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DISTRIBUTION AND DIVERSITY OF ALPINE LICHENS: BIOTIC AND ABIOTIC FACTORS INFLUENCING ALPINE LICHEN COMMUNITIES IN THE NORTHEAST OLYMPIC AND NORTH CASCADE MOUNTAINS

by

Katherine A. Glew

A dissertation submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

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Approved by J. F. Ammirati
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Abstract

DISTRIBUTION AND DIVERSITY OF ALPINE LICHENS: BIOTIC AND ABIOTIC FACTORS INFLUENCING ALPINE LICHEN COMMUNITIES IN THE NORTHEAST OLYMPIC AND NORTH CASCADE MOUNTAINS

by Katherine A. Glew

Chairperson of the Supervisory Committee: Professor Dr. Joseph Ammirati
Chair, Department of Botany

Alpine lichens from six specific sites in the northeastern Olympic and North Cascade Mountains were studied. Sites included Elk Mountain, Deer Park, and Buckhorn cirque from the Olympic Mountains; and Skyline Divide, Slate Peak and the Tatie Peak area of the North Cascade Mountains. Lichens and vascular plants, and bryophytes were inventoried from each site. Over 170 species of lichen were identified, representing more than 70 genera. Of these, 65% were macrolichens and 35% were microlichens. For lichen percent cover from all sites, 2% were foliose, 18% were fruticose and 8% were crustose. Diversity analyses showed that drier exposed fell field sites with south and southwestern aspects had a higher species richness and diversity index. Lichens found on eastern and northeastern slopes had higher snow accumulations during the winter months, were slow to lose their snow in the summer, and mesic due to the snow melt run-off. Ericaceous plants dominated these areas affecting soil pH, other plant associations, and the diversity of lichens. Correlations and ordination analyses were employed to determine the biotic and abiotic factors influencing lichen distributions. Abiotic factors included slope, elevation, aspect, soil pH, substrate stability, substrate type, and moisture class. Biotic factors included the percent vegetation cover and plant species composition found within each quadrat. DCA and CCA analyses displayed similar distributions of lichens within the ordinations. Abiotic factors showed a strong relationship between slope, aspect, and substrate type. Substrate appeared to be a leading factor influencing lichen communities within the sites. Saxicolous lichen communities were influenced by the parent material of the rock and its pH. Vegetation significantly influenced the type of lichens on the sites. Dry tundra locations exhibited a positive correlation between lichen cover and plant cover. At the mesic sites, there was a negative relationship between plant cover and lichen cover. Species of plants associated with lichens were not be as important as the assemblage of plants found at each site. Plants were converted into functional groups to represent the types of "structural framework" they provide for the lichens. Many of the fruticose lichens form associations with these functional groups of plants.

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ACKNOWLEDGMENTS

I would like to thank the members of my committee, Drs. Joe Ammirati (chair), Roger del Moral, Bruce McCune, David Teller and Robert Waaland for their support, assistance, and stimulating discussions over the years. My reading committee (Joe, Roger, and Bruce) was particularly patient and thorough in assisting with the final version of the dissertation. Joe Ammirati was hesitant in taking on a graduate student in lichenology, but I am very grateful that he did because this opportunity to study alpine lichens has changed my life.

Financial support was provided from a variety of sources. The Murdock Charitable Trust granted me a stipend for two summers for research at the University of Washington that also included funds for traveling to my sites and required field equipment. Two scholarship funds were received from the Northwest Horticultural Society (Elisabeth Carey Miller Scholarship Award in Horticulture) and the Northwest Orchid Society. The Botany Department at the University of Washington provided funding for travel to my sites that were widely spaced across the state. The Daniel E. Stuntz Memorial Foundation was generous to provide me with tuition for two years and funds for hiring field assists during the summer of 1995.

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Field work would not have been possible without help from many people who were willing to record the lichens and plant names along a transect usually involving 10 hour days. These people were Birgit Semsrott, Betsy Lyons, Cindi Zeik, Edwin Stone, Kris Rhode, Jim Evans, Steve Trudell, Briana Timmerman, Kay Sujimura, and Robert Drucker.

Many people were important in the development of this work. The Olympic National Park and Olympic National Forest was very cooperative in assisting with this project, particularly Ed Schreiner who suggested locations with lichens and plant distributions. The arctic/alpine lab at the University of Washington was an integral part of the development of this research. Drs. Astrid Volder and Warren Gold, along with Jim Evans, Dave Anderson and Dr. Larry Bliss all had valuable expertise that assisted me with this study. The conversations that I had with all of these people were stimulating and encouraging when it seemed as though I had taken on too much. Steve Trudell provided me with indispensable lichen photography in exchange for lichen names. Dr. Jon Titus was always positive and supportive throughout his stay at the University of Washington and has continued to be an incredible friend.

An essential part of this study was the inclusion of vascular plants and cryptogams (in addition to the lichens). Mildred Arnot and Alan Yen helped me with the identification of graminoids, Judy Harpel identified the mosses, and Jim Evans pointed out the finer distinctions between alpine plant species.

Throughout this whole process the Seattle Lichen Guild was always there to champion me. They knew the importance of developing lichen inventories for Washington state and why lichen ecology needs to be studied.

DEDICATION

The author wishes to dedicate this dissertation to my parents, Gretchen B. Glew and Raymond E. Glew along with my husband Edwin C. Stone. They all stood behind me during the development of this research and dissertation. They were always there, reinforcing the value of persistence and reminding me why this project was so important.

INTRODUCTION

Lichens are a major component of the vegetation of Washington's alpine areas, yet few studies have documented their diversity and patterns of distribution across the state. This is partially due to limited access to many alpine areas but also reflects the limited number of lichenologists exploring these areas. The Olympic and Cascade Mountains provide a wide variety of alpine habitats with high lichen diversity. For example, in some of the present study sites, lichens comprise over half the vegetation cover.

Most of the records of alpine lichens are from studies not dealing specifically with one ecological area. Early works on lichens from Washington state were by Suksdorf, Merrill (1911), Evans (1952), Grant, Herre (1917), and Eyerdam (1960). Howard (1937, 1950, 1955) provided compilations of lichens for the state, which included species from subalpine and alpine areas. Imshaug (1957) included Washington in his treatment of alpine lichens from the western states, which was the first significant taxonomic paper to address this group of lichens in Washington. He recorded macrolichens from nine alpine locations, including Elk Mountain in the Olympics and Slate Peak in the North Cascades, two of the main sites for the present study.

Alpine lichens were not specifically addressed again in Washington until the 1970s and 1980s. Douglas (1973, 1974) and Douglas & Bliss (1977) focused on alpine and high subalpine communities in the North Cascade Mountains, examining both the vascular plant vegetation and cryptogams. Ryan (1985), inventoried the lichens from Chowder Ridge and Skyline Divide on Mount Baker, but community studies were not included in his investigation. Kunze (1980) carried out the first alpine lichen community study for the Olympic Mountains. She studied the terricolous lichen communities found at a variety of habitats in Deer Park in the northeastern part of the Olympic National Park.

Thomson's book on arctic lichens (1984) included species distribution maps of alpine lichens recorded for Washington. Some of these lichens showed preferences for oceanic or continental locations, while others were cosmopolitan. Thomson's book did not indicate abundances or frequencies of these lichens. However, his contributions to the arctic and alpine lichen floras of North America have been immense. Beginning with his studies of the arctic in the 1950's and continuing into the 1960's, he developed many lists of lichens from this area and new monographs for North American species. His major contributions to the crustose lichen species are essential to any arctic/alpine lichen community study.

Arctic and alpine studies involving lichens from North America have been sporadic. Inventories include those of Thomson (1979, 1984, 1998), McCune (1998), and Eversman (1995, 1998). Alpine lichen community studies are scattered and have mainly occurred in Canada (Flock, 1978; See & Bliss, 1980; Robinson et al., 1989; St. Clair, 1984). Nimis (1981) examined phytosociological patterns of epigaeous lichens in the Yukon Territory, using classification and ordination techniques, to describe new alpine lichen synusiae. Ecophysiological studies involving arctic lichens were carried out in the 1970s by Kershaw (1975, 1985); Kershaw & Larson (1974); Larson (1980); Larson & Kershaw (1975).

Other lichen community studies from North America have focused on epiphytic lichens from both deciduous and coniferous forests (Brodo, 1961, 1968; Jesberger & Sheard, 1972; Sheard & Jonescu, 1974; McCune & Antos, 1981, 1982; Schmitt and Slack, 1990; Sillett, 1995). These studies greatly improved methodologies for sampling and analyzing lichen communities. The study of forest layers (McCune & Antos, 1981), further supports observations by Europeans (Canters et al., 1991) that lichens (and other cryptogams) do not necessarily follow the same patterns of distribution as higher plants. Schmitt & Slack (1990) demonstrated that while lichen species may not be host specific, the communities that they belong to can be specific to an assemblage of trees. Other community studies for Washington, outside the alpine zone, included works done by Cooke (1955), Hoffman

(1971) and Hoffman & Kamierski (1969). These studies examined lichens and their relationship with vascular plants and bryophytes.

This study was developed to further analyze Washington's alpine lichen communities; their structure and composition. Because lichens are known to be indicators of air quality and changes in the environment, it also seemed valuable to provide a baseline inventory of these communities. Future studies could then determine any detrimental effects of human activity on alpine lichen communities.

The objectives of this study were:

1. Inventory alpine lichens from six specific sites found in the northeastern Olympic and North Cascade Mountains. These sites included Elk Mountain, Deer Park, and Buckhorn cirque from the Olympic Mountains; and Skyline Divide, Slate Peak and the Tatie Peak area of the North Cascade Mountains.
2. Analyze the alpine lichen communities from these sites and determine distribution patterns of lichens, their percent cover, richness, frequency, and diversity.
3. Develop a definition of lichen communities in alpine regions.
4. Examine abiotic and biotic factors that influence the distribution of lichens in alpine landscapes. Abiotic factors included elevation, slope, aspect, soil pH, substrate, substrate stability, and moisture class. Biotic factors included the effect of vascular plants and their percent cover on lichen distributions. Plant structure was studied to understand how it may positively or negatively affect specific lichen species, and the relationships that lichens may have with certain groups of plants.

CHAPTER 1: SITE DESCRIPTIONS

GENERAL DESCRIPTIONS

Six sites with extensive lichen fields were chosen for this study (Figure 1). Three sites are in the Olympic Mountains: Elk Mountain, Deer Park (including Blue Mountain and Deer Ridge) in the Olympic National Park and Buckhorn Cirque (southwest of Buckhorn Mountain) in the Buckhorn Wilderness area; and three sites are in the North Cascades: Skyline Divide on Mount Baker, on the western slopes of the Cascade Mountains in the Mount Baker Wilderness area, and Slate Peak and Tatie Peak on the eastern slopes of the Cascades. Field data and lichen specimens were collected during the summers of 1990 - 1995.

OLYMPIC MOUNTAINS

The Olympic Mountain sites lay between latitude 47° 49' - 55'N and longitude 123° 7' - 23'W (Figure 1).

Buckhorn Cirque's elevation ranges from 1965 to 2025m (Tabor, 1987; U.S. Forest Service, 1987). Transects were placed in the cirque to the southwest of Buckhorn Mountain (Figure 2). All transect had a northwest aspect and were above treeline. The cirque has a very gentle slope ranging from 0° - 10° with the southeast end of the transect lines gradually sloping upward to 20° (Appendix A). Vegetation covers all areas of the cirque except in one location where a significant snow patch remains until mid-July. This area, devoid of any vegetation, is unstable, and consists mainly of tallus rock.

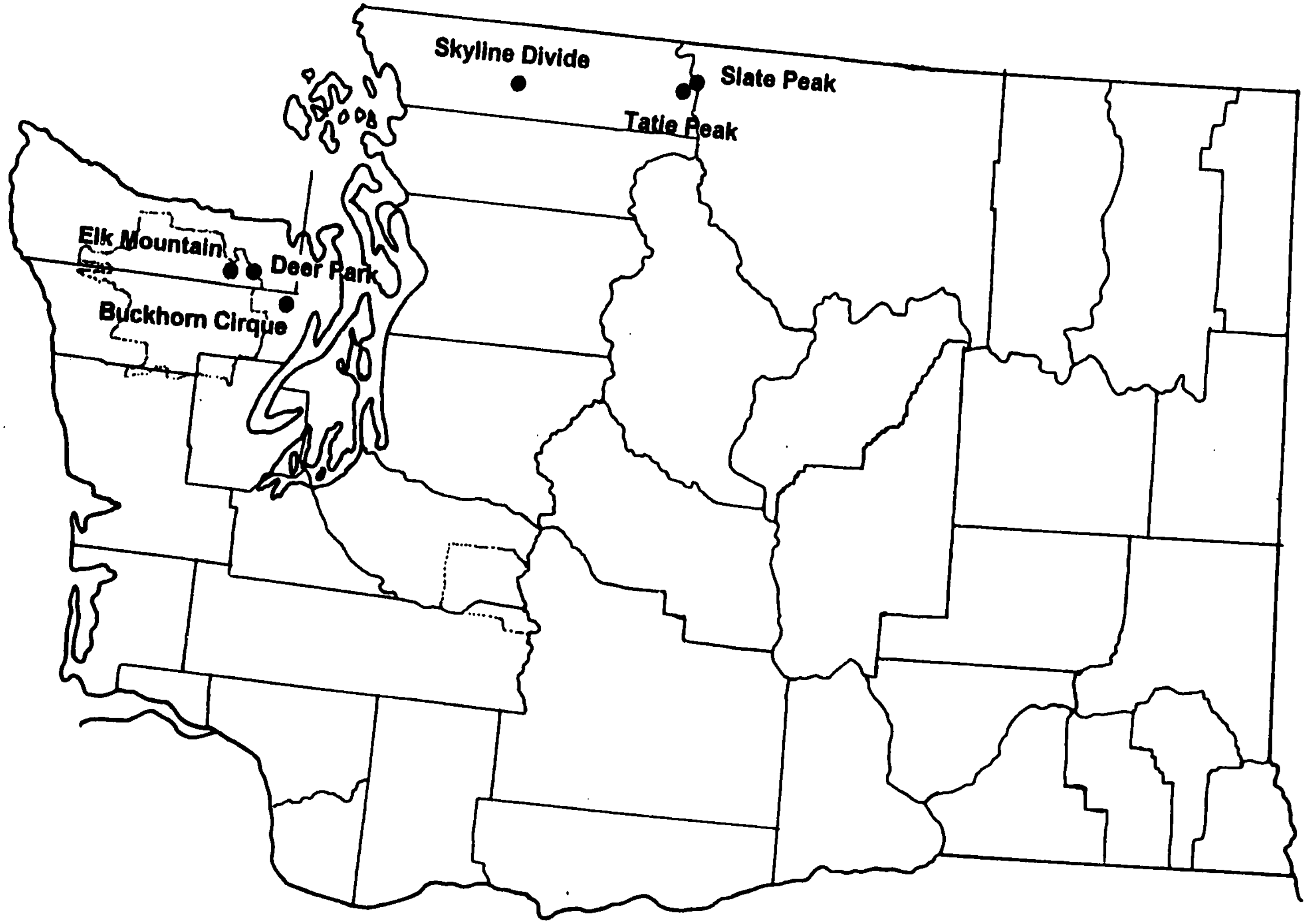

Figure 1. Locations of alpine sites in Washington state.

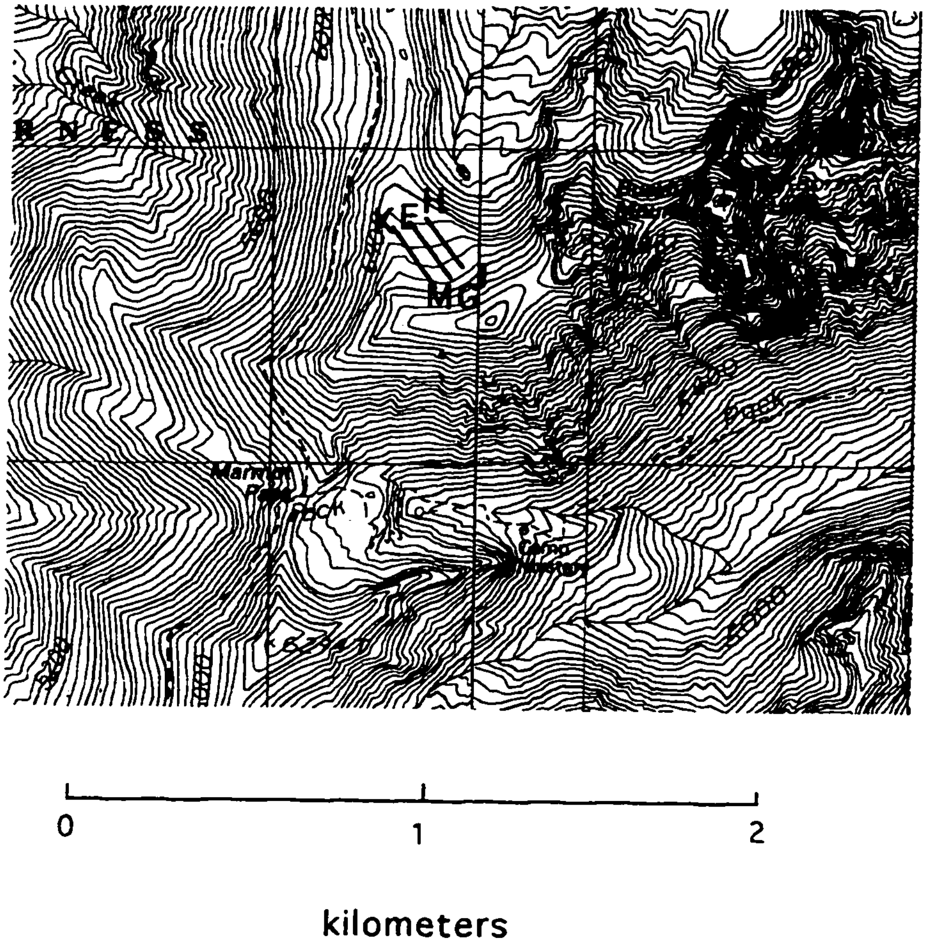

Figure 2. Location of transects (letters) at Buckhorn Cirque, Buckhorn Wilderness.

