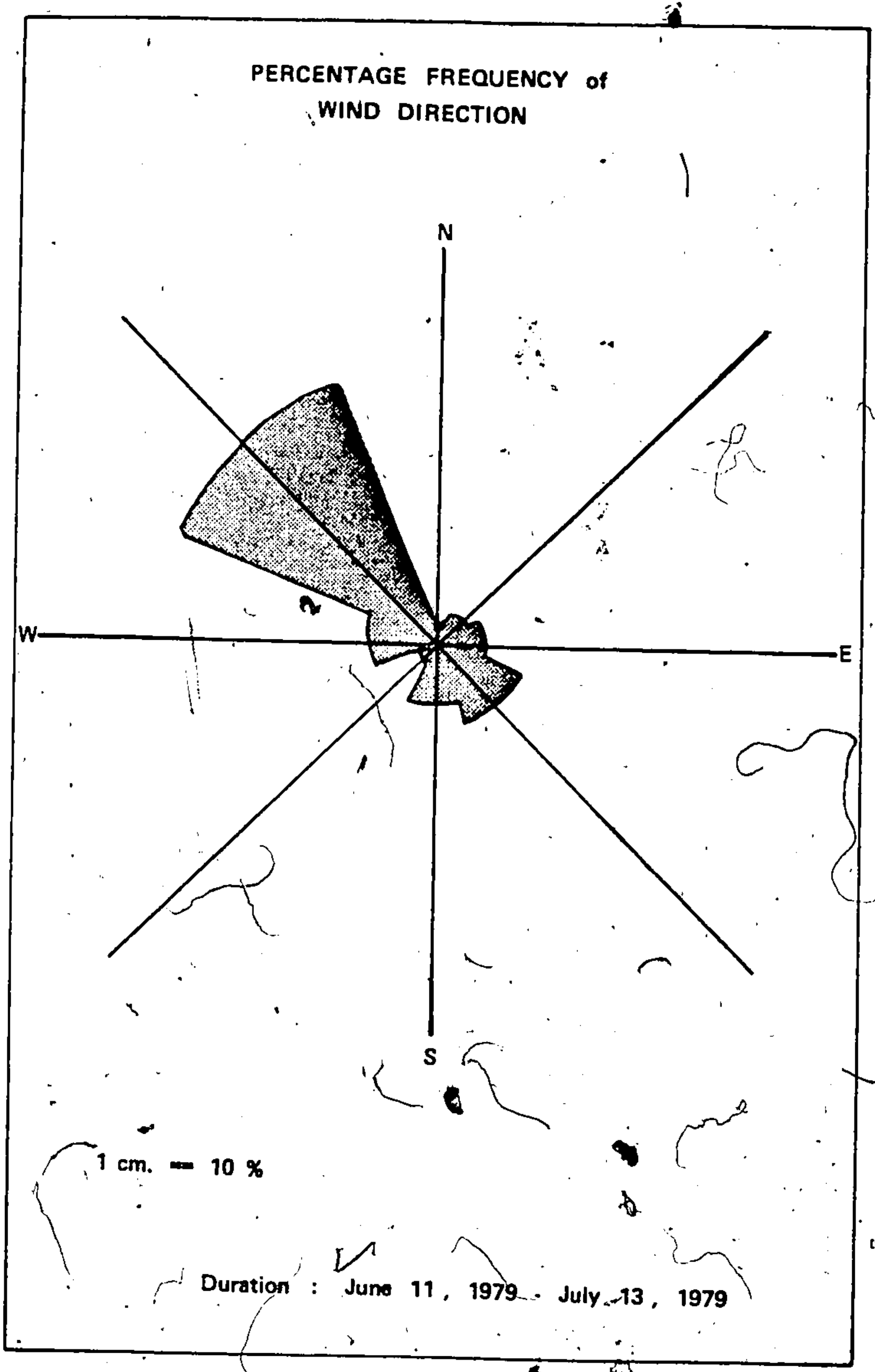

MEAN DAILY RELATIVE HUMIDITY
at the MIDPOINT OF NORTH– and SOUTH – FACING SLOPES
North-Facing Slope
South-Facing Slope
Mean Daily
Relative Humidity
%
100
90
80
70
60
30
20
10
0
11
15
20
25
30
5
10
June
TIME (Days)
July

Figure 5.2.11


PERCENTAGE FREQUENCY of WIND DIRECTION

1 cm. = 10 %

Duration : June 11, 1979 - July 13, 1979

Figure 5.2.12

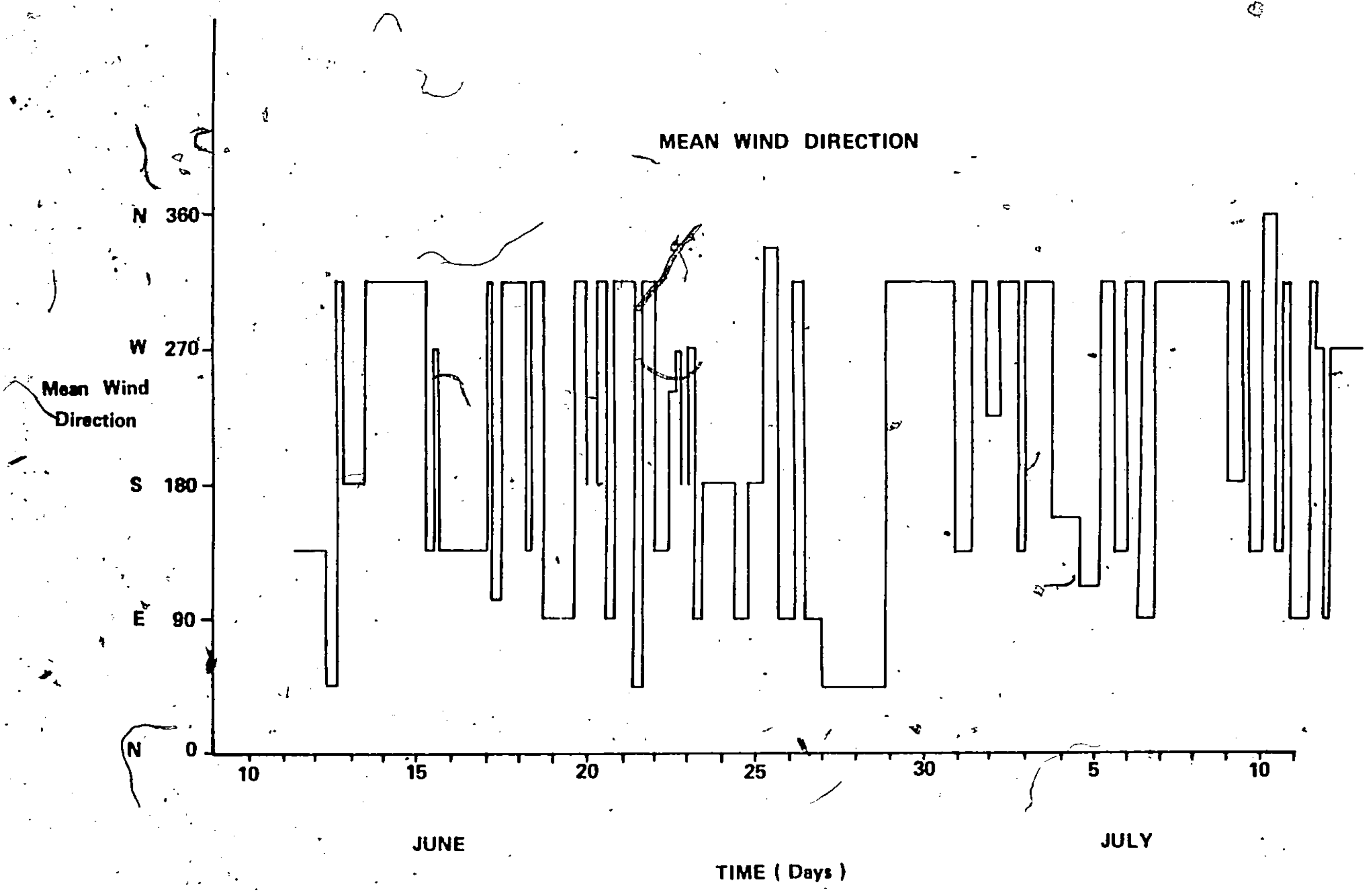

MEAN WIND DIRECTION
Mean Wind Direction
N 360
W 270
S 180
E 90
N 0
10
15
20
25
30
5
10
JUNE
JULY
TIME (Days)

Figure 5.2.13

5.3.1 Vegetative Analysis:

Table 5.3.1 provides in alphabetical order, a list of those plant species present or absent in each of the sample quadrats along the transect.

5.3.2 The Species Area Curve:

In all community sampling it is important to try and collect a sample representative of the total number of plant species occurring at the site. By plotting the cumulative number of species found against the number of sample sites that have been chosen to represent the sample area one can assess how well a specific area has been sampled. Species-area curves initially rise steeply then level off. The point at which the curve levels off is considered to be the min~~imal~~ suitable sampling area. Thus Figure 5.3.1 would indicate that the north- and south-facing slopes were adequately sampled whereas sampling for the central east-facing slope would appear to be inadequate. This apparent inadequacy may however be misleading, since the vegetation on the east-facing slope has a much higher diversity of species along its periphery. The increase in the number of species present along this boundary (illustrated in Figure 5.3.2) can be interpreted as representing the region of transition between the differing slope exposures. Commonly referred to as an ecotone (Odum, 1971), this transitional zone between the varying slopes contains plant species common to both the

TABLE 5.3.1

Presence-Absence Table

Genus - Species	North-facing	East-facing	South-facing
Aconitum delphinifoluum	Present	Present	Present
Anemone drummondii	Present	Present	Present
Anemone multifida	Present	Present	Present
Anemone parviflora	Present	Present	Present
Antennaria monocephala	Present	Present	Present
Arnica frigida spp.			Present
Artemisia arctica	Present	Present	Present
Artemisia globularia	Present	Present	
Astragalus umbellatus	Present	Present	
Castilleja hyperborea	Present	Present	Present
Cardamine purpurea	Present	Present	
Claytonia sarmentosa	Present	Present	
Clover		Present	
Corydalis spp.		Present	Present
Draba spp.	Present	Present	Present
Dryas octopetala	Present		Present
Equisetum variegatum		Present	
Erigeron spp.	Present	Present	Present
Fern		Present	Present
Gentian spp.	Present		
Graminae spp.	Present	Present	Present
Lichen	Present	Present	Present
Liverwort	Present	Present	Present
Lloydia serotina	Present	Present	Present
Lupinus arcticus		Present	Present
Mellandria spp.		Present	Present
Minuartia spp.	Present	Present	Present
Mertensia paniculata		Present	Present
Mosses	Present	Present	Present
Mushrooms spp.		Present	Present
Myosotis alpestris		Present	Present
Oxyria digynia	Present	Present	
Oxytropis nigrescens	Present	Present	
Oxytropis splendens		Present	Present
Parrya nudicaulis	Present	Present	
Pedicularis lanata	Present	Present	Present
Petasites hyperboreus		Present	
Palemonium boreale	Present	Present	Present
Polygonum bistorta	Present	Present	Present
Potentilla spp.			Present
Ranunculus pedatifidus	Present	Present	Present
Salix spp.	Present	Present	
Salix reticulata	Present	Present	
Salix rotundifolis	Present	Present	
Salix stolonifera	Present	Present	
Saxifraga loronchialis		Present	
Saxifraga davurica	Present	Present	Present

Presence-Absence Table

Genus - Species	North-facing	East-facing	South-facing
Saxifraga punctata	Present	Present	
Saxifraga reflexa	Present	Present	Present
Saxifraga tricospidata		Present	Present
Sedum rosea	Present	Present	
Senecio spp.	Present		
Stellaria spp.	Present	~~Present~~	Present
Valerian capitate		Present	
Zygodenus elegans		Present	Present

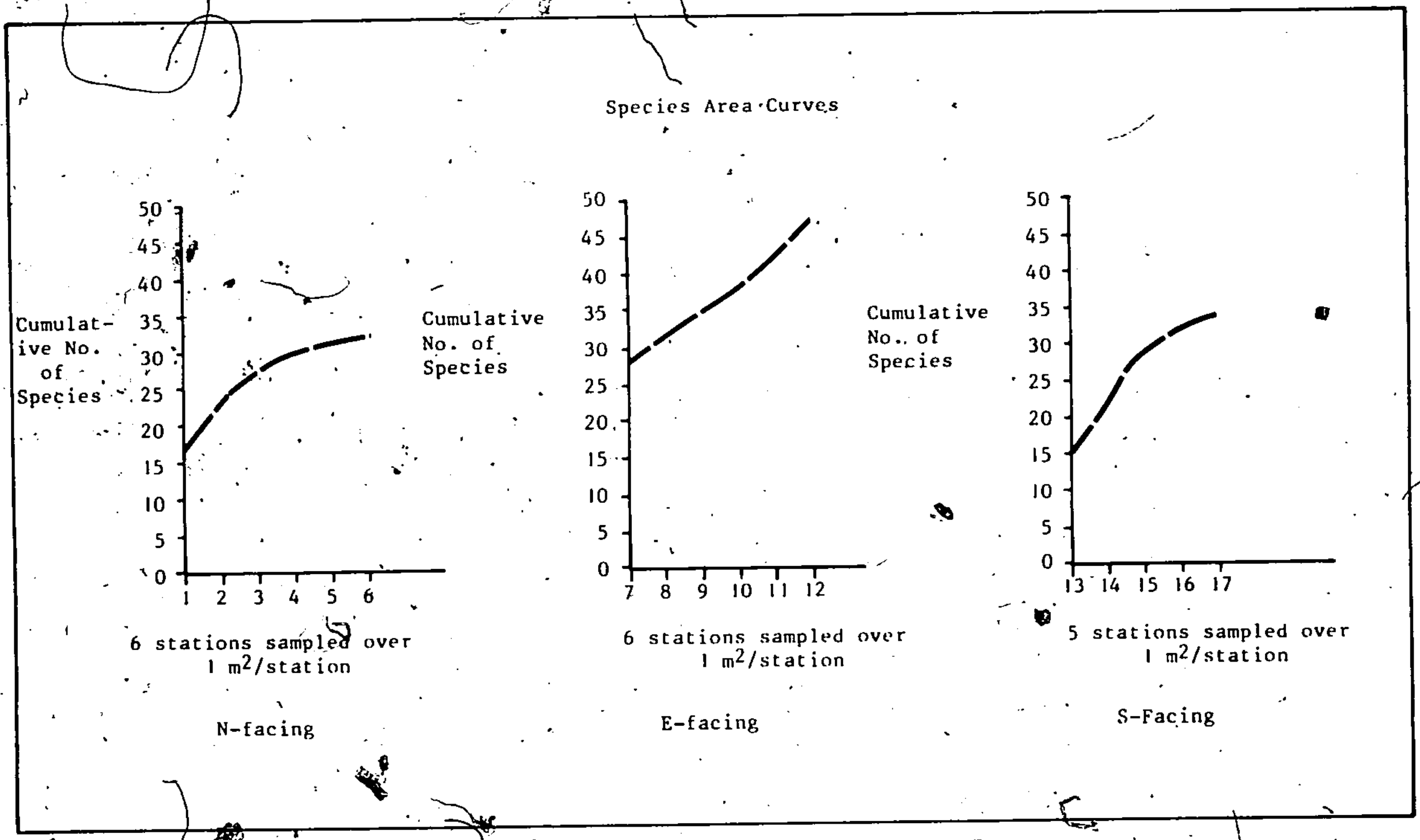

Species Area Curves
Cumulative No. of Species
50
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
6 stations sampled over 1 m^2/station
N-facing
Cumulative No. of Species
50
45
40
35
30
25
20
15
10
5
0
7
8
9
10
11
12
6 stations sampled over 1 m^2/station
E-facing
Cumulative No. of Species
50
45
40
35
30
25
20
15
10
5
0
13
14
15
16
17
5 stations sampled over 1 m^2/station
S-Facing