Transects at Elk Mountain were placed along a ridge between the peak and Obstruction Point (Figure 3). All transects faced south or southwest with elevations ranging from 1950 to 2060m and above treeline (Tabor, 1987; U.S. Forest Service, 1987). The trail along the ridge provided a baseline for the transect placement. Four locations were chosen along the trail with transects placed perpendicular to the trail, one above and one below. Slopes typically ranged from 12° to 23° (Appendix A). The north side of the ridge had a slope greater than 40°, making it difficult to place transects and hence, this aspect was not used in the study. Vegetation is patchy with many rock outcrops, rock stripes, and gravelly areas formed by frost boils.

The Deer Park site occurs between 1785 to 1830m elevation on Blue Mountain and 1680 to 1770m on Deer Ridge (Tabor, 1987; U.S. Forest Service, 1987) with aspects facing southwest or west (Figure 4). Four transects were placed on Blue Mountain where there were well developed lichen communities. Slopes ranged between 17° and 20°. Deer Ridge has more gradual slopes ranging from 10° to 20°. Although Blue Mountain is above treeline, Deer Ridge was in transition with the south, southwest aspects above treeline and the north side of the ridge supporting a subalpine *Abies lasiocarpa* forest.

NORTH CASCADE MOUNTAINS

The North Cascades sites are between latitude 48° 50' -51'N and longitude 121° 50' - 51'W for Skyline Divide and latitude 48° 44' - 45'N and longitude 120° 41' - 45'W for the eastern slopes of the north Cascades (Figure 1).

Skyline Divide on Mount Baker had transects ranging from 1815 to 1995m (Douglas, 1984; Alt & Hyndman, 1984) with aspects facing west, southwest, or north (Figure 5). Slopes ranged from 0° - 20°. Transects with northwestern or eastern slopes have patches of late snow run-off, making the areas mesic with a lower pH and ericaceous plants. These areas are in transition with pockets of alpine vegetation surrounded by krummholz

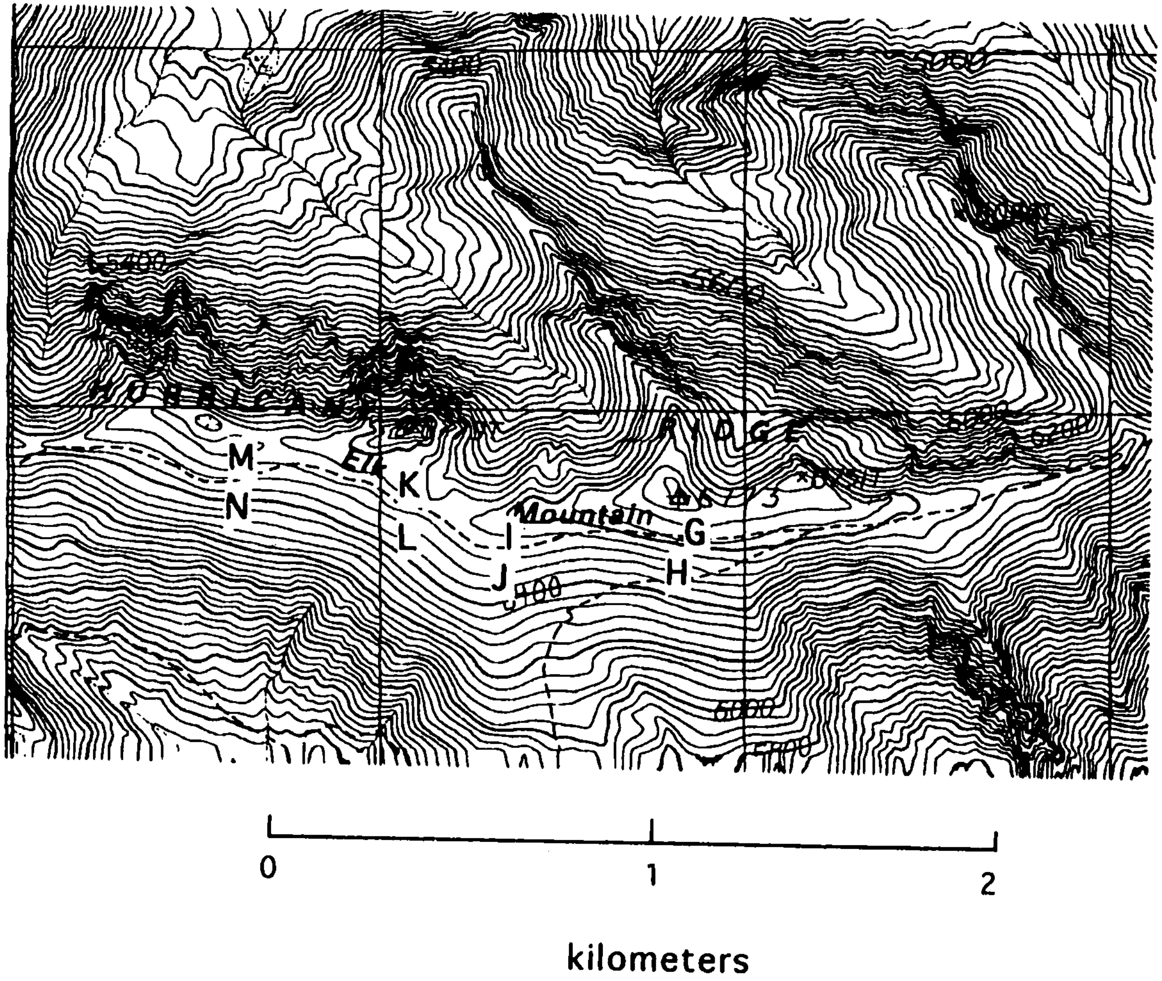

Figure 3. Location of transects (letters) at Elk Mountain, Olympic National Park.

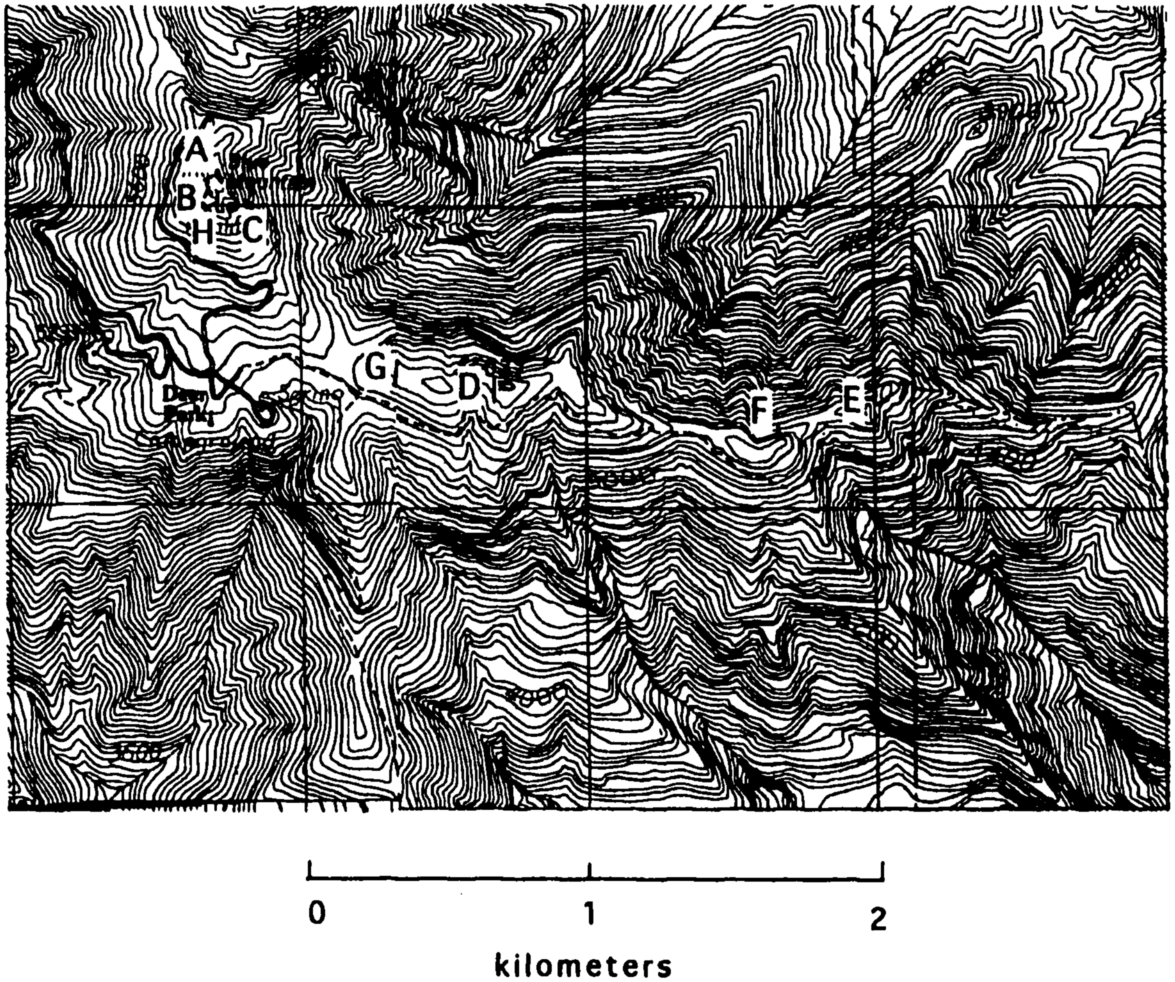

Figure 4. Location of transects (letters) at Deer Park, Olympic National Park.

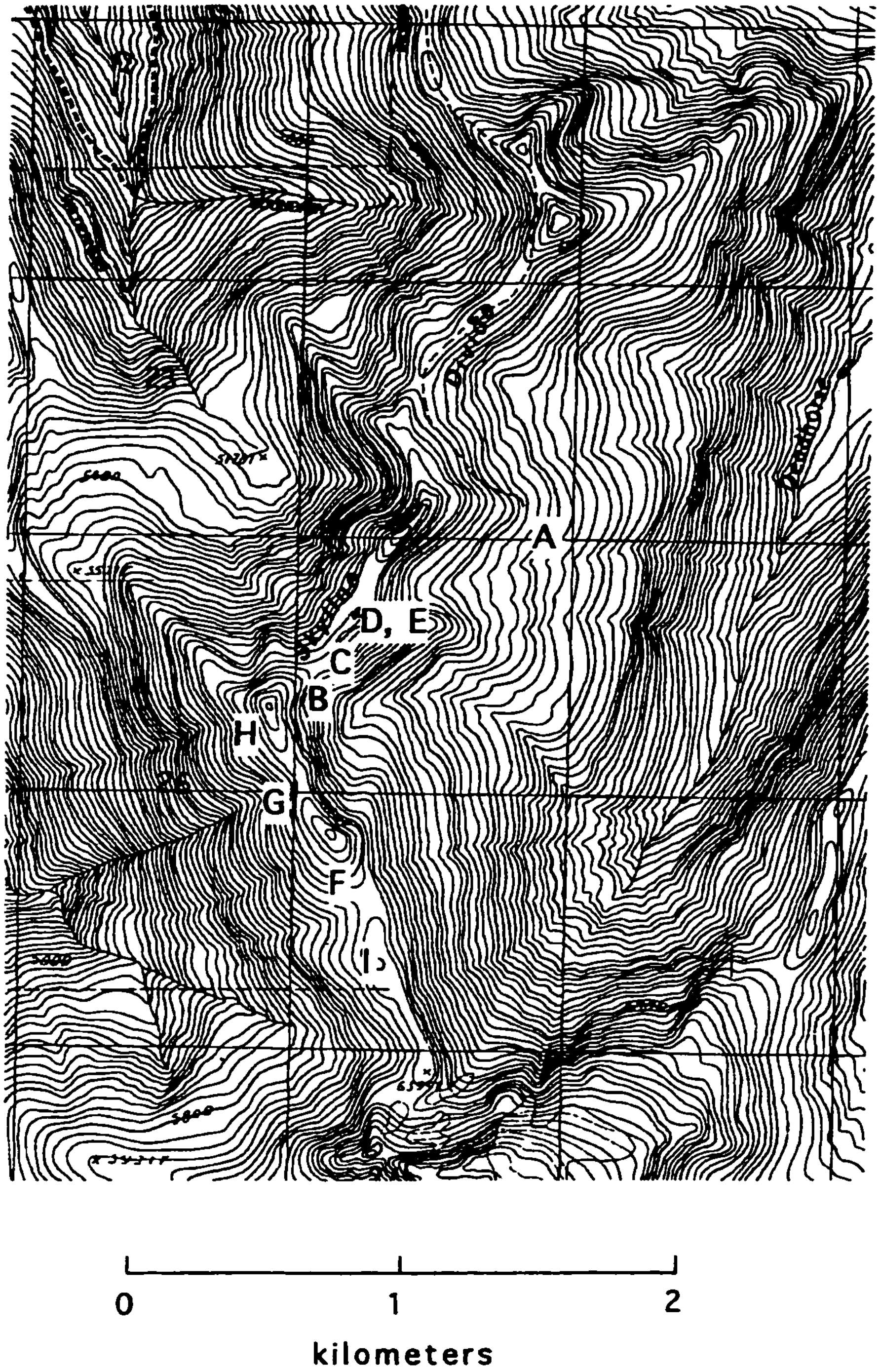

Figure 5. Location of transects (letters) at Skyline Divide, Mount Baker Wilderness.

vegetation and ericaceous shrubs and mats. The transects above 1930 m and treeline were south to southwest facing (one transect faced north). These transects were along an exposed and windswept ridge, experiencing xeric conditions. Substrate changed from soil and lower pH to a gravelly and rocky terrain with a more neutral pH (Appendix A).

Slate Peak, on the eastern slopes of the North Cascade Mountains, had transects with elevations ranging from 1965 to 2165m (Douglas, 1984; Alt & Hyndman, 1984), slopes from 6° - 30°, facing northwest, west, north and northeast (Figure 6). Transects facing north and northeast were mesic, subject to late snow patches and melt water run-off. Transects were stable and consisted of a soil substrate. Transects on the south, southwest side of the ridge were more exposed with xeric conditions. The substrate was loose and gravelly with occasional rock outcrops. (Appendix A)

Tatie Peak's transects ranged from 2040 to 2100 m (Douglas, 1974; Alt & Hyndman, 1984), facing east, northeast or northwest (Figure 7). Transects were placed along the Pacific Crest Trail #2000, between the ridge above 99 Basin and Grasshopper Pass. Slopes along the ridge are steep, between 20° to 30° (Appendix A). The transects placed in the drainage area to the southwest of Tatie Peak had more gradual slopes from 5° - 15°. The transects on the ridge are exposed and windswept creating drier conditions, although the top of the ridge has seasonal snow patches lasting into July. The transects placed in the drainage area were more stable and made up of humus, providing conditions for ericaceous plants, but appeared to be a limiting factor for many lichens.

GEOLOGY

The parent materials of Olympic Peninsula sites at Elk Mountain and Buckhorn Cirque are made up of sedimentary rock uplifted from the ocean floor and glacial debris. At Buckhorn Cirque the majority of the soil and rocks are made up of sedimentary and calcareous materials from ocean deposits and crust (Taber, 1987; Taber & Cady, 1978),

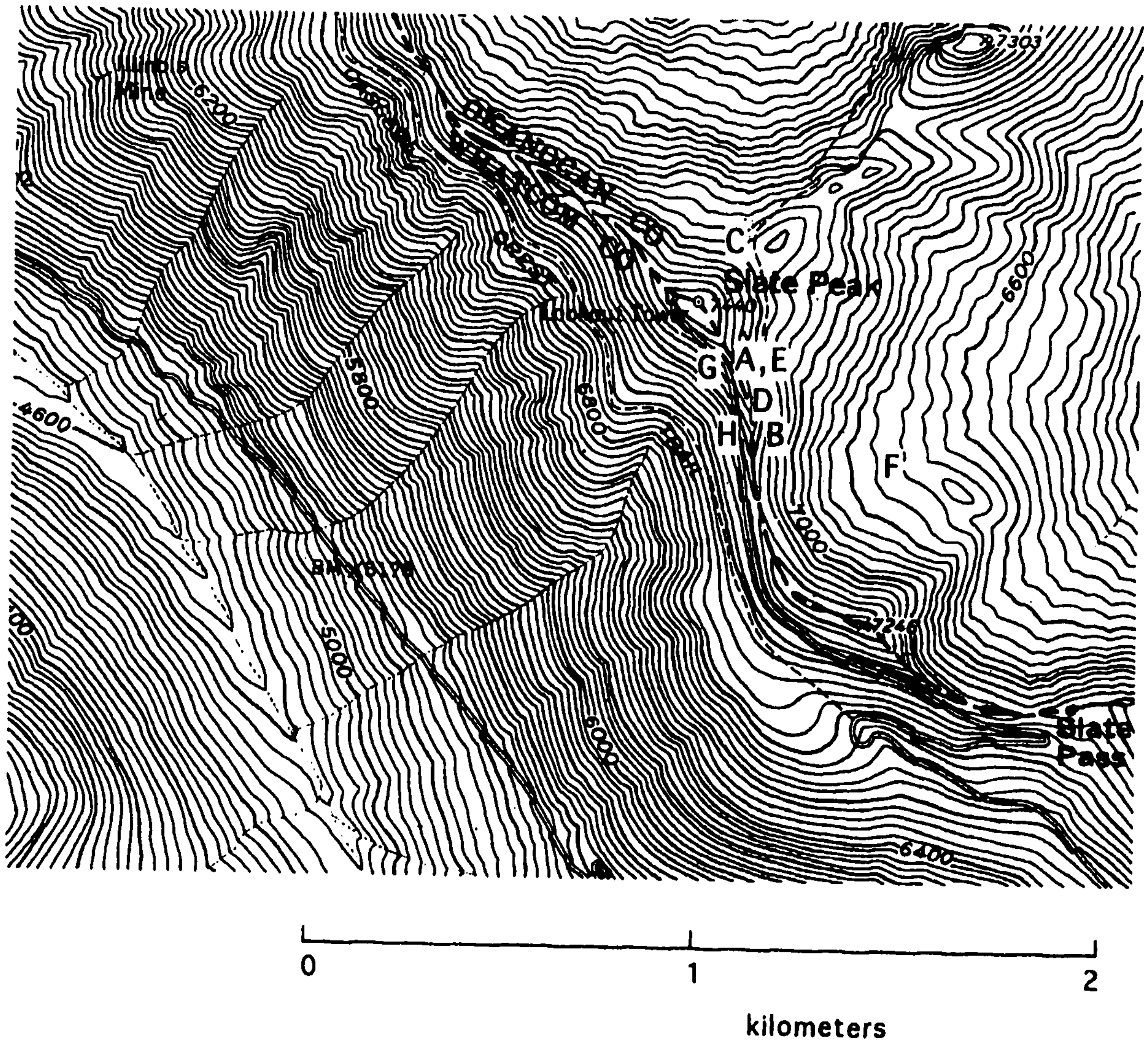

Figure 6. Location of transects (letters) at Slate Peak, North Cascades, Okanogen National Forest and Pasayten Wilderness.

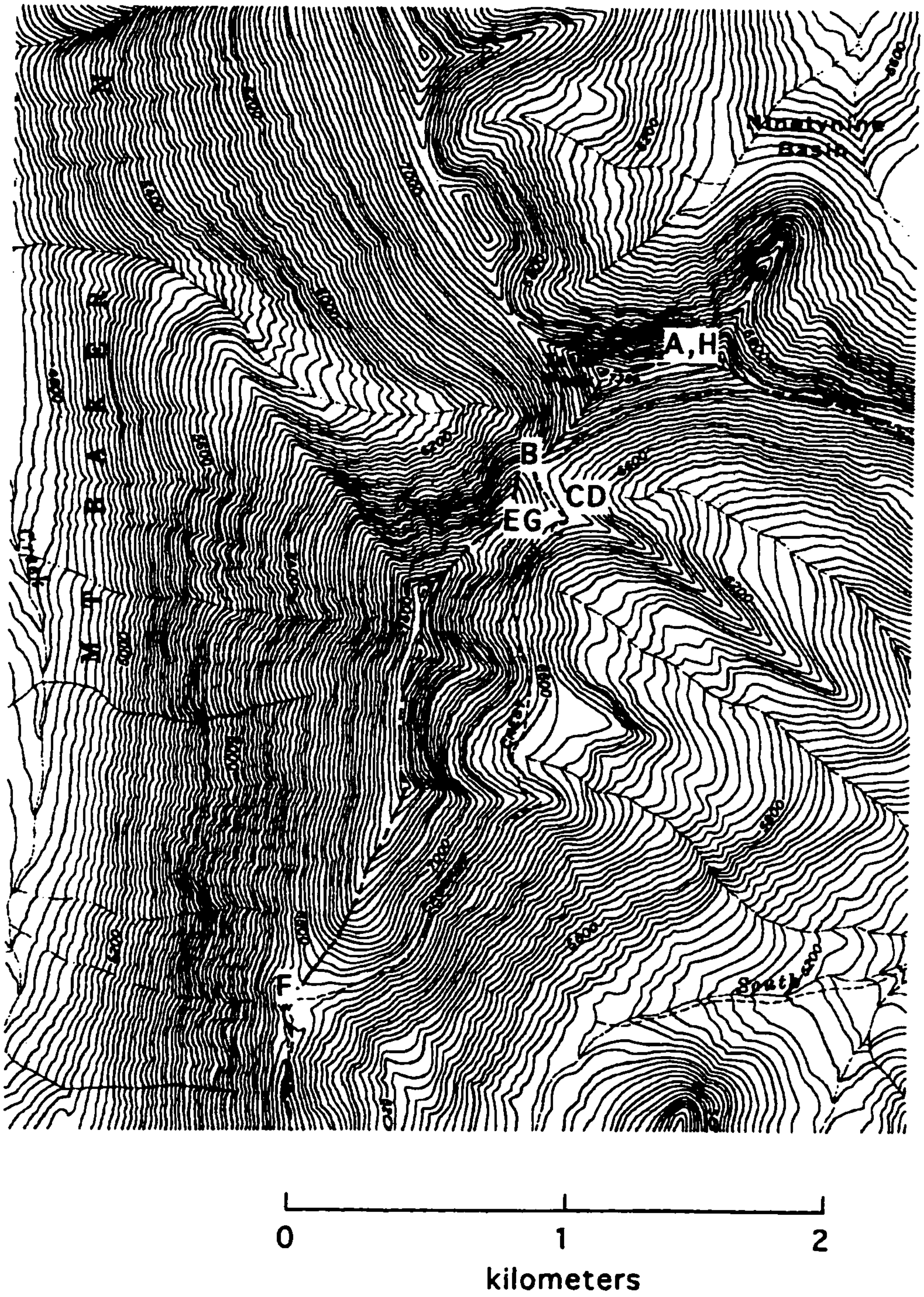

Figure 7. Location of transects (letters) in the Tatie Peak area, North Cascades, Okanogen National Forest.

along with igneous materials such as basaltic rocks and pillow lava with few rocks in the cirque (Stoffel & McGroder, 1990). Buckhorn Cirque has gradual slopes with stable surface soil and rock. The landscape at Buckhorn Cirque exhibits solifluction, with horizontal undulations. Parts of Elk Mountain are made up of slate rock, on steep slopes, makes the parent material very loose and unstable at. Most of the substrate at this sites is made up of soils from sandstone and slate. The substrate was created from thrust faults, trench filling, and folding oceanic rock. Deer Park is similar to Elk Mountain, but also contains white granite deposited by glaciers from Cordilleran ice sheets (Taber, 1987; Taber & Cady, 1978). A ridge oriented to the east of Blue Mountain (Deer Ridge), included in the study, has less granite and more sandstone substrate from glacial debris and oceanic crust (Taber, 1987; Taber & Cady, 1978). The substrate at these Olympic sites is predominately sedimentary, with an average soil pH ranging from 5.5 to 6.7 (Appendix A). The northeastern side of the Olympic Mountains are rugged and relatively inaccessible by road (Figure 1).

The Skyline Divide site, in the North Cascades, has unusual geology for a volcanic ridge. It is composed of sedimentary rock, including fossils and siltstone, as well as volcanic rock and glacial debris (Talyor & Douglas, 1978). Average soil pH ranges from 4.6 to 5.0 (average for all sites - 4.7; mesic - 4.6; xeric - 5.0). An exception was the north-facing transect which had and average pH of 5.9 (Appendix A).

Tatie Peak and Slate Peak are on the eastern slopes of the Cascade Mountains with a predominately sedimentary substrate with some metamorphic rock. Slate Peak is made up of Methow graben (sedimentary rock), Cretaceous silt stone, glacial debris and graywacke mudstone (Alt & Hyndman, 1984; Stoffel, & McGroder, 1990). At Slate Peak, both xeric tundra and mesic snow bank sites were studied. Soil pH averages 5.6 with the ridge top pH at 6.0 and the northeast mesic slopes pH at 5.0. The Tatie Peak site consists of fine- to coarse-grained feldspathic sandstone, black shale and minor pebble conglomerate (Alt & Hyndman, 1984; Stoffel & McGroder, 1990). Much of the eastern North Cascades resulted from uplifted and folded rock material that was later covered by glaciers (Alt & Hyndman, 1984). Average soil pH for the sites on the eastern slopes of the Cascades ranges from 3.8 to 6.6 (Glew, 1998). Tatie Peak's soil pH is lower, between 3.8 - 5.4 (averaging at 4.8), a result due to snow melt run-off that allows for the development of ericaceous plant communities and humus development (Appendix A).

CLIMATE

The Olympic Mountain sites, Elk Mountain, Deer Park, and Buckhorn Cirque, are located in the northeast section of the Olympic Peninsula and occupy a rain-shadow. This area receives less precipitation (125 cm/yr) than other parts of the peninsula (200 - 500 cm/yr), falling mostly as snow (Buckingham et al., 1995). This results in relatively dry conditions for the three sites. Due to their proximity (20-22 km) to the Strait of Juan de Fuca and Puget Sound, these locations experience a maritime climate. Fog frequently occurs at all sites, due to high humidity. This maritime influence on the sites has mild temperatures (January average, -2.5° C; July average, 15° C), and heavy winter snowfall at the higher elevations (Henderson et al., 1989). Summers are short, cool, and dry, barely giving the snow an opportunity to melt on the northern slopes, which lingers through the summer on north and northeast facing slopes (Arno & Hammerly, 1990). The sites from this study are exposed and wind swept, with south and southwest aspects that allow limited amounts of snow accumulation and an average annual temperature of 0° C (Henderson, 1996).

Skyline Divide on the northwest slopes of Mount Baker is also influenced by a maritime climate (Arno & Hammerly, 1990), as it is approximately 50 km from Puget Sound. Annual precipitation is 300 cm/year (Franklin & Dyrness, 1988), highest of all alpine sites in this study. Average annual temperature is 0° C (Henderson, 1996).

The eastern slopes of the North Cascade Mountains, inland by 160 - 200 km further, exhibits a modified continental climate, but milder than what is found in the Great Plains or Rocky Mountains. Compared to the maritime climates, continental climates larger temperature fluctuations; colder winters with fewer frost-free days; and much warmer summers (Henderson et al., 1989). Average precipitation is 120 - 130cm/yr (Henderson, 1996), falling mostly as snow. Annual rainfall is approximately 125 cm/yr but drier than Skyline Divide on the western Cascades. Winters above timberline are very cold, with dry, windy conditions and moderate to heavy accumulations of dry, powdery snow. Generally, the snow pack does not persist through the summer (Arno and Hammerly, 1990), but the Tatie Peak area often has snow lingering into July. Temperature for the year averages -2.5° C (Henderson, 1996).

GENERAL VEGETATION

OLYMPIC MOUNTAINS

These sites exhibit mainly dry tundra vegetation. Typical plants include *Agoseris glauca* (Pursh) Raf., *Solidago multiradiata* Ait., *Minuartia obtusiloba* (Rydb.) Fern, *Phlox diffusa* Benth., *P. hendersonii* (E. Nels.) Cronq., *Antennaria microphylla* Rydb., *Lupinus lepidus* var. *lobbii* (Grey) Hitchc., *Synthris pinnatifida* Wats., *Smelowskia calycina* (Steph.) C.A. Mey, *Salix nivalis* Hook., *Carex phaeocephala* Piper, *C. spectabilis* Dewey, *Luzula spicata* (L.) DC., *Festuca idahoensis* Elmer, and *F. ovina* var. *brevifolia* (R. Br.) Wats. with mosses and *Selaginella* spp.

NORTH CASCADE MOUNTAINS

Dry tundra vegetation contained the following plants: *Phlox diffusa*, *Saxifraga bronchialis* L., *Erigeron peregrinus* (Pursh) Greene, *Solidago multiradiata*, *Antennaria alpina* (L.) Gaertn., *Dryas octopetala* L., *Empetrum nigrum* L., and *Sedum lanceolatum* Torr., *Carex phaeocephala*, *C. spectabilis*, *Festuca ovina* var. *brevifolia*, *Poa* spp., mosses, and *Selaginella* spp.

On mesic sites, with late melting snow banks, the vegetation consists of *Erigeron aureus* Greene, *Antennaria lanata* (Hooke) Greene, *A. rosea*, *Polygonum bistortoides* Pursh, *Veronica cusickii* Gray, *Luetkea pectinata* (Pursh) Kuntze, *Cassiope mertensiana* (Bong.) G. Don, *Phyllodoce empetriformis* (Sw.) D. Don, *P. glanduliflora* (Hook.) Cov., *Kalmia microphylla* (Hook.) Heller, *Vaccinium deliciosum* Piper, *Carex nigricans* Retz., *C. spectabilis*, *Luzula piperi* (Cov.) Jones, *Festuca viridula* Vase., and mosses.

CHAPTER 2: TAXONOMIC IDENTIFICATION OF LICHENS AND BIOGEOGRAPHY

INTRODUCTION

Alpine lichen collections from Washington are limited in scope and there are few rigorous studies of sites or locations. The first significant taxonomic paper was by Imshaug (1957) who worked on the alpine lichens of western United States and adjacent Canada. He discussed 61 macrolichens found from nine alpine locations in Washington. Later studies by Douglas (1973, 1974) and Douglas and Bliss (1977) focused on the North Cascade Mountains. Douglas' work presented lichens and mosses in the context of alpine plant communities. Ryan's (1985) work in the North Cascades provided a detailed study of lichens and documented species from both Chowder Ridge and Skyline Divide on Mount Baker. In the Olympic Mountains, Kunze (1980) examined lichen communities of Blue Mountain and Deer Ridge within the Olympic National Park for a limited number of species. Thomson (1984) included Washington state records in his treatment of arctic/alpine lichens. This document was extensive and based on his collections as well as those from other herbaria. More recently alpine lichens from the Olympics and North Cascades have been reported by Glew (1997, 1996b, 1993a,b), including the range extension of *Vulpicida tilesii* in the Olympic Mountain range of Washington (Glew, 1994a).

Early works by Howard (1937, 1950), included records of alpine lichens for the state of Washington. Riley (1995) and Riley, McCune & Neitlich (1995) have further updated our alpine lichen records by the discovery of *Arctoparmelia incurva* (Pers) Hale and the range extension of *Usnea sphacelata* R. Br. in Washington. Regional studies have provided new records or range extensions of alpine lichens from Northwestern United States (Hammer, 1995) and British Columbia, Canada (Goward et al., 1994).

This chapter provides a taxonomic list and additional baseline data for Washington alpine lichens and emphasizes studies in the Olympics and North Cascades during the summers of 1990 - 1996. These preliminary findings emphasize macrolichens from these areas.

COLLECTION METHODS

At each site, areas were chosen with large, well defined lichen communities (communities with lichens becoming part of the dominant vegetation). With the exception of the Tatie Peak site, the selected areas had lichen cover representing at least 30 percent of the total vegetation cover. Within each site eight transects were placed along an elevation gradient. Nine transects were place at Buckhorn Cirque in the Olympics and Skyline Divide in the North Cascades, because of their diverse terrain. Twenty 0.25m^2 quadrats were placed along the transects, 5m apart, resulting in 160 quadrats at each site (180 for Buckhorn and Skyline Divide). To accurately determine the lichen species and percent cover, quadrats were divided into 25, 100cm^2 subquadrats. Of these, 10 were randomly chosen and averaged to represent the whole quadrat (Glew, 1994bd, 1996a, 1997, 1998). Lichen species and their percent cover were determined at the subquadrat level. This resulted in 1600 subquadrats for each site (1800 for Buckhorn and Skyline). The information collected on this fine scale allowed for the analysis microhabitat features, that affect lichen species distributions. A total of 1,000 quadrats and 10,000 subquadrats were used in the analyses of the alpine sites. General collecting supplemented the lichen species found along the transects at all sites.