Figure 5.3.1

TABLE 5.3.2

Percent Coverage of Each Species
Using Daubenmire Cover Scale

Quadrat Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Exposure	N	N	N	N	N	N	E	E	E	E	E	E	S	S	S	S	S
Total spp.	18	20	25	22	20	20	28	24	25	25	23	28	17	20	28	23	21
Genus or Species % Coverage/Quadrat																	
Aconitum delphinifolium			1						1		1	1		1	1	1	
Anemone drummondii	1	1	1	1	1			1	1	1	1		1	1	1		
Anemone multifida	1		1	1	1		1	1	1	1	1	1	1	1	1	1	1
Anemone parviflora			1	1	1	1	1	1	1	1		1	1	1	1	1	1
Antennaria monocephala		1		1	1	1	1										
Arnica frigida														1	1		1
Artemisia arctica			1	1	1	1	1	1	1	1	1	1			1	1	
Artemisia globularia	1		1									1					
Astragalus umbellatus	1		1				1	1	1	1	1	1					
Castilleja hyperborea												1			1	1	
Cardamine purpurea	1	1	1		1		1	1	1								
Claytonia sarmentosa		1	1		1	1	1	1	1	1	1						
Clover spp.											1	1					
Corydalis spp.							1	1	1	1			1				
Draba spp.				1		1	1		1	1	1	1	1	1	1	1	
Dryas octopetala	4		4	1	2											2	4
Equisetum variegatum								1									
Erigeron spp.		1	1	1		1	1	1	1	1	1	1	1	1	1	1	1
Fern												1		1	1		
Gentiana spp.	1	1															
Graminae	2	1	2	1	1	1	4	4	3	2	5	3	5	4	1	2	1
Lichen	1	2	2	2	1	2	1	1		1	1	2	1	1	2	2	2
Liverwort	1	1	1	1	1	1				3		1		1	1	1	1
Lloydia serotina		1	1	1					1	1							
Lupinus arcticus											1	1	1	2	1	1	1
Mellandrium										1					1		
Minuartia spp.	1	1						1		1					1		
Mertensia paniculata								1	1	1	1	1	1	1	1	1	
Mosses	3	6	2	6	6	6	5	4	3	4	1	2	1	2			2
Mushrooms										1							1
Myosotis alpestris											1	1	1	1	1	1	1
Oxyria digynia	1	1		1	1	2	2	1	1								
Oxytropis nigrescens	1		1	1					1	1	1				1	1	1
Oxytropis splendens											1	1			1		
Parrya nudicaulis	1	1	1	1	1	1	1	1	1	1	1						
Pedicularis lanata				1	1					1							1
Petasites hyperboreus							1										
Polemonium boreale					1		1	1	1	1	1	1	1		1		
Polygonum bistorta	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1
Potentilla spp.												1	1	1	1	1	1
Ranuneulus pedatifidus			1			1	1		1			1			1	1	1
Salix spp.		2	1	2	1	1	2	1									
Salix reticulata			1	1	2	1	1	2	1								
Salix rotundifolia		1		1		2		1									
Salix stolonifera	2		1					3	2	4							

Quadrat Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Exposure	N	N	N	N	N	N	E	E	E	E	E	E	S	S	S	S	S
Total spp.	18	20	25	22	20	20	28	24	25	25	23	28	17	20	28	23	21
Genus or Species % Coverage/Quadrat																	
Saxifraga bronchialis							1										
Saxifraga davurica		1		1	1	1	1					1					
Saxifraga punctata						1	1										
Saxifraga reflexa		1					1				1	1	1	1	1	1	1
Saxifraga tricuspidata												1				1	1
Sedum rosea							1										
Senecio spp.	1																
Stellaria spp.		1	1			1	1	1	1	1	1	1	1	1	1	1	1
Valerian capitate							1		1								
Zygodenus elegans											1	2	1	1	1	1	
Bare ground				1	2	2	2						2				
Rock				1				2				3		1	2	2	2

TABLE 5.3.3

Frequency of Occurrence

Total No. Quadrats order of Constancy %	North-facing Slope 6	East-facing Slope 6	Order of Constancy	South-facing Slope 5
100%	Mosses *Graminae* spp. *Salix* spp. Lichen Liverwort *Parrya nudicaulis*	Mosses *Graminae* spp. *Anemone* *Polygonum bistorta* *Artemisia arctica* *Stellaria* spp. *Erigeron* spp. *Astragalus umbellatus*	100%	*Graminae* spp. *Anemone* spp. *Saxifraga* Lichen *Stellaria* spp. *Erigeron* spp. *Lupinus arcticus* *Myosotis alpestris* *Potentilla* spp.
83%	*Anemone* spp. *Artemisia* spp. *Oxyria Digynia*	Lichen *Parrya nudicaulis* *Claytonia sarmentosa* *Mertensia peniculata* *Polemonium boreale*	80%	*Polygonum bistorta* Liverwort *Mertensia paniculata* *Zygodenus elegans*
67%	*Saxifraga* spp. *Dryas octopetala* *Claytonia sarmentosa* Cardamine purpurea	*Salix* spp. *Draba* spp. *Oxytropis* spp. Corydalis spp.	60%	Mosses spp. *Oxytropis* spp. *Lloydia serotina* *Ranunculus pedatifidus* *Aconitum delphinifolium* *Arnica frigida*
50%	*Stellaria* spp. *Oxytropis* spp. *Lloydia seratina*	*Saxifraga* spp. *Oxyria digynia* *Aconitum delphinifolium* *Cardamine purpurea* *Ranunculus pedatifidus*		

Total No. Quadrats order of Constancy %	North-facing Slope 6	East-facing Slope 6	Order of Constancy	South-facing Slope 5
	Erigeron spp.	Liverwort	40%	Dryas octapetala
	Astragalus umbellatus	Lloydia serotina		Artemisia spp.
	Ranunculus pedatifidus	Lupinus arcticus		Polemonium boreale
	Minuartia spp.	Myosotis alpestris		Castilleja hyperborea
	Pedicularis lanata	Zygodenus elegans		Fern
	Erigeron spp.	Minuartia spp.		
	Gentian spp.	Clover spp.		
		Valerian capitate		
17%	Polemonium boreale	Potentilla spp.	20%	Draba spp.
	Aconitum delphinifolium	Pedicularis lanata		Corydalis spp.
	Sedum rosea	Castilleja hyperborea		Pedicularis lanata
	Senecio spp.	Fern		Mellandrium spp.
		Mellandrium		Mushrooms spp.
		Sedum rosea		Minuartia spp.
		Equisetum variegatum		
		Petasites hyperboreus		
		Saxifraga spp.		
		Mushrooms spp.		

east- and the north-facing slope and the east- and the south-facing slope.

5.3.3 Index of Similarity:

Table 5.3.4

Index of Similarity	$\frac{\text{common species}}{\text{all species}} \times 100$			
Site Exposure	N:E:S	N:E	N:S	E:S
	33.93	69.96	39.22	55.77

An index of similarity was calculated to determine what percentage of the total number of plant species were common to all 3 sites. Another index of similarity was established, comparing the 3 slopes to each other. Only 34% of the species occurred in all 3 sites (Table 5.3.4). The north- and east-facing slopes had the highest percentage of common species (63%). The east- and south-facing slopes had 56% of the plant population common to both. The highest occurrence of common species is expected to be between these sites since both contain regions of overlap. In contrast, there is a substantial difference between the north- and south-facing slopes, with only 40% of the total plant cover common to both.

5.3.4 Vegetation Cover:

Cover is defined as the proportion of the ground occupied by a perpendicular projection of the aerial parts of individuals of the species under consideration and is usually expressed as a percentage (Greig-Smith, 1964). Because of the overlaying of different species, the total cover for an area may exceed 100%. Although sometimes termed 'pseudoquantitative' coverage values obtained through visual estimate, are an easy and useful means of determining the percentage cover of a specific type of vegetation. The percentage obtained for each species may then be expressed as a figure, indicating the range within which it falls. In Grizzly Creek, the Daubenmire cover scale was employed as a means of estimating the total percent cover of each plant species (Daubenmire, 1968).

Cover Class	Range of Cover %
6	95-100
5	75-95
4	50-75
3	25-50
2	5-25
1	0-5

The results of this analysis for each m^2 quadrat are presented in Table 5.3.2.

5.3.5 Presence-Dominance of Vegetation:

Information concerning the presence-dominance of each type of vegetation can be determined by comparing Tables 5.3.1, 5.3.2 and 5.3.3. Grasses for example are present on all 3 slopes and occur in all of the quadrats. Grasses however, have a much higher percent cover on the east- and south-facing slopes than on the north-facing slopes (Table 5.3.2).

Mosses are also present at all 3 sites (Table 5.3.1), occurring in all the quadrats on the north- and east-facing slopes and only 60% of the quadrats on the south-facing slope (Table 5.3.3). A qualitative assessment of total percent cover using Daubenmire's coverage scale (Table 5.3.2), indicates that there are high percentages of moss cover on the north-facing slope, moderate to high amounts on the east-facing slope and low amounts on the south-facing slope.

In terms of percent-cover, mosses and grasses are the dominant forms of vegetation on the 3 slopes. Using the data available in this section, it is possible to estimate the total percent coverage of each plant species in the plant community.