Total vegetation cover (including vascular plants and cryptogams, excluding lichens) was estimated on the subquadrat level. Individual vascular plant species and cryptogams were recorded at the quadrat level. For three of the six sites (Deer Park in the Olympics and Skyline Divide, Tatie Peak area in the North Cascades) percent cover of each plant species was estimated at the quadrat level. Over 90 plant species were recorded for all six sties (Appendix AI). Frequency and percent cover of lichens, plants and other cryptogams were determined at the subquadrat level and were then computed for each transect. Vascular plant species were determined using Hitchcock and Cronquist (1973), Pojar and McKinnon (1994), Buckingham et al. (1995), McKinnon et al. (1994),

TAXONOMIC METHODS FOR LICHEN IDENTIFICATION

The identification of lichen species involves morphological characteristics and the determination of particular chemical substances. Morphology is the main character used for identification. Morphological characters include growth form (foliose, fruticose, crustose and squamulose), auxiliary thallus structures (rhizines, tomentum, cilia, cephalodia, pores, cyphellae, etc.) (Hale, 1979, 1983; Poelt, 1973) and sexual and asexual reproductive characters (apothecia, ascospores, pycnidia and diaspores[soredia, isidia]). Internal structure of the thallus, such as layering and thickness of the cortex and medulla provide informative characteristics (McCune & Goward, 1995; Purvis, et al 1992). Lichens descriptions also include the type of substrate on which they are found , such as saxicolous (rock), terricolous (ground) or corticolous (tree bark). *Umbilicaria hyperborea* (Ach.) Hoffm., for example, is a saxicolous lichen found on acidic sandstone.

Many lichen species are morphologically similar and differences between species are distinguished only by the use of chemical tests (Hale, 1979, 1983). Chemical tests include spot testing and thin-layer chromatography (TLC). Spot tests are done with potassium hydroxide, calcium hypochlorite, iodine, and paraphenylenediamine, observing color changes in the cortex, medulla, apothecia and/or soralia of the lichen. TLC is used to determine the specific chemical compounds found in a lichen species. This method of testing identifies secondary metabolic compounds of lichens, for instance, vulpanic acid in *Vulpicida tilesii*. TLC tests involve extracting lichen substances with acetone and then exposing the substances to three solvent systems on silica covered plates (White and

James, 1985). The solvent systems are: A) toluene:dioxane:acetic acid, 45:15:2 (by volume), B) hexane:methyl *tert.*-butyl ether:formic acid, 6.5:5:1 (by volume), and C) toluene:acetic acid, 20:3 (by volume) (Arup, et al., 1993). After lichen substances separate on the plates, they are dried, sprayed with a 10% sulfuric acid solution and baked to develop distinctive color patterns on the plates (White & James, 1985). By comparing these patterns with the Rf (relative position of the spot on the plate) values of known lichen substances, the identity of the chemicals is determined. All of the *Cladonia* spp. (80+ specimens) from collections have been run through the TLC system to determine their chemical compounds for identification.

Representative voucher specimens are deposited in the herbarium at the University of Washington (WTU). Taxonomic determinations were made following standard methods (Hale, 1979; James & White, 1985; McCune & Goward, 1995). Keys used were those of Breuss & McCune (1994), Dobson (1981), Gowan (1989), Goward, McCune, & Meidinger (1994), Hale (1979, 1990), Kärnefelt (1979), Lamb & Ward (1974), Laundon (1989), Llano (1950), Lohtander, (1995), McCune & Goward (1995), McCune & Geiser (1997); Orange (1995), and Purvis, et al (1992), Thomson (1979, 1984, 1987), Nomenclature follows that of Esslinger & Egan (1996).

GENERAL OVERVIEW OF LICHEN COMMUNITIES

Lichen communities fall into two major habitats: dry tundra and mesic sites (Glew, 1996a). The dry sites generally occur along exposed, wind-swept ridges. The south and southwest aspects have little snow accumulation due to their high insolation and the snow pack does not persist through the summer (Arno & Hammerly, 1990). Conditions in these areas are harsh resulting in low vascular plant vegetation. Soils are very shallow with gravel and rocks a few centimeters beneath. Due to the steep slope of some of these areas, solifluction (soil movement) often occurs when the snow melts. The mesic north and northeast facing slopes have snow accumulations that linger throughout the summer.

Most of the moisture influencing the vegetation in these areas is from melt water originating from snow pack. They tend to be level and very stable, with dominant vascular plant vegetation. Summers are short, cool, and dry, barely giving the snow on northern slopes an opportunity to melt (Arno & Hammerly, 1990). However, the snow that does melt creates a very moist environment that, along with the predominance of ericaceous plants, has a very acidic humus and soil.

Soil and rock habitats also contain distinctive lichen communities. In areas where soil was exposed and relatively dry, cladonias and crust species such as *Trapeliopsis granulosa* and *Lepraria cacuminum* would dominate an area. Transects at the Buckhorn Cirque site had a much greater richness of soil lichens than the Tatie Peak area (Appendix B). Those sites with stable rock outcrops (i.e., Elk Mountain and Deer Park) had a greater diversity of saxicolous species than those areas with unstable rock substrate (Appendix B). Although, it was observed that certain species of saxicolous crusts were consistently found on looser shale in the Olympic sites. One explanation is that these crusts are able to grow more rapidly than other saxicolous species and become established, even though the substrate is prone to movement.

RESULTS

To date more than 170 lichen species from 71 genera have been identified from the six study sites (Appendix B). For the northeast Olympic Mountain sites 132 species in 60 genera have been recorded. For the North Cascade Mountains, a total of 125 species in 53 genera have been documented. Forty-four lichens from this study were found only on the Olympic Mountain sites and 40 were found only in the North Cascades sites, although other reports show that many of these species have been found in both mountain ranges. Seventy-four lichen species occur in sites with oceanic influences. For the individual sites in the Olympics, 80 species are from Elk Mountain, 72 are from Deer Park, and 81 are from Buckhorn Cirque. In the North Cascades, 81species are from Skyline Divide, 72 species are from Slate Peak, and 50 are from the Tatie Peak area

One lichen, *Vulpicida tilesii*, found at Buckhorn Cirque in the Olympics (also Mount Angeles, Tyler Peak, and Heather Meadows [J. Evans, pers. comm.]), is thus far unknown from the North Cascade Mountains. It is disjunct from the Rocky Mountains, has not been collected from any location in the Cascade Mountains (Glew, 1994a).

Certain species of lichens are present only at the Olympic sites or are more common and widespread there. The species confined to the Olympic sites include: *Umbilicaria krascheninnikovii, Rhizoplaca melanophthalma, Ophioparma lapponica, Buellia geophila, Hypogymnia austerodes, Xanthoparmelia coloradoënsis* and *X. wyomingica* (Appendix B). These lichens **are** known from Cascade locations other than the three study sites. *Rhizoplaca melanophthalma*, is common in the Cascade Mountains and in eastern Washington on basaltic columns. Ryan (1985) and Douglas (1974) documented this lichen from other alpine locations. Lichens occurring more frequently at the Olympic sites than the North Cascades sites include *Umbilicaria torrefacta, U. havaasii, Pseudephebe minuscula, Lecanora polytropa* and *Lecanora bicincta. Umbilicaria rigida* is frequently collected from exposed ridges in the Olympic Mountains. Its distribution includes arctic locations, and two other Washington locations, one from the central Cascade Mountains (Thomson, 1984) and on an exposed ridge at Slate Peak, in the North Cascades (Glew, 1998).

Species of lichens that were found only at the North Cascades sites include *Arthroraphis citrinella, Umbilicaria cylindrica, U. vellea*, and *U. arctica. U. virginis* and *U. proboscidea* were more common at the North Cascades sites. *Dermatocarpon rivulorum* was only in subalpine meadows at Slate Peak and the Tatie Peak area in running streams resulting from snow melt. *D. rivulorum* was not observed at any of the alpine locations from the northeast Olympic Mountains.

Common lichen assemblages in alpine areas of the northeast Olympics include cetrarioid lichens made up of *Cetraria ericetorum, C. islandica, C. muricatum* (occasionally *C. aculeatum*), *Flavocetraria cucullata, F. nivalis*, combined with *Thamnolia vermicularis* and *T. subuliformis* (Glew, 1996b). These lichens always occur together within alpine vegetation. Lichens found on the soil are *Cladonia carneola, C. macrophyllodes, C. ecmocyna, Ochrolechia upsaliensis, Peltigera rufescens, Stereocaulon alpinum, S. glareosum*, and *S. tomentosum*,. Many of the cladonias do not have podetia at these drier sites. Frequent saxicolous species include *Pseudephebe pubescens, P. minuscula, Melanelia stygia, Caloplaca* spp., *Candelariella* spp., *Lecanora polytropa, Lecidea atrobrunnea*, and *Rhizocarpon geographicum, sensu latu* (Appendix B).

Buckhorn Cirque has the greatest number of fruticose lichens, mainly cetrarioid species. *Cetraria islandica* and *C. ericetorum* commonly occur and codominate in large patches up to 30 cm. across. *Flavocetraria cucullata* and *F. nivalis* also are in mixed patches with *F. cucullata* having the greatest cover. *Stereocaulon* spp. and *Cladina mitis* are mainly associated with graminoids appearing in patches ranging from 10 - 30 cm. Several *Umbilicaria* species are collected at this site (Appendix B) with *Umbilicaria hyperborea* being the most common species. *Vulpicida tilesii*, found only at this Olympic site, was found in the cirque opposite the mid summer snow patches. This site has the highest lichen cover of all of the Olympic sites.

At Deer Park *Thamnolia* spp. (both *T. subuliformis* and *T. vermicularis*) are the most predominant lichens found, followed by *Cladonia* species. *Cetraria muricatum* is frequently found mixed with vegetation and the brown cetrarioid lichens. *Flavocetraria cucullata* is found in large patches mixed with grasses and sedges. *Umbilicaria rigida* is the most common umbilicate lichen found on rocks. The substrate at Deer Park can be unstable, thus preventing lichens from becoming established. Lichens were frequently associated with the other vegetation patches, entangled in their branches and leaves.

Elk Mountain lichen communities have the highest percent of saxicolous lichens, or about one third of the lichen cover found in the quadrats. Much of this is made up of the black macrolichens *Cornicularia normoerica, Melanelia stygia, Pseudephebe minuscula, P. pubescens, Umbilicaria hyperborea* (the most abundant umbilicate lichen), *U. kraschenimnikovii, U. rigida*, and *U. torrefacta*, which can entirely cover the rocks. Half of the saxicolous species are crustose lichens. Lichen diversity on shale is not as great as sandstone, probably a result of the sandstone stripes being more stable than the shale.

Elk Mountain has many epiphytic and terricolous lichens. Along some areas next to rock stripes and on ridge tops, *Letharia vulpina* could be found growing amongst vascular plant vegetation and other epiphytic lichens. *Cetraria islandica* and *Flavocetraria cucullata* are the most common of the cetrarioid lichens seen at this site. *C. islandica* is commonly found along the edge of rock stripes, but still mixed with vascular plant vegetation. It may be that it is blown there by the high winds along the ridges. *Peltigera rufescens*, and occasionally *P. malacea* and *P. ponojensis*, are frequently found on the soil, especially where there has been a disturbance such as along the trail edge. In some mossy areas peltigeras could be found almost completely embedded in moss with only the upper tips exposed. This is also seen at Buckhorn Cirque. Soil crusts such as *Ochrolechia upsaliensis* and *Lepraria cacuminum* can be repeatedly seen amongst the mosses, *Selaginella* spp. and on bare areas by plants.

Buckhorn Cirque and Elk Mountain have the highest number of lichen species of the sites studied. For Elk Mountain, this is partly due to a combination of terrestrial vegetation and rock outcrops, providing a variety of substrates. Buckhorn Cirque has very stable substrate which allows for the establishment of slow-growing lichens, such as soil crusts and saxicolous crustose forms. Deer Park's terrain is gravelly and less stable, reducing the diversity of lichens.

In the North Cascades mesic snow-bank communities of the Tatie Peak area, Skyline Divide, and Slate Peak have a distinctive assemblage of lichens. These lichens generally do not occur in the more xeric tundra communities. There is greater diversity of cladonias, including *Cladonia bellediflora, C. squamosa, C. ecmocyna,* and *C. carneola.* Podetia are more developed than what is seen in the Olympics and mats cover larger areas. *Tuckermannopsis subalpina* and *Solorina crocea* are found more frequently at these mesic sites, even though they are found at lower elevations into the montane zone. *Lepraria cacuminum* and *Leprocaulon subalbicans* regularly occur at the mesic sites. Deteriorating heathers, such as *Cassiope mertensiana, Phyllodoce empetriformis,* and *P. glanduliflora* are commonly covered with patches of *Trapeliopsis granulosa.*

The mesic sites are at or barely above tree line, where alpine vegetation begins to interdigitate with the subalpine zone. This can be seen at sites where *Cetraria islandica* and sometimes *C. ericetorum* begin to mix with populations of *Tuckermannopsis subalpina.* At these sites, *T. subalpina* is very robust and lobes develop the same size as *C. islandica.* Even though these three species can have very distinctive chemistry, it is sometimes difficult to determine morphology of a species in the field, especially when two or three of them grow together in large mats. *C. islandica* has large laminal cephalodia on the under surface, but in mesic areas, they were located only at the base and hidden in the humus layer. In exposed areas, *T. subalpina* acquires a darker brown color, but it is still paler than the dark forms of *C. islandica.* As the sites become more exposed and the ericaceous plants disappear, *C. islandica* and *C. ericetorum* become more frequent. At Slate Peak, on the ridge top trail, *T. subalpina* is the main cetrarioid lichen on the north and northeast facing slopes while on the south and southwest facing slopes, *C. islandica* and *C. ericetorum* dominate.

The exposed dry tundra communities of Skyline Divide and Slate Peak share many of the lichens found in the northeast Olympic Mountains: the cetrarioid species, *Thamnolia subuliformis, T. vermicularis, Cladina mitis,* cladonias, stereocaulons, umbilicarias, *Peltigera rufescens, Lecidea atrobrunnea, L. cascadensis, Rhizocarpon geographicum,* and a variety of soil crusts where the substrate is more stable. At Skyline Divide *Cladina* *mitis* is widespread and abundant, even in the mesic sites at this location. *Flavocetraria nivalis* and *F. cucullata* are both at Slate Peak, but in small quantities. Only *F. nivalis* is found at Skyline Divide which is unusual because at all other dry tundra sites it is found with *F. cucullata* and is less abundant. Ryan (1985) also noted the absence of *F. cucullata* on Skyline Divide and Chowder Ridge on Mount Baker. *Peltigera malacea* and *P. rufescens* are both found along the ridge at Skyline Divide with *P. malacea* being more frequent. *P. malacea* is commonly found growing epiphytically on *Empetrum nigrum*, *Cassiope mertensiana* and *Phyllodoce* spp. *P. rufescens* is always on soil.

CONCLUSIONS

From this study over 170 lichen species have been identified. Of these, 65% are macrolichens and 35% are microlichens. Based on this study, the two mountain ranges have approximately the same number of species of lichens. The Olympics sites have greater diversity than the sites from the eastern North Cascades. Those sites with a maritime influence, the Olympics and Skyline Divide, have a greater species richness than the sites on the eastern slopes of the North Cascade Mountains. In general, the dry tundra sites have greater species richness than the mesic snow bank sites. This may result from a greater substrate variety, characteristic of the drier, exposed locations. Mesic sites are composed of lichen assemblages that are able to exist in more acidic soils. The moist substrate and generally shaded environment also allows for the development of ericaceous plants. Lichens such as *Tuckermannopsis subalpina*, *Solorina crocea*, and *Cladonia* spp. are common in these locations. Differences in the species richness between sites may be the result of poor spore dispersal or subtle differences in the habitat preferences of lichens.

When compared to other studies of alpine lichens (see bibliography), the following similarities were observed. For the lichen species from this study that have currently been identified, 75% have arctic affinities (Thomson, 1979, 1984). Of these, 25% are strictly arctic/alpine. Eighty-five percent are found in the alpine or subalpine areas of Glacier

National Park, Montana (Debolt & McCune, 1993). Fifty percent of the lichens found on the Beartooth Plateau in Montana and Wyoming (Eversman, 1995) also occur in alpine areas of the Washington sites. Ten percent of the lichens from this study are found at all six sites.

Moisture content of the site, along with other abiotic factors and vegetation, has a strong influence on the lichen species composition found within a community (Glew, 1996a). For example, when macrolichens were examined from dry tundra sites at both Olympics and North Cascades locations, very similar assemblages are revealed. Also, cetrarioid lichens and *Thamnolia* spp. often occur throughout the dry, exposed ridge tops, but their abundance varies from site to site (Glew, in prep.). The main crustose species commonly found at all sites were on similar rock substrates, such as sandstone or basalt.

An exception to the above situation is the umbilicate lichens where certain species seem to thrive only at one of the two alpine locations. Their distribution does not seem to be dependent on soil moisture content, since the rock environment is exposed and dry on both sites. These differences may be related to glacial processes and remnant populations of species surviving the last ice sheet. *Vulpicida tilesii* also shares this disjunct distribution, being found in the Olympic and Rocky Mountains, but not in the Cascades (Glew, 1994a).

This study comprises a large number of collections covering a wide range of habitats that have not been examined previously. Approximately eighty percent of the specimens are identified, leaving twenty percent to be examined in the future. Therefore, further identifications of unique lichens will be discovered, increasing the number of species from each site. This study sampled a portion of the Olympic and Cascade Mountains. Further studies in these mountains will extend the distributions of alpine lichens and add to the number of lichens found in these areas.