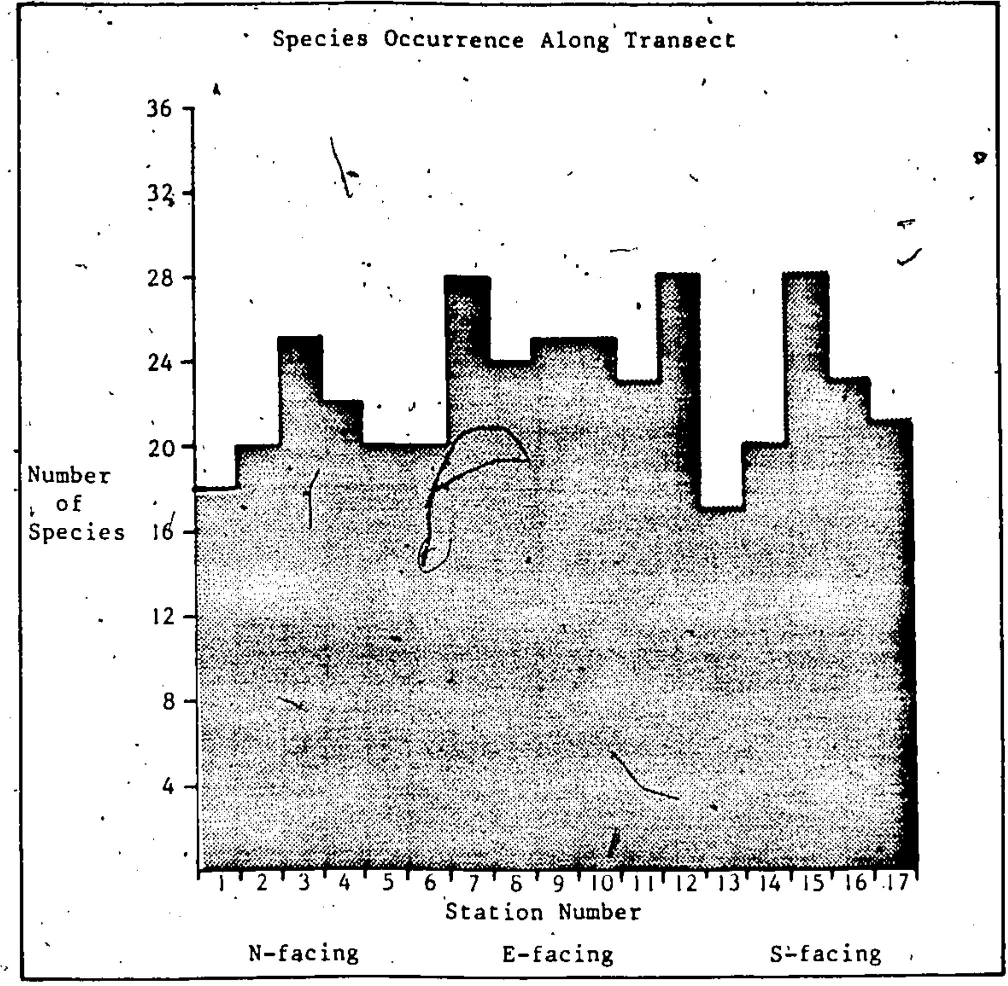
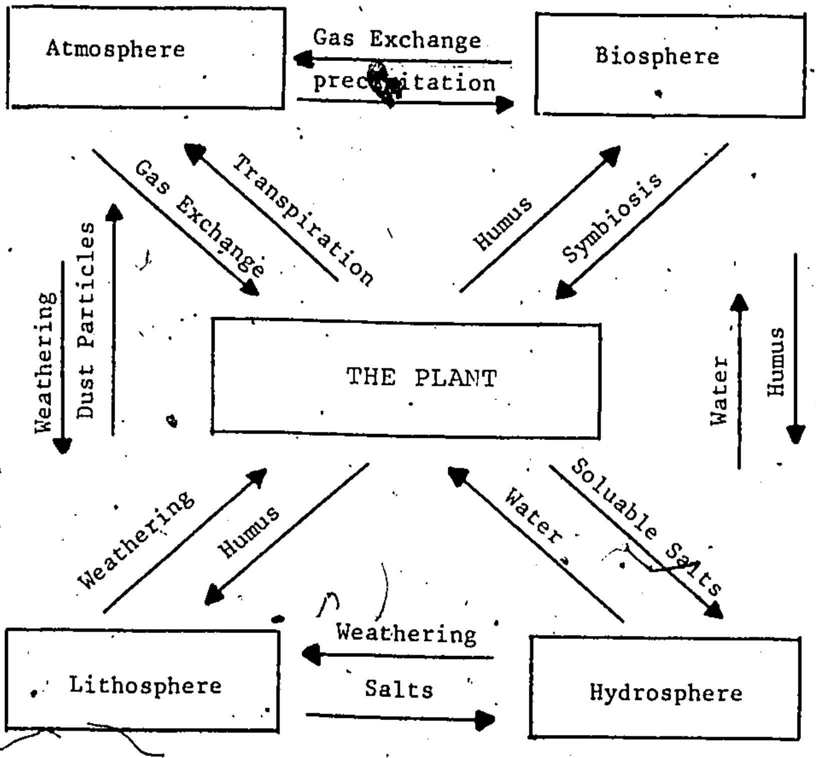

Species Occurrence Along Transect
36
32
28
24
20
16
12
8
4
Number of Species
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Station Number
N-facing
E-facing
S-facing

Figure 5.3.2

THE EFFECT OF MICROCLIMATIC AND PEDOLOGIC VARIABLES ON THE DISTRIBUTION OF VEGETATION



Examples of direct and indirect relationships between plants and the environment (modified from Stafelt 1972).

Figure 5.4.1

5.4.1 The Effect of Microclimate and Pedologic Variables on the Distribution of Vegetation:

Other than the qualitative work of Douglas (1974), no comprehensive examination of the relationship between vegetation, climate and soil has ever been undertaken in the St. Elias Mt. Range of the Yukon Territory. The primary objective of this study was to investigate dissimilarities in soil development, nutrient availability, microclimate and vegetation over three select sites and to attempt to establish the major biotic and abiotic controls responsible for these differences. Figure 5.4.1 is a schematic representation of some of the interrelationships which exist between vegetation and the microenvironment.

Low temperatures, low solar radiation, high wind velocities, low nutrient levels, and slow rates of organic matter decomposition retard plant growth and development in this subarctic-alpine environment. In turn, the vegetation affects the local physical environment. The following section will be an attempt at illustrating the dissimilarities which exist between these biotic and abiotic variables across the valley transect. While the proceeding results will appear self-evident, no statistical validity can be ascertained, due to the size of the sample.

5.4.2 A Comparison of North- and Southfacing Slopes:

In the Ruby Range of the St. Elias Mountains, Price (1971) found a smaller distribution of plant species on a north-facing slope than on adjacent southwest- and southeast-facing slopes. In Grizzly Creek, a major difference in species dominance occurred between the north- and south-facing sites (Table 5.3.2) but not in the total number of species present (Table 5.3.1). The most commonly occurring types of vegetation on the north-facing slope were mosses, grasses, lichens, liverwort, Parrya nudicaulis and Polygonum bistorta. In comparison, the most commonly occurring species of vegetation on the south-facing slope were grasses, lichens, mosses, Anemones, Lupinus arcticus, Erigeron Spp. , Myosotis alpestris, Potentilla Spp. , Saxifraga reflexa and Stellaria Spp..

The total number of plant species on the south-facing slope was 33 while the total number of plant species on the north-facing slope was 38. The Index of Similarity comparing the two slopes showed that only 40% of the total number of species were common to both sites (Table 5.1.1). While species diversity appears to be greater on the north-facing slope, total percent coverage and frequency of occurrence is much less than the total percent coverage and frequency of occurrence of plant species on the south-facing slope.

Soil development was much more pronounced in the Ah and B horizons on the south-facing slope (Figure 5.1.4). Organic matter content was also higher on the south-facing slope

(Table 5.1.1). Moisture contents, however, were similar on both slopes. Sampling time probably best explains this anomaly since the samples were collected during a period of heavy precipitation.

Nutrient availability varied considerably between the north- and south-facing slopes. Levels of all nutrients appear to be deficient on the north-facing sphagnum soils. Total quantities of P^+, K^+, Ca^{++}, Mg^{++} and N in available and exchangeable forms are consistently lower in the soils on the north-facing slope (see Table 5.1.3). The distribution of soil nutrients is however, much more even on the north-facing slope than on the south-facing slope, where nutrients appear to be concentrated in the organically rich Ah horizon (see Table 5.1.2).