VASCULAR PLANTS

Vascular plants followed the same distribution patterns as lichens. Very few species were found at all six sites, although *Selaginella wallacei* was an exception. *Achillea millefolium*, *Antennaria alpina*, *Erigeron peregrinus*, *Phlox diffusa*, *Potentilla diversifolia*, and *Solidago multiradiata* were found at all sites but the Tatie Peak area. *Sibbaldia procumbens* did not occur within the Buckhorn Cirque, but was seen at the other five sites. *Antennaria microphylla*, *Arenaria capillaris*, and *A. obtusiloba* were not seen along the Skyline Divide ridge but were seen at all other sites. The plants listed here are typical for Washington's alpine environments. (Appendix E)

Several species were observed only in the Olympic Mountain sites. These were *Allium cernuum*, *Allium crenulatum*, *Artemesia trifurcata*, *Calamagrostis purpurascens*, *Carex obtusata*, *Cerastium arvense*, *Chamaecyparis nootkatensis*, *Danthonia intermedia*, *Douglasia laevigata*, *Erigeron compositus*, *Eriophyllum lanatum*, *Festuca idahoensis*, *Gentiana calycosa*, *Geum triflorum*, *Happlopappus lyallii*, *Hedysarum occidentale*, *Luzula spicata*, *Oxytropus campestris*, *Phacelia sericea*, *Poa cusickii* var. *purpurensis*, *P. sandbergii*, *P. stenantha*, *Polemonium pulcherrimum*, *Potentilla fruticosa*, *Saxifraga tolmiei*, *Smelowskia calycina*, and *Synthris pinnatifida*. Many of these plants can occur in the Cascade Mountains, as well, but were not detected in the lichen communities from this study.

Those plants found in the North Cascades sites, but not in the Olympic sites were *Agrostis scabra*, *Abies lasiocarpa*, *Aster alpigenus*, *Carex nigricans*, *C. pyrenaica*, *Cassiope metensiana*, *C. stelleriana*, *Castilleja paviflora* var. *albida*, *Deschampsia atropurpurea*, *Dryas octopetela*, *Empetrum nigrum*, *Erigeron aureus*, *Festuca viridula*, *Juncus drummondii*, *Kalmia microphylla*, *Laryx lyallii*, *Leptarrhena pyrolifolia*, *Lupinus latifolius*, *Luzula campestris* var. *multiflora*, *L. piperi*, *Lycopodium sitchensis*, *Phleum alpinum*, *Phyllodoce empetrifomris*, *P. granduliflora*, *Picea engelmannii*, *Pinus albicaulis*, *Poa alpina*, *P. cusickii* var. *epilis*, *P. incurva*, *Polygonum bistortoides*, *Potentilla drummondii*, *P. flabellifolia*, *Ranunculus escherscholtizii*, *Salix cascadensis*, *Sedum divergens*, *Silene parryi*, *Vaccinium scoparium*, and *Valeriana sitchensis*. Again, some of these plants occur in the Olympic Mountains, but in this project were not observed in the study sites.

CHAPTER 3: COMMUNITY STRUCTURE (DIVERSITY)

INTRODUCTION

Studies of alpine lichen community diversity have been conducted in Europe (Gjaerevoll, 1956; Creveld, 1981; Magnusson, 1982; Oksanen, 1983; Daniels, 1985; Haapasaari, 1988; Akatov, 1995) and Siberia (Yurtsev, 1982), but are uncommon in North America (See & Bliss, 1980; Eversman, 1995). Many studies list species from a particular area but do not report species richness, frequency or abundance. Alpine lichen communities lend themselves to diversity studies because: 1) they are easily observed; 2) they can be a major component of the vegetation (Glew, 1997, 1998; Thomson, 1984; Ahti & Oksanen, 1990; Creveld, 1981); 3) though they can be three-dimensional, their height usually does not exceed 10-15 cm; and 4) their abundance (percent cover) can be easily determined.

In Washington only three ecological studies have involved alpine lichens. Douglas (1973, 1974) included lichens in his alpine study of the North Cascade Mountains; Kunze (1980) at Deer Park in the Northeast Olympics; and Ryan (1985) on Chowder Ridge, Mount Baker. Two of these studies involved rigorous sampling using transect lines (Douglas, 1973, 1974) or well-defined plots (Kunze, 1980).

This study intends to examine lichen richness, frequency, and abundance of each site to determine similarities and differences in alpine lichen communities in Washington state. Questions addressed are:

How does the lichen species richness compare between sites?

How do site location and mountain range affect the abundance of lichen species?

Are lichen species equally frequent along a transect at each site?

Which species are dominant at each site?

How do the growth forms of lichens compare between sites?

What are the most common substrates upon which lichens occur at each site?

Environmental factors that affect diversity will be considered, but will be analyzed further in Chapter 4. Unlike alpine areas of the Rocky Mountains or the northern arctic tundra, alpine communities in Washington are small. Partly due to the relative "young" age of the Olympic and Cascade mountain ranges (30 million yrt), alpine lichen communities have been confined to areas where there has been sufficient time for lichen development on soil, gravel or rock. Some of these alpine areas have been undisturbed for a period of time to allow lichen communities to mature. Areas in the Rocky Mountains and arctic tundra may exhibit greater lichen diversity because they are areas of well-established communities covering broader areas and connected with the arctic tundra. Washington's alpine communities are still developing and isolated from arctic vegetation. This research established which lichens are present so that these communities can be monitored over time.

OBJECTIVES OF THE STUDY:

The objectives of this study are as follows:

1. Determine and compare lichen species richness, frequency, and abundance on alpine sites using data from quadrats, transects and sites.
2. Calculate the Shannon diversity index of lichens for each site.
3. Compare lichen species growth form and substrate type among sites.
4. Compare percent cover of cyanolichens by site.

METHODS

TRANSECT PLACEMENT

See Appendix A for specific transect characteristics.

Olympics

At Buckhorn Cirque, southwest of Buckhorn Mountain, the transects have a gradual slope that supports a relatively lush tundra vegetation. This area comprises equal amounts of lichens and vascular plant species. Since the cirque resembles a bowl, nine transects were placed in three lines of three placed end to end. This produced three 300 meter transects in the cirque all running southeast to northwest. These transect lines detected homogeneous areas of lichen and plant communities, as well as transition areas, defining differences in the sizes of each type of community. The cirque is exposed, windy, and experiences frequent fog. The central and northern part of the cirque exhibits solifluction, with fellfields surrounding this area. There is little snow accumulation on the northeast side of the cirque, but the south and southwest sides have snow patches lingering into July.

Elk Mountain transects were arranged along the main ridge of the mountain, along an elevation gradient. This follows a trail along the ridge from Obstruction Peak eastward to Deer Park. Starting at the highest point of the Elk Mountain massif and moving westward, transects were placed along the trail at four locations; one transect placed perpendicular above the trail and the other placed perpendicular to and below the trail, for a total of eight transects. Information involving variation in lichen species and vegetation over 200 meters, including a 50 to 100 meter elevation gain, was recorded. Sandstone rocks were more stable and had a higher diversity and abundance of lichens than shale and slate. The ridge is exposed and windy, with little snow build up. Many rocky outcrops were observed. Elk Mountain has vegetation stripes surrounded by stable rock stripes. Level areas are fellfields with loose rock and scattered patches of vegetation.

In Deer Park, two areas were chosen, Blue Mountain and Deer Ridge. Blue Mountain is at a higher elevation, more exposed, and above treeline with alpine communities covering most of the area, except for the northeast side. Deer Ridge is in a transition zone where the south and southwest side of the ridge contains alpine vegetation. The north and northeast side has krummholz vegetation and snow patches lasting into the summer. Four transects were placed on Blue Mountain and four on Deer Ridge. This site is also exposed and subject to strong winds. It has an intermediate amount of rocky outcrops, compared to the other two Olympic sites.

North Cascades

Skyline Divide on Mount Baker has distinctive habitats in which transects were placed. Five of the nine transects were placed at treeline where alpine vegetation was beginning to intergrade with the subalpine vegetation. These transects, with northwest to northeast exposures, tended to have mesic conditions due to water run-off from melting snow patches. Transects A to E (Appendix A) were at a lower elevation than transects F to I, by approximately fifty meters. This elevation difference plays an important role in determining the kinds of vegetation seen along the transects. The transects with the lower elevation had abundant ericaceous communities with rich humus soil. The higher elevation transects were represented by fell fields and exposed windy conditions with typical alpine vegetation as seen in the Olympics.

Slate Peak on the eastern slopes of the North Cascades also exhibits distinctive types of communities. Those sites on the north, northeastern slopes were more mesic with lower lichen diversity. Four of the transects were placed on stable soils in areas that were protected snow melt areas. Two of the transects were in mesic meadows. The other four transects were placed on the south, southwest side of the slopes which were exposed to the sun and wind with fellfield habitats and loose substrates. These areas were free of snow during the spring and summer.

The Tatie Peak area in the North Cascades is only 5.25 km southwest from Slate Peak and approximately 100 meters lower in elevation, yet display a much different type of alpine habitat than that of Slate Peak. The soil is a much finer-grained sedimentary rock compared to Slate Peak. Two of the transects were placed along the top of the ridge above Ninety-nine Basin. This area is drier than the other six locations, but is also subject to lingering snow-patches. The other six transects were placed in areas where *Tuckermannopsis subalpina*, *Lepraria cacuminum*, and heathers were the dominants. Two sets of transects, C,D and E,G were positioned perpendicular to each other to determine the effect of transect direction on lichen species richness and abundance. These transects bordered on high subalpine vegetation, which resulted from the aspect of the slopes. Slopes facing south to west were too steep for the placement of transects.

DIVERSITY MEASUREMENT

PCORD 2.1 and 3.1 (McCune & Mefford, 1995, 1997) were used to determine species richness, percent cover, species frequency and the Shannon diversity index along each transect and for each site. The results represent lichens found on the quadrat level (0.25 m^2). Alpha diversity (α) was the total number of lichens found in a quadrat or transect. Beta diversity (β) was calculated as γ/α (Whittaker, 1972; Wilson and Shmida, 1984). Gamma diversity (γ) was the total number of species found at a site. An estimate of the gamma diversity was calculated as a first-order jackknife estimator (γ') of total species richness based on the total number of species found in one sample unit (Palmer, 1990; McCune & Mefford, 1995). Species identified from general collecting were not included in calculating the jackknife estimate. The Shannon Diversity Index was calculated to account for both species richness and abundance. Comparison of means of the above parameters between sites was performed with a Tukey-HSD (SPSS, 1995) test.

The Sørensen Index was used to measure similarities between lichen species composition at each site. The index is 2w/(a+b), where a = the number of species in site A; b = the number of species in site B; w = the number of species they have in common.

RESULTS OF LICHEN DIVERSITY

Of the over 170 lichens identified at the six study sites, only 97 species were used in the analyses of community structure. The remaining lichens included many crustose species that were not identifiable in the field and krummholz and epiphytic lichens that did not occur along the transects. Results from this study therefore emphasize the diversity of the more common macrolichens. The crustose lichens, were combined into one of two categories, "rock crusts" or "soil crusts". Those crustose species that were distinctive enough to identify in the field were included in the list of lichen used for analyses. Table 1 compares the diversity of lichens on the basis of abundance, richness, Shannon Index, evenness, and the total number of lichens found at each site.

In this study I defined a lichen community on the basis of an assemblage of uniform lichen vegetation and then recorded plants found within the community. Most previous research involving alpine communities analyzed lichens in relation to plant communities or phytosociological synusiae (See & Bliss, 1980; Douglas 1973, 1973, Komarkova, 1979; Willard, 1979). When examining lichen communities, vascular plants and non-lichen cryptogams were included as part of the environmental surroundings that make up these alpine areas (Glew, 1994bc, 1997).

ABUNDANCE

Percent cover of all lichens at all sites was assessed (Figure 8, Table 2) and compared with plant cover. In general, the three Olympic and two North Cascade tundra sites (five bars on the left) had an average lichen cover that is similar to vegetation cover. The other three locations in the North Cascades, representing more mesic conditions had, a much lower ratio of lichen cover to vegetation cover. Buckhorn Cirque had the highest lichen cover (40.8%), with Tatie Peak displaying the lowest cover value (11.8%). However, when Skyline Divide and Slate Peak were separated into mesic and tundra transects, Skyline Divide had the highest lichen cover value at 51% and Slate Peak mesic transects had the lowest cover at 10%.

The Olympic sites and tundra transects on Skyline Divide, Mount Baker had a much higher percent cover of lichens than the other four sets of transects in the North Cascade sites (Figure 8, Table 2). Slate Peak was an area subject to trampling by humans which may be reflected in the low cover for that site, as compared to the other tundra sites. In general, lichen cover was much lower in the mesic sites with north to northwest aspects.

Plant cover displayed the opposite effect being higher in the mesic sites and lower for the tundra sites (Figure 9, Table 4). The high plant cover most likely had an impact on the lichens present (Petzold & Mulhern. 1987). Taller, fast growing plants, utilized space that potentially would be available to lichens. Many of these lichens, were found in open areas where sufficient light was available for photosynthesis (Kappen, 1973).

High plant cover can block this light, slowing lichen growth and potentially preventing communities from developing. The slow growth rate of lichens is widely known (Hale, 1983; Ahmadjian, 1993; Nash, 1996). In alpine tundra other plants also grow slowly. Thus lichens can become established without being overgrown by other vegetation.

Previous studies from the alpine and subarctic have shown that bryophytes tend to be more abundant in mesic habitats than lichens (Flock, 1978; Robinson, 1989a,b). This phenomena also has been observed in lower elevation forests (Carleton, 1990; Hoffman & Kazmierski, 1969). In the present study, however, bryophyte abundance was not necessarily greater than lichen cover in mesic habitats. Within a site, bryophyte abundance was greater than lichens in the mesic habitats. But between sites, some tundra areas had equivalent or higher lichen cover than bryophytes in mesic sites or transects (Appendix F). This was seen at Skyline Divide where the tundra bryophyte cover was at 15.3% and at the Tatie Peak sites the cover was 15.7%. Based on frequency data (number of occurrences per 160 quadrats), bryophyte frequency was higher at two tundra sites, Buckhorn Cirque (74%) and Deer Park (60%), than it was for the mesic transects at Slate Peak (57%). Along the drier transects within a site, lichen cover was higher than bryophyte cover.

Table 1. Comparison of lichen diversity between sites.

Similar letters indicate sites not significantly different. Lichen diversity based on the quadrat level, along with γ and β diversity. **Site** values (γ) are based on the number of species used in the analyses (out of 96 species). The first-order jackknife estimator (γ') is determined from species area curve calculations. **Total** species reflects the actual number of lichen species identified from each site.

SITE	% LICHEN COVER	DIVERSITY H'	LICHEN RICHNESS	EVENNESS	TRANSECT DIVERSITY	γ'	β	TOTAL sp. for SITE (γ)
BUCKHORN, O. M.	40.8^{bc}	1.56^{c}	10^{b}	0.693	2.42	55	8	81
DEERPARK, O. M.	25.6^{ab}	1.26^{abc}	7.7^{ab}	0.637	2.0	57	9	72
ELK MOUNTAIN, O. M.	35^{abc}	1.67^{c}	11^{b}	0.720	2.51	68	7	81
SKYLINE DIVIDE, N. C.	37.1^{cd}	1.27^{abc}	6.8^{ab}	0.662	1.92	63	12	81
SKYLINEDIVIDE, tundra	51^{c}	1.48^{c}	10.3^{b}		2.24			
SKYLINE DIVIDE, mesic	26^{abc}	1.0^{ab}	5^{a}		1.66			
SLATE PEAK, N. C.	12.4^{ab}	1.08^{ab}	5.7^{a}	0.632	2.21	58	13	72
SLATE PEAK, tundra	16^{ab}	1.38^{abc}	7.7^{ab}		2.38			
SLATE PEAK, mesic	10.0^{a}	0.83^{a}	3.9^{a}		2.05			
TATIE PEAK, N. C.	11.8^{a}	0.86^{ab}	4.1^{a}	0.538	1.83	41	12	50

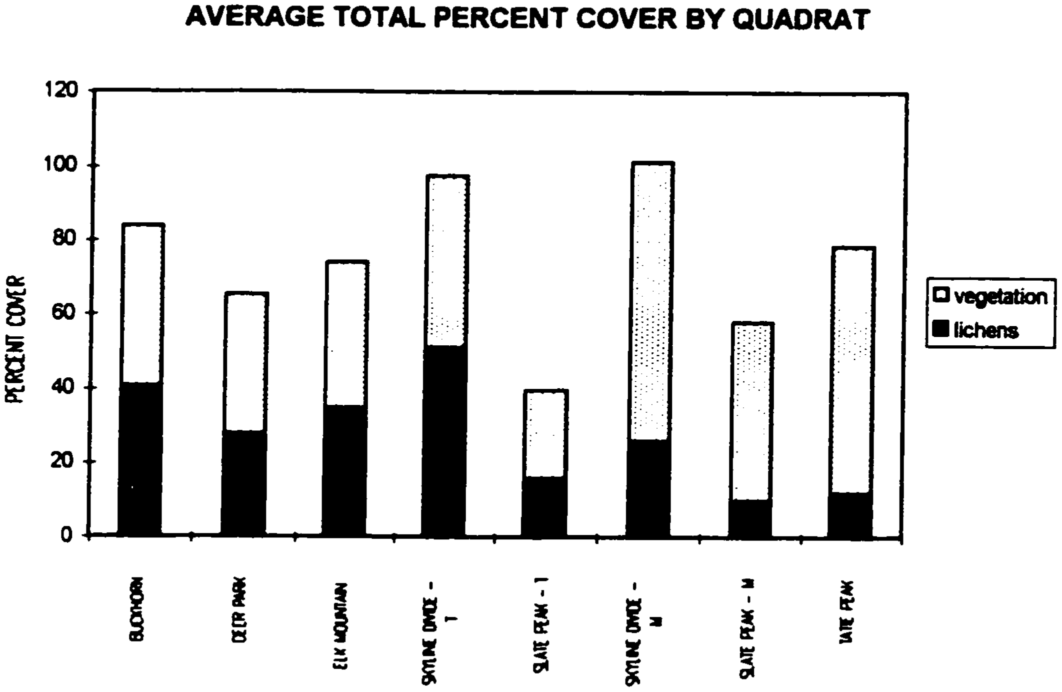

Figure 8. Percent cover of lichens compared to plants.
Lichen cover is represented in black on the bottom portion of each bar. Plants are represented in light gray at the top of each bar. The three sites on left are from the Olympic Mountains. The three sites on the right are from the North Cascades Mountains.