This resultant increased acidity on the northerly exposed slope, is probably due mainly to differences in the rates of moisture infiltration. These variations are related primarily to the poorer physical soil properties of the north-facing slope, resulting in increased leaching of major base cations. Declining availability of plant nutrients between these two sites, seems to have a greater impact on plant growth and development, rather than on species diversity.

Climatic differences existing between the two opposing slopes can have a very important affect on plant distribution.

Mooney and Billings (1961) for example, concluded that the primary restrictive factor limiting the distribution of arctic and alpine populations of Oxyria dygnia is high summer temperature. Under these conditions, carbohydrate reserves are depleted because of low photosynthetic economy at high temperatures (Mooney and Billings, 1961). In Grizzly Creek Oxyria dygnia, while being present on the north-facing slope, was totally absent on the south-facing slope of the study area (Table 5.3.1) where the mean soil surface and air temperatures were much more extreme.

Over a 20-day period the mean daily amount of direct solar radiation received on the south-facing slope remained consistently higher than amounts received on the opposing north-facing slope. During this period albedo rates remained slightly higher on the north-facing slope. Variations in amounts of incoming radiation and reflectance values are a result of differences in exposure and slope angle.

Air temperatures recorded at screen height over the six week field season, were higher on the south-facing slope 84 percent of the time. Similarly, soil surface temperatures were much more extreme on the south-facing slope. Diurnal fluctuations in subsurface soil temperature were also much more extreme on the south-facing slope.

Total precipitation was much higher on the south-facing slope than on the north-facing slope (Figure 5.2.6). Wind direction was, in general, out of the northwest during storm periods. A decrease in wind velocity on the south-facing slope during these events explains this anomaly.

In summation, tremendous differences exist between the biotic and abiotic components of these two opposing slopes. The south-facing slope appears to have a richer layer of organic material resulting in a higher availability of plant nutrients. Solar radiation inputs are also much higher on the south-facing slope, resulting in greater diurnal fluctuations in air and soil temperature. Precipitation inputs are also greater on the south-facing slope and wind velocities are much lower. Qualitatively speaking, the result of these differences is a retarding of plant development and a lag time in plant growth between the two sites. By the end of the field season, many of the herbacious plant species on the north-facing slope remained dwarfed and showed little evidence of flowering in the immediate future.

5.4.3 Biotic and Abiotic Differences on an East-facing Slope:

The central east-facing slope was underlain with permafrost and has been subjected to cryoplanation processes. Solifluction lobes extended three quarters of the way down the east-facing slope. In this central region the depth of the active layer is sometimes no greater than 18 cm. No study of community dynamics in relation to permafrost was carried out.

The dominant plant species in the central portion of the depression were the mosses, followed by the grasses, Anemone's, <u>Polygonum</u> <u>bistorta</u>, <u>Artemisia</u> <u>arctica</u>, <u>Stellaria</u> spp. , <u>Erigeron</u> spp. , and <u>Astragalus</u> <u>umbellatus</u>. Overall, a total of 50 plant species were found. Along the boundaries of the east-facing slope with the north- and south-facing slopes, there were sudden increases in specie occurrence (Figure 5.3.2). This area represents the region of overlap between the different plant communities commonly referred to as an ecotone.

In the ecotone between the east- and south-facing slopes, 28 plant species occur (Figure 5.3.1). In the ecotone between the east- and north-facing slopes, 28 plant species also occur. However, only 7 of these species occur in both the north- and south-transition sites.

Soils in the central region have been dislocated due to solifluction activity. At a depth of 18 cm a rich dark organic layer was found. Soil texture was similar to that of the other slopes having a high sand silt content in the Ah and the C horizons directly below it. Moisture content was much higher in the central region, than on the opposing mid-slopes. A large percentage of this moisture resulted from the downslope movement of meltwater from the underlying permafrost. Moisture content was also high in the buried organic layer.

Nutrient availability varied in the central east-facing region. While soil pH remained similar to that of the south-facing slope, the amount of K^+ tended to increase. These higher values of K^+ in the valley bottom may be related to meltwater leaching. Nutrient availability is considerably higher than on the north-facing slope.

Although no quantitative data is available concerning solar radiation inputs into the valley bottom, comparisons may be drawn between air and soil temperatures. During the field season, the climate of the central region was not as harsh as that of the north- and south-facing slopes (Figure 5.2.4). The minimum air temperatures were usually substantially higher in the central region (Figure 5.2.4).

The mean soil surface and subsurface temperature was usually lower on the east-facing slope than on the north- and south-facing slopes (see Figure 5.2.8). The depth of the active layer in relation to the underlying permafrost must have a moderating effect on soil subsurface temperature. The impact of this moderating effect on the distribution of vegetation unfortunately was not studied.

From the results presented here it is apparent that substantial differences do exist between the major biotic and abiotic controls affecting soil development, nutrient availability, microclimate and vegetative cover. Lower temperatures, lower amounts of solar radiation, high wind velocities, low nutrient levels and slower rates of organic decomposition retard plant growth and development on the north-facing slope.

CHAPTER 6

CONCLUSIONS

Topographic differences in the high altitudes of Grizzly Creek, resulted in the formation of a number of heterogeneous microenvironments. The preceding case study examined 3 opposing slopes which exemplified extremes in topographic variability, and environmental conditions. In order to fulfill this task, an analysis of the dissimilarities in soil development, nutrient availability, microclimate and vegetation was conducted over the 3 sites, in an attempt to establish the major biotic and abiotic controls responsible for these differences.

There was a major difference in exposure between the selected study sites. The angle of incidence of solar radiation at noon on June 25, 1979, for example, was 62.5° on the south-facing slope and only 36° and 17.5° on the respective east- and north-facing slopes. This resulted in a tremendous variation in temperature and radiation receipts over the selected sites.

The largest amounts of radiation were received on the south-facing slope. Similarly, the greatest mean daily air, soil and subsurface soil temperatures were recorded on the south-facing slope. The lowest radiation, daily air and soil surface temperatures were recorded on the north-facing slope. The lowest soil surface temperatures however, were recorded on the east-facing slope. The east-facing slope also experienced higher minimum daily air temperatures than the opposing sites.

Wind direction appears to be an important factor affecting the distribution of precipitation over the study sites. The north-facing slope was subjected to upvalley northwesterly winds 45 percent of the time. This was usually during low pressure periods, resulting in the receipt of high amounts of precipitation on the leeward south-facing slope. The south-facing slope received downvalley southeast winds off the glacier 14 percent of the time. This was usually during periods of high pressure and while reducing air temperatures, had no affect on precipitation. Overall, almost twice as much precipitation fell on the south-facing slope as on the north-facing slope. In comparison, the east-facing central region was much more protected by the north and south slopes and were not as greatly affected by wind.

There were also differences in relative humidity between the study sites which were directly correlated to temperature and precipitation.

Loamy soils were characteristic of the 3 major study sites. Soil moisture contents were highest on the east-facing slope where permafrost was present. The north- and south-facing slopes had moisture contents all in excess of 100 percent. Soil pH and the organic matter content was lowest on the north-facing slope and highest on the east- and south-facing slope.

Nutrient availability varied tremendously from site to site. Levels of all major macronutrients appear to be deficient on the north-facing slope. The depth distribution of these nutrients also differs between sites. Nutrients are much more evenly distributed in the sphagnum soil on the north-facing slope whereas on the south- and east-facing slopes, they are concentrated in the Ah horizon. Therefore, plant growth and development would be expected to be much slower on the north-facing slope.

A total of 54 plant species were identified at the field site. Only 34 percent of this entire plant population were common to all three exposures. Only 39 percent of the plant species were common to the north- and south-facing slopes. In contrast, 63 percent of the plant species on the north-facing slope were also found on the central east-facing slope. Similarly, 56 percent of the plant species found on the south-facing slope occurred on the east-facing slope.

Plant communities were most poorly developed on the ridgetops. Billings and Mooney (1968) point out that in alpine environments, windswept ridges experience the most severe temperatures, drought stress and wind abrasions - all factors limiting plant growth.

The greatest plant diversity for any sampling area, was found in the boundary regions between the central area and the south- and north-facing slopes. The highest total number of plant species was found on the east-facing slope. In comparison, the north-facing slope had a lower diversity of plant species than the east-facing slope, but a higher diversity than the south-facing slope. However, the rate of growth and development was much slower, exemplified in a much lower percent cover for each species.

In general, mosses tended to dominate the north-facing slope in terms of percent cover while grasses dominated the south-facing slope. In the valley depression, the half of the east-facing slope closest to the north-facing slope tended to be dominated by moss while the other half was dominated by grasses similar to the south-facing side.

The differences in slope and aspect caused by topographic variations, has had a strong affect on solar radiation inputs, temperature, precipitation and relative humidity of the three study sites. The overall impact this has had on soil development and soil chemistry is evident in the depth of profile development and nutrient availability. Consequently, microclimatic and soil differences between the three sites are the most important factors determining the distribution of subarctic-alpine vegetation. The acid-tolerant moss species tend to dominate the cooler north-facing environment. Here herbacious plant species are reduced in size and distribution. On the eastern and south-facing environment herbacious plant species and graminoid species are better developed and show a higher percent cover.

In terms of general sensitivity, the north-facing slope appears to be much more fragile. Recovery times, due to limiting factors such as general climate and nutrient availability will be increased. Therefore, hikers or general plant enthusiasts should be selective in choosing their hiking trails and observation sites.

In retrospect, this was only a preliminary analysis of what the author viewed as being the major biotic and abiotic components affecting soil, microclimate and vegetation distribution in Grizzly Creek. Unfortunately, although illustrating a host of differences between the two slopes, this study was unable to relate any of them to the vegetation disymetry with a minimum of certainty. Further, more in-depth, analysis of these delicate ecosystems will hopefully provide the scientific community with a much more specialized appreciation of these microenvironments.

If a further study was logistically feasible at this site, certain changes would be made in research technique. For example, less emphasis would be placed on trying to relate the entire plant community to the surrounding environment. Instead, more emphasis would be placed on studying individual plant species, their distribution and how they are physiologically adapted to survival in their specific microenvironments. Appropriate changes would also be made in sampling technique. Rather than running a single transect through the valley, transects would be ran in a parallel fashion, across the slopes and valley bottom, providing a more representative sample of the study area.

In conclusion, in subarctic-alpine environments altitude, slope and exposure are three of the most important factors determining the location, growth and development of individual plant species. Variations in microclimate and soil appear to be extremely important factors in giving certain species a competitive edge.

APPENDIX A

List of Vegetation (identified to species wherever possible)

Note: The identifications have been verified by the National Museum of Canada.

Aconitum delphinifolium	DC. - Monkshood
Anemone drummondii	Wats. - Drummond Anemone
Anemone multifida	Poir ex. Lam - Cut-leaf Anemone
Anemone parviflora	Michx. - Northern Anemone
Antennairia monocephala	DC.
Arnica frigida	C.A. Mey - Frigid arnica
Artemisia arctica.	A.
Artemisia globularia	Cham. ex. Besser
Astragalus umbellatus	Bunge - Tundra Milk-vetch
Castilleja hyperborea	Pennell - Alaska Indian Paintbrush
Cardamine purpurea	Cham. & Schecht. - Purple cress
Claytonia sarmentosa	C.A. Mey - Alaska Spring Beauty
Clover sp.	
Corydalis Medic. Nom. Cons.	
Draba sp.	
Dryas octopetala	L. sub sp. octopetala - Mountain aveno
Equisetum variegatum	Schleich - Variegated Scouring-rush
Erigeron sp.	
Fern sp.	
Gentiana sp.	
Graminae sp.	
Lichen sp.	
Liverwort	
Lloydia serotina	(L). Wats. - Alp Lily
Lupinus arcticus	S. Wats - Arctic Lupine
Mellandrium sp.	
Minuartia sp.	
Mertensia paniculata	(Ait.) G. Don - Tall Bluebell
Moss sp.	
Mushroom sp.	
Myosotis alpestris	
Oxyria digyna	(L.) Hill - Mountain Sorrel
Oxytropis nigrescens	(Pall.) Fisch. Sub sp. Bryophila (Green) Hult
Oxytropis splendens	Dougl. ex Hook. - Shawy Oxytrope
Parrya nudicaulis	(L.) Reg.
Pedicularis lanata	Cham. & Schlecht - Kane louse wort
Petasites hyperboreus	Rydb. sub sp. frigidus (Fries)
Polemonium boreale	Adams - Northern Jacobs - ladder

Polygonum bistorta	L. - Meadow Bistort
Potentilla sp.	
Ranunculus pedatifidus	J.E. Smith ex Rees - Northern buttercup
Salix sp.	
Salix reticulata	L. - Netted Willow
Salix rotundifolia	Trautv.
Salix stolonifera	Cov. - Stoloniferous Willow
Saxifraga bronchialis	L. - Spotted Saxifrage
Saxifraga davurica	Willd.
Saxifraga punctata	L. - Brook Saxifrage
Saxifraga reflexa	Hook. - Yukon Saxifrage
Saxifraga tricuspidata	Rottb. - Three-tooth Saxifrage
Sedum rosea	L. Scop. subsp. integrifolium (Raj) Hult-Roseroot
Senecio sp.	
Stellaria sp.	

APPENDIX B

LABORATORY PROCEDURES

B.1 Extraction of Soil for Cation Analysis (McKeague, 1978)

Reagents:

1) 1.0N NH_4OAc, pH 7.0 (77 gm of salt to 1 litre H_2O)

Procedure:

1) Weigh out 1.0 gm soil into a 100 ml centrifuge tube.
2) To 1.0 gm samples, add 25.0 ml 1.0N NH_4OAc, shake and let stand for at least six hours.
3) Shake and centrifuge, then decant into 125 ml plastic bottles, then resuspend pellet in 25 ml of 1.0N NH_4OAc. Repeat until the sample has been extracted four times.
4) Retain final pellet for cation exchange capacity analysis.
5) Extracted ions can be analyzed by atomic absorption and flame emmission. K, Na, Mn, Fe, Pb can be read directly. Ca and Mg must be read in the presence of LaCl. Make up LaCl to 65,000 ppm and add two drops to 10 ml of extract just prior to sample reading.

B.2 Cation Exchange Capacity (McKeague, 1978)

Reagents:

1) 1.0N $CaCl_2$ - 73 gm$CaCl_2$ $2H_2O$ per 1 litre water
2) 1.0N NH_4OAc - 77 gm NH_4OAc salt per 1 litre water (pH 7.0)

Procedure:

This is a follow-up to the cation extraction process. Extractions are carried out as in the cation extraction using 4 x 25 ml extracts.

1) Add 25 ml 1.0N $CaCl_2$ to extraction pellet left from step five in the cation extraction procedure, shake and let set for at least six hours, centrifuge, discard supernatant and repeat three more times.
2) Repeat 1) using 4 x 25 ml washes of distilled deionized water. (Disgard 6 hour waiting period).
3) Repeat 1) using 4 x 25 ml 1 NH_4OAc, but decant supernatant into 125 ml plastic bottles.
4) Extracted Ca can be analyzed by atomic absorption.

B.3 Total Nitrogen Determination by the Modified Macro-Kjedahl Method (Jackson, 1958)

Reagents:

1) 50% NaOH: dissolve 3 kgm NaOH in 3 litres distilled H_2O.

2) Mixed indicator solution: dissolve 0.5 gm bromcresol green and 0.1 gm methyl red in 100 ml 95% ethanol; adjust solution to blueish purple in colour at pH 4.5 with dilute NaOH or HCl (indicator is pink at pH 4.2 or less and blueish green at pH 4.7 or higher).

3) Boric Acid: 4% solution; dissolve 40 gmH_3BO_3 in one litre of distilled H_2O.

4) Standard acid: .015 N HCl.

Digestion:

1) Weigh out .5 gm of soil material into Kjedahl digestion flasks.

2) Add 1 gm catalyst (100 pts K_2SO_4:10 parts $CuSO_4$: 1 part Se).

3) Place flasks on the heater manifold apparatus of the Kjedahl digester and turn heaters to 3 on the dial setting.

4) When smoke appears, turn heaters to 7 and continue to heat until solution turns green; heat for another five minutes at same setting.

5) Wash flask contents into test tubes for storage (use no more than 20 ml water to wash).

6) Prepare one blank (catalyst and acid) for each set of 11 samples.

Preparation for Distillation:

1) Turn on still and water bath.

2) Fill still to the 500 ml level with distilled H_2O.

3) Turn water on to flow through cooling condenser.

4) Heat samples (from digestion) in water bath, but do not boil.