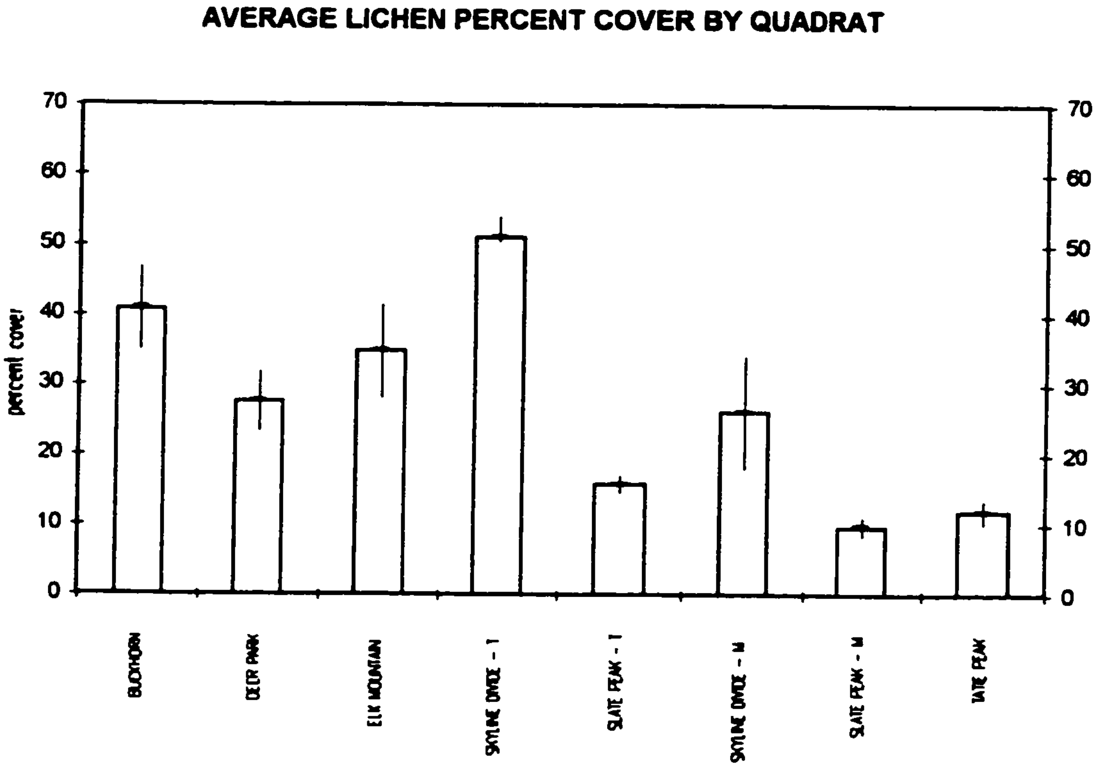

Figure 9. Average percent cover of lichens on the quadrat level.
Bars represent median values, vertical lines represent standard error. The three sites on left are from the Olympic Mountains. The three sites on the right are from the North Cascades Mountains.

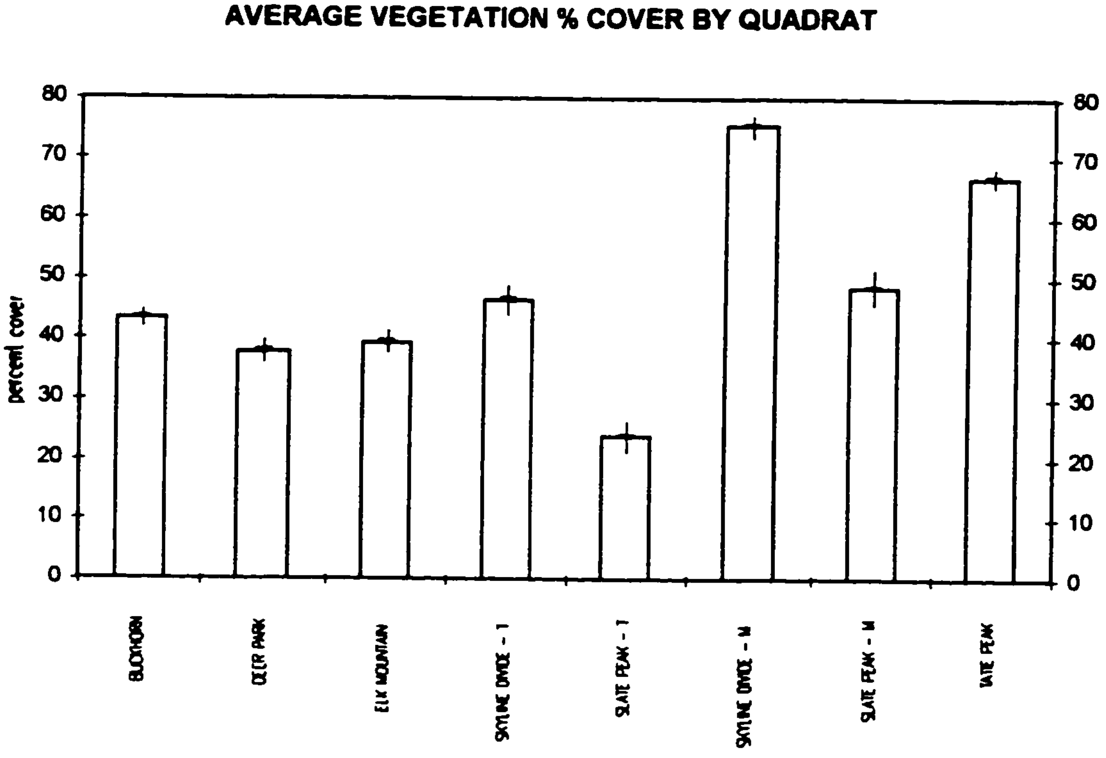

Figure 10. Average percent cover of vegetation on the quadrat level. Bars represent median values, vertical lines represent standard error. The three sites on left are from the Olympic Mountains. The three sites on the right are from the North Cascades Mountains.

DOMINANT LICHENS AT EACH SITE

In most cases, lichen percent cover for individual species was never greater than 10%, (Table 3, Appendix C). Exceptions included *Thamnolia* spp. (*T. subuliformis* and *T. vermicularis*), thus comprising 10.8 percent of the cover at Deer Park. All other species were below 2% at Deer Park. *Thamnolia* spp. were a major component of the tundra sites seen in the northeast Olympics and Skyline Divide on Mount Baker ranging between 4-5% at each site. However, for the two sites on the eastern slopes of the North Cascade Mountains, Slate Peak and Tatie Peak, *Thamnolia* was poorly represented. *Cladina mitis* at Skyline Divide was the most abundant lichen with an average cover of 11%. These two lichens were not the major component of any other site, particularly *C. mitis* which only appears at Buckhorn Cirque and Deer Park as one of the dominant species. In dry areas where graminoid cover was high, *Cladina* could be found to form large mats, 20 - 30 cm across. This phenomenon was also seen with *Stereocaulon* spp. Although this lichen genus was commonly found in large mats, it could be very specific in the types of conditions it preferred. *Stereocaulon* spp. was not frequent and did not compose a large portion of the total lichen cover at any of the six sites.

Abundant species found at tundra sites and transects follow the same patterns described in Chapter 2, with *Thamnolia* and cetrarioid species being the most abundant and *Cladonia* and *Cladina* species being common. Other frequent lichens, but not abundant in percent cover included *Candelariella* spp., both on soil and rock, and *Lecanora polytropa*. Because the latter two are crusts, often only the apothecia were present and they did not cover a large area on the substrate. Dry tundra communities are more likely to have well-developed saxicolous lichens communities (Appendix D). Common and abundant species for these communities are *Umbilicaria hyperborea*, *Rhizocarpon geographicum*, *Pseudephebe pubescens*, *P. minuscula*, *Melanelia* spp., *Lecidea atrobrunnea*, and *Brodoa oroarctica*. *Cornicularia normoerica*, *U. kraschenínnikovii*, *U. rigida*, *Xanthoparmelia coloradoënsis*, *Lecanora bicincta*, and *Lecidea c.f. tessellata* are more commonly seen in the Olympic sites. *Umbilicaria arctica*, *U. cylindrica*, *U. proboscidea*, *Umbilicaria*

Table 2. Dominant lichens found at each site based on percent cover

Buckhorn Mountain Cirque

Lichens:	*percent cover**
Cetraria islandica	6.7
Cladonia spp.	5.1
Thamnolia spp.	5.0
Flavocetraria cucullata	3.4
Cetraria ericetorum	2.6
Cladina mitis	2.0
Rock crusts	4.5
Soil crusts	2.6

Deer Park - Blue Mountain and Deer Ridge

Lichens:	
Thamnolia spp.	10.8
Cladonia spp.	1.8
Peltigera rufescens	1.5
Melanelia muricatum	1.5
Cladina mitis	1.0
Rock crusts	2.4
Ochrolechia upsaliensis	1.1

Elk Mountain

Lichens:	
Thamnolia spp.	4.3
Umbilicaria hyperborea	3.2
Cladonia spp.	2.7
Cetraria islandica	1.7
Flavocetraria cucullata	1.5
Pseudephebe pubescens	1.4
Rock crusts	8.3
Rhizocarpon geographicum	1.5
Soil crusts	1.4

Table 2. (continued)

B. North Cascade Mountains

Skyline Divide, Mount Baker

Lichens:	*percent cover**
Cladina mitis	11.0
Thamnolia spp.	4.2
Tuckermannopsis subalpina	3.2
Cetraria ericetorum	2.9
Cladonia spp.	2.9
Cetraria islandica	1.2
Rock crusts	2.3
Soil crusts	1.7

Slate Peak

Lichens:	
Cladonia spp.	1.1
Cetraria islandica	0.8
Tuckermannopsis subalpina	0.7
Peltigera rufescens	0.6
Cetraria ericetorum	0.5
Rock crusts	3.1
Rhizocarpon geographicum	1.3
Lecidea atrobrunnea	0.1
Soil crusts	0.4
Lepraria cacuminum	0.9

Tatie Peak

Lichens:	
Tuckermannopsis subalpina	1.5
Cladonia spp.	0.6
Solorina crocea	0.6
Cetraria islandica	0.5
Rock crusts	2.7
Rhizocarpon geographicum	0.9
Lecidea atrobrunnea	0.3
Soil crusts	0.1
Lepraria cacuminum	2.3

* cover is based on a $0.25m^2$ quadrat

virginis, *Dermatocarpon reticulatum*, and *D. rivulorum* are saxicolous species found more frequently at the North Cascades sites.

Communities on soil at all sites consisted primarily of *Caloplaca jungermanniae*, *C. tiroliensis*, *Candelariella terrigena*, *Cladonia* squamules, *Lecidoma demissum*, *Lepraria cacuminum*, *Leprocaulon subalbicans*, *Ochrolechia upsaliensis*, *Pannaria pezizoides*, *Peltigera* spp., *Physconia muscigena*, *Placynthiella uliginosa*, *Phaeorrhiza nimbosa*, and *Solorina crocea*. *Ochrolechia upsaliensis* and *Lecidoma demissum* were more common on the tundra sites and transects while *Lepraria cacuminum*, *Leprocaulon subalbicans*, and *Solorina crocea* were predominately found in mesic habitats (Appendix D).

Mesic sites and transects in the North Cascades had very low diversity. *Tuckermannopsis subalpina* was very common and abundant on ericaceous shrubs, mainly *Cassiope* spp. *subalpina* and *Phyllodoce* spp. *Tuckermannopsis subalpina* was much more common than the typical fellfield lichens of *Cetraria islandica* and *C. ericetorum*. In transition areas between subalpine and alpine, all three of these lichens can occur together. This grouping of cetrarioid lichens was seen most commonly at Tatie Peak and along Skyline Divide and Slate Peak.

Cyanolichens formed a very small portion of the lichen cover, ranging between 0.6 - 2.0% (Table 6) . However, a previous study by Gold (1996) showed that these lichens produce a significant amount of nitrogen compared to areas with no cyanolichens or bare ground. It may be that these communities do not require high amounts of nitrogen in the soil and this small cover of cyanolichens, along with nitrogen-fixing plants, such as lupine, are sufficient in maintaining the community. Other possibilities are that these communities are able to make do with less nitrogen or that nitrogen is not a limiting factor.

SPECIES RICHNESS

The mean number of lichen species per quadrat for the six sites ranged from 4 to 11 lichens (Table 1, Figure 11). This number is deceptively low since many of the individual crustose species occurred in one of two categories of "crusts" (rock and soil). This species richness value is mainly the macrolichen richness, not the total lichen species richness. Except for Tatie Peak, the actual number of lichen species per quadrat is higher at all sites, because field identification of crustose lichens is difficult. Table 1 reflects this discrepancy displaying the number of species used in the analyses and the number actually identified from each site. Many crustose species require special techniques for identification (i.e., chemical and/or microscopic examination), and due to their small size (sometimes represented only by a few tiny apothecia) are often overlooked. Several species were discovered later while examining rocks or pieces of sod collected with a larger specimens.

Buckhorn Cirque (10.0 species) and Elk Mountain (11.0 species) had the highest number of species per quadrat (Figure 11, Tables 1 and 3). For Buckhorn this was due to the high diversity of soil crusts within the vegetation. The vascular plant canopy layer was thin, allowing only for some shading. The soil was less gravelly than at the other sites and had a neutral soil pH. The vegetation held moisture within microhabitat (Gold, 1996), creating ideal conditions for lichen growth. Elk Mountain had a coarser substrate, with a preponderance of rocky outcrops and stable rock strips that provided greater substrate variety. Therefore there were more lichen species. The Skyline Divide tundra transects also had a high species mean richness (10.3). This was most likely the result of rocks providing additional substrate to increase the diversity. The sites in Washington with oceanic influence had more species per quadrat than continental sites. Even though this follows the suggested pattern of decreased lichen diversity as one moves inland (Nash et al., 1979), there are additional factors that must be accounted for. The ridge to Slate Peak had more human activity than the other sites which could cause lower diversity. Also, several of the slopes at Slate peak were very steep (> 25 °) with a loose substrate. Both factors would interfere with lichen establishment and their growth. Another factor is that the North Cascades sites had mesic areas from snow melt run-off and a habitat unfavorable to high diversity within the lichen community.

Tatie Peak and the mesic transects at Slate Peak had the lowest richness of the sites with an average of four lichen species for each quadrat (Figure 12). The low species richness was correlated with the lush vascular plant growth. Lichens did not develop well in these areas. The presence of thick mats of heathers dominated the landscape. Other than *Tuckermannopsis subalpina* growing epiphytically on these mats and *Vaccium* shrubs, lichens were not found mixed in with these plants. In open gaps between ericaceous mats and shrubs, lichen diversity increased to include soil crusts, cyanolichens, cladonias and *Cladina* spp.

On the transect level (Table 3, Figure 12), the tundra sites and transects have a greater lichen species richness than the mesic sites and transects. Buckhorn, Elk Mountain, Deer Park, and the tundra transects on Skyline Divide and Slate Peak have species richness numbers that are significantly higher than the mesic transects of Skyline Divide, Slate Peak, and Tatie Peak. Even though the species richness is fairly equal among sites, mesic transect richness remains significantly lower than what is seen for the tundra transects (Table 1 and 3, Figure 12).

Plant species richness followed the same pattern as lichens (Table 4, 5; Figures 13, 14). More species were found in the tundra transects/sites than the mesic transects/sites and those sites with oceanic influences had a greater richness than those sites on the eastern slopes of the North Cascades. The results of this study indicated a trend of decreased alpine species diversity as one moves inland.