5) Begin distillation as soon as samples are hot and the still is boiling.

Distillation:

1) Add heated sample to the boiling chambers and allow it to come to a boil again.

2) Rinse funnel with squirts of distilled water to ensure that all of the sample is washed into the still.

3) Place receiving flask with 10 ml of boric acid and mixed indicator solution under the receiving outlet.

4) Fill funnel with 50% NaOH and add dropwise into sample.

5) When reaction turns black add a few more drops of 50% NaOH then stop.

6) Check the distillation process with wide range pH indicator paper. When the paper indicates a neutral

reaction, the ammonia will be distilled over and the colour of the receiving solution will have turned blue.

Titration:

1) Fill the burrette with standard acid and record the top level.
2) Titrate the receiver flask to its original colour and record the end point volume on the burrette.

B.4 Extractable Phosphorus (Olsen and Dean, 1976)

Reagents:

1) Sodium Bicarbonate ($NaHCO_3$) solution, 0.5M - 42 gm $NaHCO_3$ in 1 litre distilled H_2O; adjust pH to 8.5 with 1M NaOH; add mineral oil to avoid exposure of the solution to the air.
2) Carbon black: Carbon Black G (Fisher Scientific Company, Cat. No. C-179); use as received.
3) Ammonium molybdate - ascorbic acid: dissolve 8 gm of ammonium molybdate $(NH_4)_6Mo_7O_{24}\cdot 4H_2O$ in 250 ml of distilled water. In 100 ml of distilled water dissolve 0.2908 gm of antimony potassium tartrate. Add both of these solutions to 1,000 ml of 5N H_2SO_4 (140 ml H_2SO_4 per 1 litre H_2O). Make 2 litres and store refrigerated in a dark pyrex bottle (solution A)

A) Prepare reagent B daily as required by dissolving 1.056 gm ascorbic acid in 200 ml of solution A. Reagent B is stable for 24 hours at room temperature.

4) Standard phosphorus solution: Weigh .2197 gm monobasic potassium phosphate (KH_2PO_4) into a 500 ml volumetric flash. Add 250 ml of distilled H_2O and shake. Dilute the solution to 500 ml with distilled water.

5) Standards for standard curve: make up .1, .2, .3 ... 1.0, 1.2, 1.4, 1.6, 1.8 ppm phosphorus standards in 50 ml volumetric flasks using the stock solution of 50 ppm phosphorus. Take a 0.1 ml sample of stock P and dilute to 50 ml for 0.1 ppm P solution; similarly take 0.2 ml of stock for 0.2 ppm P solution and dilute to 50 ml, and 0.3 ml for 0.3 ppm P solution etc..

Procedure:

1) Add 5 gm of soil, 1 teaspoon of carbon black, and 100 ml of the extraction solution to a 250 ml - Erlenmeyer flask. Shake the flask for 30 minutes at 160 shakes per minute (±5 shakes). All samples must be extracted at the same room temperature (±1°C).

2). Filter the suspension through whatman No. 40 paper. Add more carbon black if necessary to obtain a clean filtrate. Shake the suspension immediately before pouring the suspension into the funnel.

3) Pipet a 5.0 ml aliquot of the extract in a 25 ml volumetric flask.

4) Add 0.5 ml of $5NH_2SO_4$ to reduce pH to 5.0.

5) Add distilled water to bring to volume to about 20 ml, then add 4 ml of reagent B, make to volume and mix.

6) Read absorbance at 820 nm on the spectrophotometer after 10 minutes (colour is stable for 24 hours).

<u>Note</u>: It may be necessary to dilute solution 5) further to obtain an accurate reading on the spectrophotometer.

APPENDIX C

Detailed Results and Calculation of Results

C.1 Calculations for Cations and Cation Exchange:

1. All ions are diluted (1 g per 100 ml of extraction fluid). Further dilution may be necessary for AA analysis and these dilutions are considered when calculating the number of ppm's in a sample. In most cases, results are quoted in terms of ppm/g/100 gm.

2. To express cations in terms of meq's, the following factors have been calculated:

Ca	.5
Mg	.82
Na	.43
K	.26

i.e. If the sample contains 55 ppm of Ca, this is equivalent to 22.5 Meq's Ca per 100 gm soil.

3. Derivation of Constants:

i.e. for 1 ppm Ca^{++} 0.5 meq Ca^{++}/100 g soil

given: Ca^{++} = 100 ppm from a 100 ml extraction of 1 gm of soil

$$= \frac{100 \text{ g substance (i.e. } Ca^{++})}{10^6 \text{ gm solvent}}$$

(note: 100 ml extraction = 100 g solvent)

i) wt of Ca per 1 gm soil $= \frac{100 \text{ gm solute} \times 100 \text{ gm solvent}}{10^6 \text{ gm solvent}}$

$= 10^{-2}$ gmCa

in 100 g of soil the weight of $Ca^{++} = 1.0$ gm

ii) Equivalent weight $= \frac{\text{molecular weight}}{\text{Valence}}$ (i.e. gm/mole/valence)

Equivalent weight $Ca^{++} = 40/2 = 20$ gm/mole/valence

iii) The equivalent weight for Ca^{++} in 100 gm soil

1 g/20 = .05 eq wt/100 gm soil

iv) 1 eq. wt. = 1000 meq wt

.05 eq. wt/100 gm soil = 50 meq/100 gm soil

v) 100 ppm = 50 meq/100 gm soil

1 ppm = .5 meq/100 gm soil

Table C.1 - Soluble Phosphorus Standard Curve Calibration

Standards ppm	% Transmittance 820 u	Optical Density
0.0	99.0	.0000
0.1	96.75	.0144
0.2	94.75	.0235
0.3	92.75	.0327
0.4	89.0	.0505
0.5	87.75	.0568
0.6	85.25	.0693
0.7	83.0	.0809
0.8	81.0	.0915
0.9	79.5	.0996
1.0	76.75	.1149
1.2	75.25	.1235
1.4	71.0	.1487
1.6	67.25	.1723
1.8	63.0	.20007