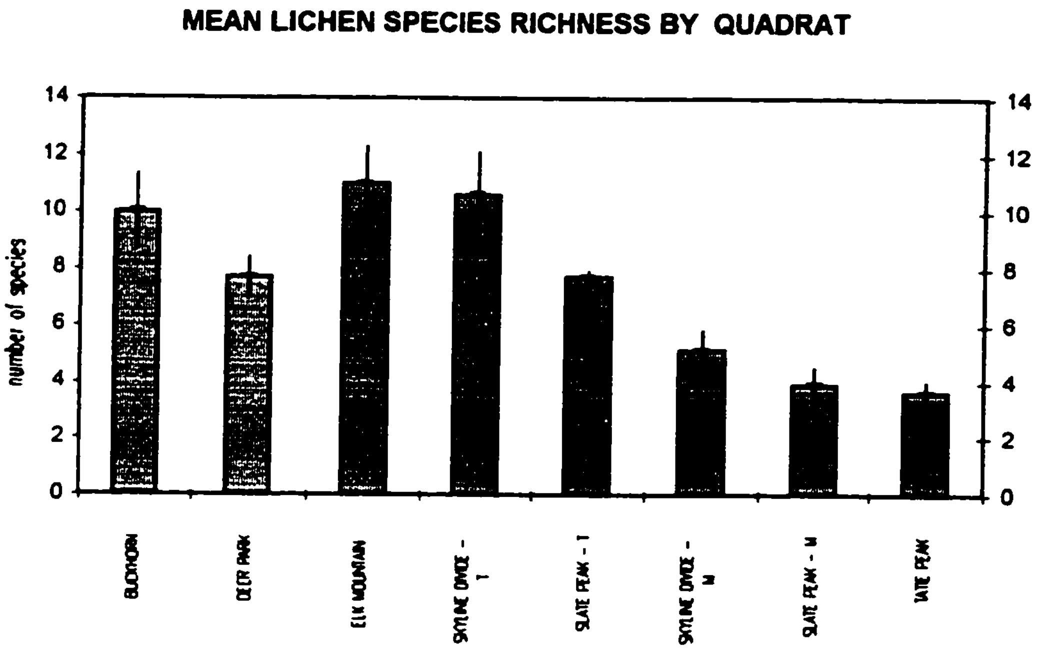

Figure 11. Mean lichen species richness on the quadrat level. Vertical lines indicate standard error.

Table 3. Lichen species richness (α diversity) compared between sites for quadrats, transects, and sites. Similar letters indicate sites not significantly different. **Site** values (γ) are based on the number of species used in the analyses (out of 96 species). The first-order jackknife estimator (γ') is determined from species area curve calculations. **Total** species reflects the actual number of lichen species identified from each site.

SITE	QUADRAT	TRANSECT	SITE	γ'	TOTAL
BUCKHORN, O.M.	10^{b}	27^{c}	49	55	80
DEER PARK, O.M.	7.7^{ab}	25^{bc}	50	57	72
DEER PARK, B.M.	8^{ab}	24.5^{bc}			
DEER PARK, D.R.	7.5^{ab}	25^{bc}			
ELK MOUNTAIN, O.M.	11^{b}	32^{c}	61	68	80
SKYLINE DIVIDE, N.C.	6.8^{ab}	22^{ab}	54	63	81
SKYLINE DIVIDE, T	10.3^{b}	32^{c}	50		
SKYLINE DIVIDE, M	5^{a}	16.4^{ab}	27		
SLATE PEAK, N.C.	5.7^{ab}	22^{ab}	47	58	72
SLATE PEAK, TUNDRA	7.7^{ab}	27.5^{c}	41		
SLATE PEAK, MESIC	3.9^{a}	17^{ab}	27		
TATIE PEAK	4.1^{a}	15^{a}	32	41	50

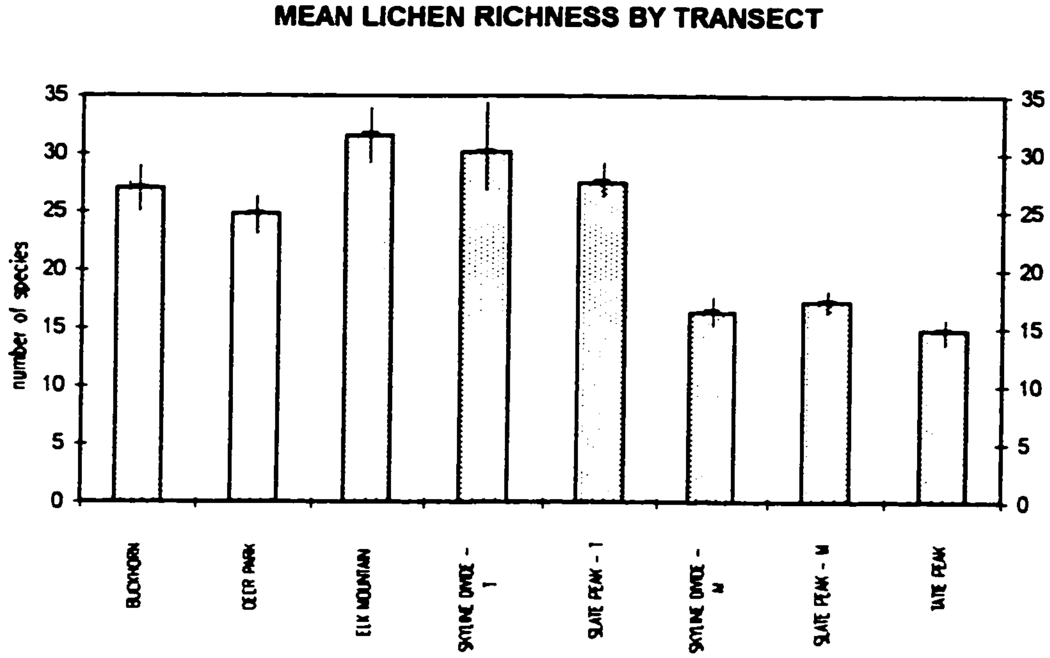

Figure 12. Mean lichen species richness for each transect. Vertical lines are standard error.

DIVERSITY INDEX

Elk Mountain had the highest diversity index (H'= 1.67) (Table 1). This is the results from its high average lichen cover and richness found within the quadrats and relative evenness of distribution. The other two Olympic sites also had relatively high H' (Buckhorn H'=1.56 and Deer Park H'=1.26). The mesic transects from Skyline Divide, Slate Peak, and Tatie Peak were all lower with H' values of 1.08, 0.83, and 0.86, respectively. The tundra transects at Skyline Divide and Slate Peak had H' values of 1.58 and 1.38 (Table 1), sharing the same range as the tundra sites in the Olympics, supporting the higher diversity found in these dryer transects. Transect diversity data ranged from 1.66 to 2.51 with an average of 2.12 (Table 1). Tundra habitats displayed the higher diversity (H') values than mesic habitats. Sites on the western side of the North Cascades had a higher H' than those on the eastern slopes of the North Cascades. These results support the pattern seen with the species richness and cover.

Table 4. Comparison of plant quadrat diversity between sites.
Similar letters indicate sites not significantly different. Plant diversity based on quadrats. Total plants for each site represent γ diversity.

SITE	% COVER	RICHNESS	DIVERSITY H'	TOTAL PLANTS (γ)
BUCKHORN, O.M.	43^{*b}	9^{b}	2.082^{*b}	43
DEERPARK, O.M.	$47^{a}/37.8^{*ab}$	6.8^{ab}	$1.287/1.778^{*ab}$	48
ELK MOUNTAIN, O.M.	39^{*ab}	6.4^{a}	1.7^{*ab}	47
SKYLINE DIVIDE, N.C.	$95^{b}/65^{*c}$	6^{a}	$1.233/1.744^{*ab}$	36
SKYLINE DIVIDE, TUND	$67^{a}/44.5^{*ab}$	6^{a}	$1.225/1.775^{*ab}$	30
SKYLINE DIVIDE, MES	$107^{b}/75^{*}{}_{d}$	5.7^{a}	$1.24/1.708^{*ab}$	22
SLATE PEAK, N.C.	36^{*ab}	5^{a}	1.477^{*ab}	51
SLATE PEAK, TUNDRA	24^{*a}	4.7^{a}	1.382^{*a}	36
SLATE PEAK, MESIC	48^{*bc}	5.4^{a}	$1.\ \ 1.572^{*ab}$	35
TATIE PEAK, N.C.	$93^{b}/66.7^{*c}$	6^{a}	$1.146/1.743^{*ab}$	25

* from presence/absence data

Table 5. Plant species richness (α diversity) compared between sites for quadrats, transects, and sites. The first-order jackknife estimator (γ') is determined from species area curve calculations. Beta diversity of plants calculated for each site.

SITE	QUADRAT	TRANSECT	SITE	γ'	β
BUCKHORN, O.M.	9^{b}	23^{b}	43	50	4
DEER PARK, O.M.	6.8^{ab}	21.6^{b}	48	56	7
DEER PARK, B.M.	7.2^{ab}	20^{b}			
DEER PARK, D.R.	6.4^{a}	23^{b}			
ELK MOUNTAIN, O.M.	6.4^{a}	21.6^{b}	47	51	6
SKYLINE DIVIDE, N.C.	6^{a}	14.6^{a}	36	39	5
SKYLINE DIVIDE, T	6^{a}	16.8^{ab}	30		5
SKYLINE DIVIDE, M	5.7^{a}	12.8^{a}	22		3
SLATE PEAK, N.C.	5^{a}	19.8^{b}	51	61	10
SLATE PEAK, TUNDRA	4.7^{a}	22.3^{b}	36		7
SLATE PEAK, MESIC	5.4^{a}	17.3^{ab}	35		6
TATIE PEAK	6^{a}	13.3^{a}	25	29	4

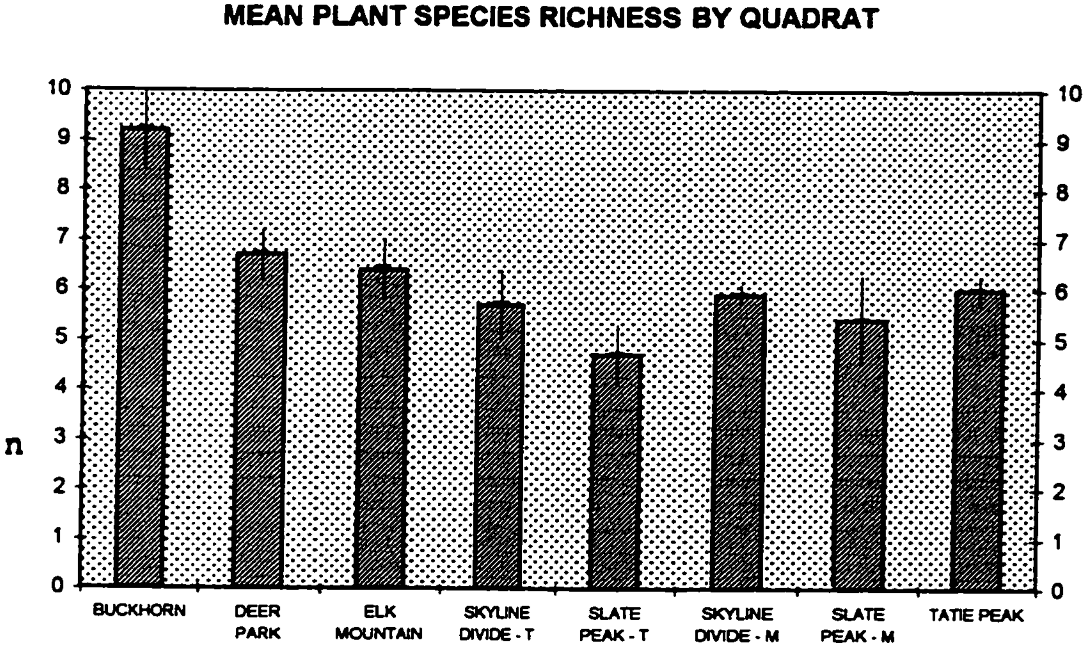

Figure 13. Mean plant species richness for quadrats.
Vertical lines indicate standard error.

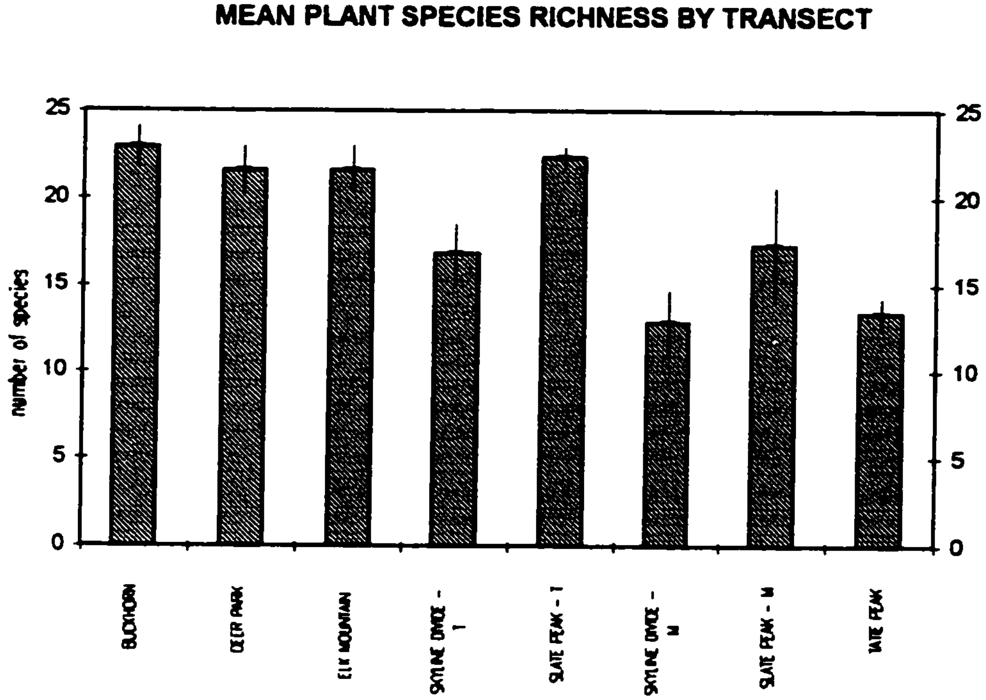

Figure 14. Mean plant species richness for transects.
Vertical lines indicate standard error.

GROWTH FORMS AND SUBSTRATES

The fruticose growth form is most common for the Olympic sites and Skyline Divide, followed by crustose forms on soil and rock. Foliose lichen cover is the least frequent growth form at all sites. Slate Peak and Tatie Peak, have a dominance of crustose species. This may be the result of a lack of vegetative substrates on which fruticose lichens can grow. Most fruticose lichens were highly correlated with plants (Table 6), while foliose forms were common on soil or rock. Foliose forms occurred more on rock substrate than on vegetation. *Peltigera* spp. (occurring on soil and vegetation) and *Umbilicaria* spp. (on rock) were the most common foliose genera.

The substrate that is associated with most lichens in the Olympics and on Skyline Divide is vegetation (Table 6). An exception is Elk Mountain where half of the lichen cover (17.2%) is associated with rock stripes and outcrops. The other 18.2% is divided between soil species (7.2%) and vegetation (11%). Of all the sites studied, Elk Mountain has the greatest rock cover. Although Buckhorn Cirque, Deer Park and Skyline Divide have some of the highest plant cover, lichens are strongly associated with this vegetation. It appears that the plants' structure can entangle the fruticose growth forms and foster the establishment of lichen communities. This is most dramatically observed at Deer Park where the pattern of lichen cover actually follows the plant cover (r = +0.31) (Glew, 1997). Many of the fruticose macrolichens may be "epiphytic" on the tundra vegetation. At Slate Peak, *Tuckermannopsis subalpina* is found attached to the branches of *Luetkea pectinata* (3-4 cm high) and low ericaceous mats.

For Tatie Peak and Slate Peak the majority of lichens grow on soil or rock, with only 2-3% of the lichen cover associated with vegetation (Table 6). At both of these sites soil lichen species make up approximately 4% of the total cover and saxicolous lichens (those found on rock) are 4 to 6% of the cover. At Tatie Peak the low percentage of lichen cover results from lush vegetation mats that make up the other 90% cover. The ericaceous mats crowd out lichens, preventing lichen establishment. The fell fields of Slate

Peak are similar to Elk Mountain and Buckhorn Cirque, but there is frequent trampling by humans. Vascular plants do not cover much of the area and their species diversity is low. In these tundra areas lichens have a positive correlation with plants because they provide a substrate for lichens.

Mesic habitats have an opposite effect on the lichen cover. At Tatie Peak and Skyline divide where ericaceous plants and hydrophilic graminoid are found, lichens cover is dramatically reduced. Few lichens are associated with these plants, therefore soil and rock are sometimes the only available substrate for lichens to colonize.

Table 6. Lichen abundance (percent cover) in relation to growth form and substrate.
All values are in percent cover with the exception of row 15 which is the number of <u>species</u> of cyanolichens recorded for each site.