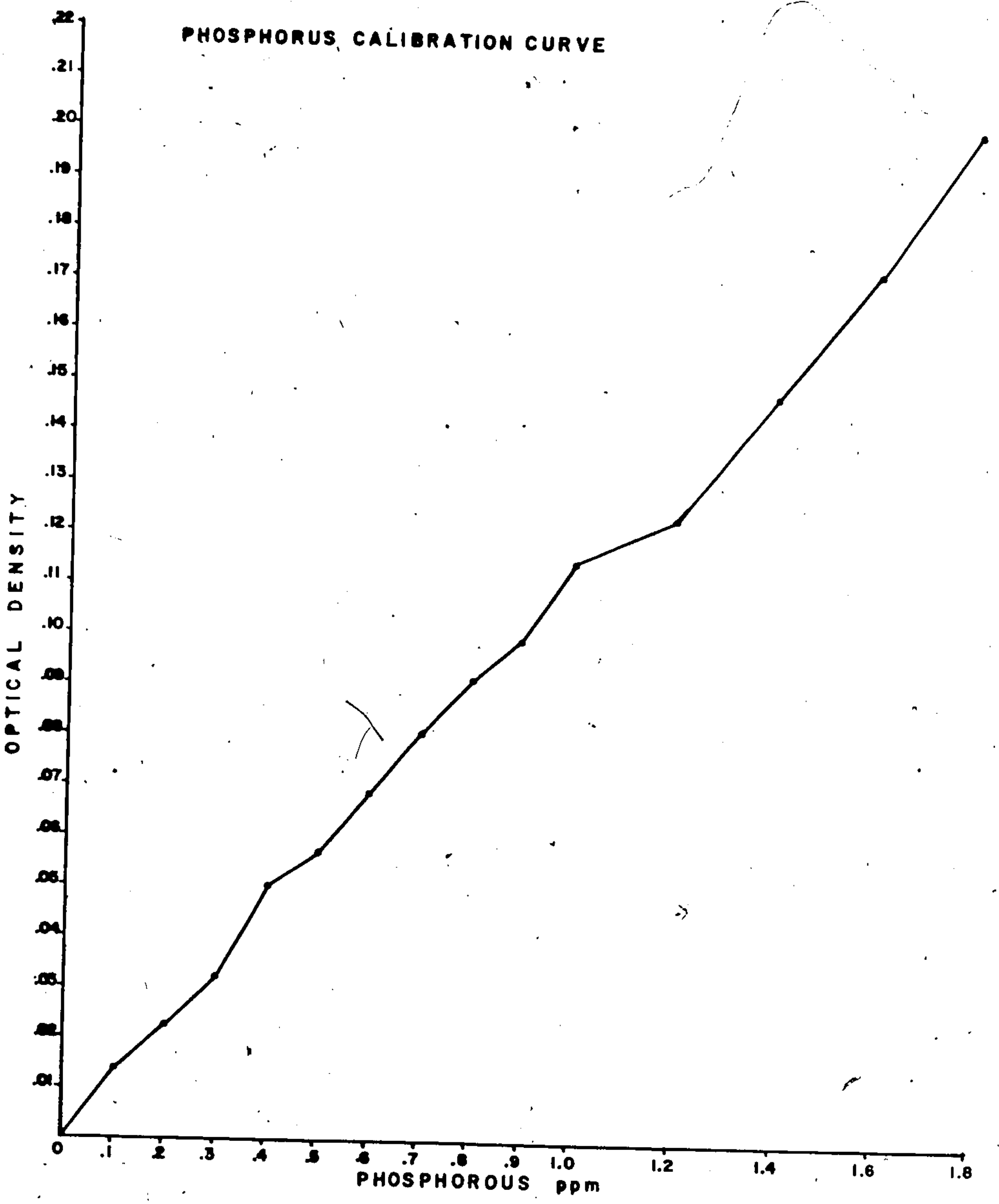

PHOSPHORUS CALIBRATION CURVE
OPTICAL DENSITY
.22
.21
.20
.19
.18
.17
.16
.15
.14
.13
.12
.11
.10
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.2
1.4
1.6
1.8
PHOSPHOROUS ppm

Figure C.1

Table C.2 - Soluble Phosphorus Percent Transmittance

10 ml Samples

Sample No.	% Transmittance	Optical Density
1-1	71.75	.1442
1-2	79.25	.1010
1-3	69.25	.1596
2-1	77.25	.1121
2-2	78.75	.1037
2-3	70.0	.1549
3-1	73.0	.1367
3-2	79.25	.1010
3-3	74.0	.1308
3-4	75.75	.1206
4-1	77.25	.1121
4-2	79.75	.0982
4-3	81.75	.0875
5-1	81.75	.0875
5-2	87.25	.0593
5-3	85.0	.0706

Table C.3 – Soluble Phosphorus Content

Sample No.	± .005 ppm $(x = \frac{y-b}{m})$	x 20	x dilution factor	
1-1	1.38	20	1.2	33.12
1-2	.45	20	1.2	10.8
1-3	.748	20	1.2	17.95
2-1	.49	20	1.2	11.76
2-2	.465	20	1.2	11.16
2-3	.725	20	1.2	17.4
3-1	.655	20	1.2	15.72
3-2	.45	20	1.2	10.8
3-3	.63	20	1.2	15.12
3-4	.565	20	1.2	13.56
4-1	.49	20	1.2	11.76
4-2	.44	20	1.2	10.56
4-3	.38	20	1.2	9.12
5-1	.38	20	1.2	9.12
5-2	.26	20	1.2	6.24
5-3	.305	20	1.2	7.32

Table C.4 – Total Nitrogen Content

Sample No.	Titration End Point Volume ± .01 (ml)	%N	mgmN/gm. Soil
1-1	22.3	1.15	11.5
1-2	3.19	.1432	1.43
1-3	2.63	.118	1.18
2-1	21.12	.9485	9.485
2-2	3.37	.151	1.51
2-3	1.38	.06198	.619
3-1	22.61	1.015	10.15
3-2	8.57	.3849	3.848
3-3	8.05	.36	3.6
3-4	2.14	.096	.96
4-1	8.56	.3844	3.844
4-2	1.72	.0772	.772
4-3	2.16	.097	.97
5-1	8.49	.3813	3.813
5-2	6.2	.2784	2.784
5-3	6.1	.2739	2.739

Available Calcium Cations

	Trial 1		Trial 2		Trial 3		Average	
Sample Number	Ca ±.05 ppm/gm/100ml	±.05 meq/100gm	Ca ±.05 ppm/gm/100ml	±.05 meq/100gm	Ca ±.05 ppm/gm/100ml	±.05 meq/100gm	Ca ±.05 ppm/gm/100ml	±.05 meq/100gm
1-1	84.0	42.0	84.0	42.0	85.0	42.5	84	42.5
1-2	15.0	7.5	15.0	7.5	15.0	7.5	15.0	7.5
1-3	19.0	9.5	19.0	9.5	19.0	9.5	19.0	9.5
2-1	65.0	32.5	64.0	32.0	65.0	32.5	64	32
2-2	25	12.5	25	12.5	25	12.5	25	12.5
2-3	15	7.5	15	7.5	15	7.5	15	7.5
3-1	62	31	62	31	62	31	62	31
3-2	37	18.5	37	18.5	37	18.5	37	18.5
3-3	38	19	39	19.5	39	19.5	39	19.5
3-4	20	10	20	10	20	10	20	10
4-1	24	12	25	12.5	25	12.5	25	12.5
4-2	17	8.5	17	8.5	17	8.5	17	8.5
4-3	16	8.0	16	8.0	16	8.0	16	8.0
5-1	19	9.5	19	9.5	19	9.5	19	9.5
5-2	19	9.5	19	9.5	19	9.5	19	9.5
5-3	16	8.0	17	8.5	17	8.5	17	8.5

Table C.5

Available Potassium Cations

	Trial 1		Trial 2		Trial 3		$\bar{x}$	
Sample Number	K±.05 ppm/gm/100ml	±.05 meq/100gm	K±.05 ppm/gm/100ml	±.05 meq/100gm	K±.05 ppm/gm/100ml	±.05 meq/100gm	K±.05 ppm/gm/100ml	±.05 meq/100gm
1-1	4.82	1.25	4.83	1.26	4.84	1.25	4.83	1.26
1-2	.98	.25	.98	.25	.98	.25	.98	.25
1-3	.94	.24	.93	.24	.94	.24	.94	.24
2-1	3.72	.967	4.71	.965	3.79	.985	3.74	.972
2-2	.98	.255	1.0	.26	.99	.257	.99	.257
2-3	.79	.205	.81	.21	.80	.208	.80	.208
3-1	5.81	1.51	5.81	1.51	5.82	1.51	5.81	1.51
3-2	1.09	.28	1.09	.28	1.09	.28	1.09	.28
3-3	1.06	.276	1.06	.276	1.05	.273	1.06	.276
3-4	.76	.198	.78	.203	.76	.198	.77	.20
4-1	1.80	.47	1.78	.463	1.78	.463	1.79	.465
4-2	.60	.156	.60	.156	.60	.156	.60	.156
4.3	.39	.101	.39	.101	.39	.101	.39	.101
5-1	.89	.23	.95	.247	.94	.244	.93	.242
5-2	.34	.088	.35	.09	.34	.088	.35	.09
5-3	.32	.083	.35	.09	.35	.09	.34	.088

Table C.6

Available Magnesium Cations

		Trial 1		Trial 2		Trial 3		Average	
	Sample Number	Mg ±.05 ppm/gm/100ml	±.05 meq/100gm	Mg ±.05 ppm/gm/100ml	±.05 meq/100gm	Mg ±.05 ppm/gm/100ml	±.05 meq/100gm	Mg ±.05 ppm/gm/100ml	±.05 meq/100gm
S	1-1	1.08	.896	1.09	.904	1.10	.913	1.09	.904
	1-2	.31	.257	.32	.266	.33	.278	.32	.266
	1-3	.35	.291	.35	.291	.35	.291	.35	.291
	2-1	1.32	1.09	1.32	1.09	1.31	1.08	1.32	1.09
	2-2	.69	.573	.70	.581	.70	.581	.70	.581
	2-3	.35	.291	.36	.298	.36	.298	.36	.298
	3-1	.73	.61	.73	.61	.73	.61	.73	.61
	3-2	.33	.278	.33	.278	.33	.278	.33	.278
	3-3	.40	.332	.40	.332	.40	.332	.40	.332
	3-4	.26	.216	.26	.216	.27	.224	.26	.216
	4-1	.60	.498	.61	.506	.61	.506	.61	.506
	4-2	.36	.298	.36	.298	.36	.298	.36	.298
	4-3	.39	.324	.39	.324	.39	.324	.39	.324
N	5-1	.62	.515	.63	.523	.63	.523	.63	.523
	5-2	.58	.48	.58	.48	.59	.49	.58	.48
	5-3	.51	.42	.50	.42	.52	.43	.51	.52

Table C.7

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