	BUCKHORN	DEER PARK	ELK MOUNTAIN	SKYLINE DIVIDE	TATIE PEAK	SLATE PEAK
% foliose	1.19	2.17	4.58	1.09	0.66	1.17
% fruticose	28.84	17.31	16.57	30.45	3.11	4.05
% rock crust	6.79	3.58	11.11	2.48	4.09	5.79
% soil crust	4.12	1.51	2.42	1.82	2.67	1.39
% foliose soil	0.91	1.76	1.35	0.35	0.61	1.02
% foliose veg				0.16	0.001	0.03
% foliose rock	0.29	0.41	3.19	0.57	0.005	0.28
% fruticose soil	7.77	2.48	3.46	6.47	1.11	1.46
% fruticose veg	22.73	14.57	10.98	22.9	2	2.39
% fruticose rock	1.64	0.46	2.88	1.8	0.01	0.22
% soil	12.8	5.75	7.23	8.64	4.39	3.87
% veg	22.73	14.57	10.98	23.06	2.001	2.42
% rock	8.72	4.45	17.18	4.85	4.11	6.29
% cyano-lichen	2	1.55	1.37	mesic 0.7, tundra 2.7 Total - 1.2	0.6	mesic 0.74, tundra 1.5 Total - 1.06
# species cyanolichen	5	3	5	mesic 4, tundra 4 Total - 4	5	mesic 5, tundra 4 Total - 7
% cyano of total cover	2.4	2.4	2	mesic 2.6, tundra 1 Total - 1.2	1	mesic 1, tundra 4 Total - 2.2
% cyano of lichen cover	5	6	4	mesic 2, tundra 5 Total - 3.2	5.1	mesic 7, tundra 9 Total - 8.5
ave % lich	40.8	25.6	35	37.1	11.8	12.4
ave % veg	43.2	37.8	39.3	65.1	66.7	36.3
total % cover	84%	63.4	74.3	102.2	78.5	48.7

SPECIES-AREA CURVES

Species-area curves were used to indicate how much sampling should be done to adequately represent lichen species richness. These curves were based on the number of identifiable lichens (mainly macrolichens with some crustose species [or groups]) observed along the transect. A jack-knife estimator value was calculated in the process of determining the species area curve (McCune & Mefford, 1995; Palmer, 1991), represented as γ' and included in Table 1.

This jack-knife estimator is lower than the actual number found at each site. This is because the number of species used in the analysis was less than the total number of species for each site. These estimators are not as reliable when there are many rare species present (Palmer, 1995) or for predicting species richness for large areas (Palmer, 1990). The estimator is fairly accurate for this study when considering only the macrolichens. The portion of lichens that are unaccountable in the transect sampling are approximately one-third of the **total** lichens determined (Appendix B). These are mainly the **micro**lichens (crustose forms) that were not identified to species in the field.

For two of the sites in the Olympic Mountains, Buckhorn and Deer Park, the species area curve leveled off after approximately fifty quadrats. For Elk Mountain, the curve leveled at 60 quadrats (out of 160). This does not indicate that new species were not found beyond these points. General collecting was still essential to developing a list of all of the species found at the sites accounting for an additional 20 - 30 species that were not accounted for in the transect data.

In the North Cascades, the two sites of Skyline Divide and Slate Peak had curves leveling at approximately 60 quadrats (of 160). The Tatie Peak site's curve leveled at 35 quadrats, reflecting the low diversity and the fact that most of the species found at that site were seen in the first fifteen quadrats.

For each site β diversity was estimated (Table 1). The measurement was calculated as an indirect method for comparing species composition of different communities (Magurran, 1988). Beta diversity tended to be higher at Skyline Divide, Slate Peak, and Tatie Peak, in the North Cascades. This may indicate that within these sites, more microsites were available for lichens than in the other sites. However, β diversity did not parallel α diversity between sites. Even though Tatie Peak had a very low α diversity of 4.1, it had a higher β diversity than the Olympic sites. This could indicate greater habitat diversity or that perturbation is experienced at this site than at Buckhorn, Deer Park, and Elk Mountain.

SORENSEN INDEX

The Olympic sites were more closely related to each other (S>0.60) than the North Cascades sites (S<0.55). Skyline Divide was more similar to the Olympic sites than to the remaining North Cascades sites. Tatie Peak had a lower index value when compared to all sites with the exception of Slate Peak. Considering the close proximity of the two sites, it is expected that they would share more species than the other dry tundra locations that are further away.

Table 7. Sørensen Index (similarity values) for the Six Alpine Sites.

Site	Buckhorn	Deer Park	Elk Mt.	Skyline	Slate Peak
Deer Park	0.60				
Elk Mt.	0.66	0.68			
Skyline	0.58	0.60	0.66		
Slate Peak	0.55	0.53	0.52	0.54	
Tatie Peak	0.55	0.51	0.49	0.50	0.66

DISCUSSION:

It is clear that species composition, richness, percent cover, and frequency varied from site to site. This may largely be due to the variation in topography, age, and specific environmental factors controlling the conditions of each site. But, lichen assemblages are fairly consistent within each site.

This question arises; why sites in the northeastern Olympics and Skyline Divide have a greater overall species diversity than the sites from the eastern slopes of the North Cascades. Site selection was certainly a major factor in this determination. However it is worthwhile to examine the factors found in the western most sites that make them more suitable for lichen community development. Even though the Tatie Peak area is not particularly rich in lichen species or cover, lichens are well established among the vascular plants.

It has previously been stated that the relative moisture level of the ground is a major component in determining which lichens occur in an area and their abundance as well (See & Bliss; Flock, 1979; Robinson, 1989a,b). But the atmospheric moisture must certainly play a major role in determining which lichens are in a particular site since most of their resources, such as water, and nutrients in solution are absorbed through their thallus surface (Blum, 1973; Nash, 1996). The Olympic sites and Skyline Divide experience frequent fog which may compensate for exposure to wind and periods of desiccation. The may have higher water demands and are unable to survive these "arid" conditions. But those plants that grow slowly, particularly cushion plants that can retain water for long periods, help provide a habitat that is conducive to lichen community development. Moist areas contain plants that grow faster and taller, and may restrict most lichen species. It its interesting to note that in the Olympic Mountains, the only location to observe well developed alpine tundra lichen communities is in the northeastern portion of the peninsula (Schreiner, pers. comm.) which is in the rain shadow of the Olympic Mountains.

Substrate can also be a major factor determining lichen diversity, as seen with Elk mountain, which has a high rocky component to its terrain. Rock outcrops and stable rock stripes found in arctic/alpine environments provide additional microhabitats for the development of saxicolous species. Well developed soil, such as observed in Buckhorn Cirque promote the development of soil communities such as crusts and foliose cyanolichens.

The types of plants present also can determine lichens diversity. *Cetraria islandica*, *C. ericetorum*, and *Tuckermannopsis subalpina*, could be found growing together at the transition areas between subalpine/alpine and heath/dry tundra habitats. *Tuckermannopsis subalpina* is epiphytic on ericaceous plants and some of the woody ground cover associated with early snow-bank communities in the subalpine/alpine zones. It is the dominant cetrarioid lichen in these areas. As the ericaceous plants are replaced by the drier tundra vegetation such as cushion plants, graminoids, and low growing plants, *Tuckermannopsis subalpina* disappears from the lichen community. Other cetrarioid species become dominant and establish themselves in the alpine. Thus one cetrarioid species is being replaced by five others.

Open areas found between plants in well developed soil areas have a greater diversity of soil lichens and crusts. In addition, the majority of the nitrogen-fixers are terricolous lichens found in these open areas. This phenomena has been seen with epiphytic lichens in "gaps" of forested areas and referred to as lichen diversity "hot spots" by Neitlich and McCune (1997). The critical size of the open area is important in maintaining diversity, but is not yet accurately determined. The diversity in these areas is dependent on topographic position, aspect along with gradients for light and moisture (Neitlich & McCune 1997). Detailed studies of diversity in these open areas have not been thoroughly conducted in alpine areas of North America. Preserving areas of high diversity is essential in maintaining the characteristics of an ecosystem.

Aspect has an influence on the moisture level of the soil. Transects on slopes with north or northeast facing aspects tended to have moister conditions (*cf.* Whittaker, 1960; John & Dale, 1990). Those slopes with south or southwest facing slopes tend to be more exposed to wind and insolation, thus were more xeric.

Time since glaciation has an influence on the diversity of the lichens in an alpine community. Areas in the northeast Olympics were hypothesized to be possible refugia in the last ice age and therefore had remnant populations of lichens to develop more diverse lichen communities (Pielou, 1991; Buckingham et al, 1995). These areas also had a longer period of time to develop into lichen communities where the vegetation at North Cascade sites may be younger. The North Cascades sites were covered during the last ice age, reducing the probability of nearby lichen populations contributing to the development of these communities. Over time these sites might develop lichen communities that more closely resemble the northeastern Olympics.

Absence of disturbance can promote a higher diversity of lichens. The major cause of the low diversity at Slate Peak probably due to the frequent human trampling. Steeper slopes can reduce human off-trail activity even though an area may be frequented by hikers. Some areas of Elk Mountain, Skyline Divide and Slate Peak have slopes 25° or steeper, and with some of that being loose talus, humans are less likely to walk across these areas. The adverse impact of human disturbance and animal trampling in alpine/arctic areas is well documented for locations with both low and high diversity (Grabherr, 1981; St. Clair, 1984; Ahti & Oksanen, 1990; Harper & Kershaw, 1996).

Environmental factors related to lichen diversity will be analyzed in the next chapter. Ordination methods will evaluate which factors are the most important at each site for affecting lichens and their distributions in the landscape. Some of the factors affecting richness and abundance will undoubtedly be the result of random distribution of lichen propagules, factors affecting dispersion in each of the mountain ranges, differences in weather patterns, and historical considerations (*cf.* McCune & Allen, 1985). In addition to the abiotic factors of aspect, substrate, and moisture, the effect of vascular plants and cryptogams other than lichens will be considered to determine their influence on lichen diversity and distributions.

CHAPTER 4: ALPINE LICHEN COMMUNITIES

INTRODUCTION

Lichens occasionally are included in community studies of alpine vascular plants (Douglas and Bliss, 1977; Daniels, 1985; Ahti and Oksanen, 1990; Canters et al., 1991), but rarely have they been the focus of alpine community studies in North America (Douglas, 1973; Willard, 1979; St. Clair, 1984; See and Bliss, 1980; John, 1989, 1990; John & Dale, 1990). This is due in part to the difficulty of determining species in the field, especially crustose lichens, insufficient monographs of lichen genera, and poor species descriptions, especially for lichens in the Pacific Northwest.

Often lichen assemblages have not been recognized as communities and consequently have been included with vascular plant communities. Lichen communities have been defined in terms of their substrate (Barkman, 1958; James, et al., 1977; Creveld, 1981; Hale, 1983; McCune & Antos, 1982) or by their dominance and permanence within a biotic system (Smith, 1921; Ahti & Oksanen, 1990). Lichen communities were described by James, Hawksworth, & Rose (1977): "Within a single climatically uniform region, each particular substrate *tends* [sic] to assume, eventually, a characteristic and often remarkably uniform lichen vegetation, under the influence of similar environmental factors."

Through the use of ordination analyses, I studied lichen communities to determine their distribution patterns within the alpine environment. Both substrate (i.e. saxicolous or rock communities) and dominance within terricolous (soil) habitats were considered in these analyses. These alpine lichen communities were also examined to determine the vascular plants and mosses found in association with them.

Few regional studies of lichens have been made for Washington state (Ryan, 1985; Rhoades, 1988, 1991; Imshaug, 1957; Douglas, 1973, 1974; Johnson, 1979; Thomson, 1969; Kunze, 1980). This study examines selected areas in the alpine zone of Washington state, the Olympic Mountains and the Cascade Mountains. These mountains have extensive alpine areas, although lichens from these regions have not been studied in detail by previous investigators. Reasons for this include the inaccessibility of many areas, and the widely scattered distributions of alpine macrolichen communities.

Alpine areas where lichens can be a dominant part of the vegetation can be used as model systems for the study of lichen communities. Abiotic factors (elevation, slope, aspect, soil pH, substrate, substrate stability, moisture class) and biotic factors, such as vegetation and plant associations, can be easily observed and recorded for these areas. Although plant diversity can be greater in these areas than in the adjoining forest communities, the layering effect seen in a forest ecosystem has been reduced to several centimeters so that the study of the "canopy" layer of lichens is easily observed. Understanding of the influence of vascular plants on patterns of lichen distribution or communities is relatively incomplete. Except for a few published lists of lichens from alpine areas (Imshaug, 1957; Douglas, 1974; and Ryan, 1985) and three studies that included lichens in plant community analyses (Douglas, 1973; Douglas and Bliss, 1977; and Kunze, 1980), few in-depth studies of alpine lichens have been conducted in Washington state.

This study includes an inventory of lichens from alpine locations in Washington (Glew, 1998) and an analysis of ecological factors that affect the distribution of lichens across the landscape, with an emphasis on macrolichens.

THE OBJECTIVES OF THIS CHAPTER ARE TO:

1. Examine the influence of abiotic factors, total vegetation cover, and plants species or functional groups on alpine lichens communities and determine which environmental factors are important for determining lichen species distributions at each site;

2. Determine the influence of a site's combined environmental variables on the lichen species and their distributions in alpine areas;
3. Compare cover of vascular plants and alpine lichens in mesic snow-bank and dry tundra communities; and
4. Determine how vascular plant structure may influence lichen distribution and community structure in alpine sites.

METHODS

Some of the environmental factors measured in this study have been evaluated in previous lichen studies (See & Bliss, 1980; John, 1989; John & Dale, 1990). Because there have been few studies that examine the influence of environmental factors on terrestrial lichen systems, these earlier investigations included environmental factors that were traditionally used for studying plant communities (Douglas & Bliss, 1977; Willard, 1979; Walker et al., 1993). For this study, those factors chosen were assumed to be significant for determining alpine lichen distributions. These factors included elevation, slope, aspect, substrate, substrate stability, soil pH, moisture class, and percent cover of vegetation other than lichens. Vascular plant and bryophyte species found in the lichen communities were also recorded as environmental factors.

ABIOTIC FACTORS

Elevation was measured with a *Gishard* altimeter and calibrated before each use at points of known altitude. This included location from a topographic map, signs along trails, or bench marks. Measurements were in feet to the nearest 50 feet and later converted to meters.

Slope of the transect was determined by a *Suunto* clinometer and measured in degrees, ranging from 0° to 30°. If there was a particularly steep section within the transect, such as a drop-off (up to 90°), that slope was measured and included in the data.

Aspect was determined with a *Silva* compass and ranged from 0° to 359° magnetic north. Declination was taken into account. Aspect was then converted to an ordinal gradient scale, based on a system developed by Whittaker (1960), which assumes that sites with a northerly aspect are more mesic and sites with a southerly aspect are more xeric. The scale used in this analysis ranged from 1-7, 1 being northerly sites and 7 being the southerly sites. The value scale is as follows:

1. north, northeast, north northeast
2. east northeast, north northwest
3. east, northwest
4. east southeast, west northwest
5. southeast, west
6. south southeast, west southwest
7. south, southwest, south southwest

Soil pH was determined from four samples taken along each transect at five, thirty, fifty-five, and eighty meters. This resulted in thirty-two and thirty-six soil samples for each site, depending on whether there were eight or nine transects. Soil was placed into aluminum canisters, and allowed to air dry in the laboratory. To measure soil pH, equal parts of soil and distilled water were mixed and allowed to sit for one hour. Samples were stirred immediately just prior to measuring the mixture with a pH meter. Three readings were taken per sample and averaged to the nearest one hundredth. pH values ranged between 4.0 and 7.64.

Percent soil was determined by a category of one, two or three: 1 - greater than 60% 2 inch cubed rocks to boulders; 2 - 50 % pea-sized gravel and pebbles to 2 inch cubed rocks; 3 - referring to soil and humus up to pea-sized gravel. Soil depth was not recorded.

Stability was also rated on a grade of one to three: 1 was loose, 0 - 40% stable, substrate easily moved; 2 - medium, 40 - 70% stable; 3 a stable situation, 70 - 100%.

Moisture class Summers often were very dry at the sites, making it difficult to determine the moisture class of an area. Therefore, this variable was determined on the presence of snow field water run-off, types of vascular plants and cryptogams indicating the relative amount of moisture (Klinka et al., 1989), and exposure. If the ground or rock was exposed with up to 30% vegetation cover and *not* in a water run-off area it was rated 1 or dry; 2 was medium with 30 - 100% vegetation, not containing plants that were considered hydrophilic; 3 was wet, 50 - 100% vegetation cover with hydrophilic indicator plants (0% cover was acceptable here if it was located in a drainage area resulting from water run-off).

Color of lichens also was determined on a scale of one to five to ascertain if there were correlations between lichen color and the substrate type or amount of vegetation in an area. One being pale, 2 - yellows and oranges, 3 - medium browns, 4 - dark browns, and 5 - black. This was determined in the field or later calculated by a species color code number (Appendix D).

BIOTIC FACTORS

A single plant cover value (other than lichens) was determined for each of the 10 x 10 cm^2 subquadrats. Ten of the 25 subquadrats in the 0.25 m^2 quadrat were randomly selected. Mean quadrat cover was determined from these ten subquadrats. At three of the sites, Deer Park, Skyline Divide and Tatie Peak, percent cover of each *individual* plant species was also recorded on the quadrat level. The percent vegetation cover calculated from the subquadrats was roughly equal to or lower than the cover determined by individual plant species (Table 4). This was mainly due to two dimensional estimations on the subquadrat level, while the individual species cover determined at the quadrat level allowed was a three dimensional estimation. This became noticeable especially along the mesic transects where plants tended to be taller and overlapping, unlike the plants observed from the tundra sites.

Table 8. Environmental variables included in the Canonical Correspondence Analysis for the abiotic factors and % vegetation cover.

Variable	Values	Explanation
Elevation	1650 - 2175	from sea level (m)
Slope	0 - 30	inclination from horizontal
Aspect	1 - 7	northerly to southerly (see above)
% Vegetation cover	0 - 100	other than lichens (in 2 dimensional space)
Soil pH	4 - 7	determined with pH meter
% Soil	1 - 3	coarse rocks (1) to soil/humus (3)
Stability	1 - 3	loose (1) to stable (3)
Moisture class	1 - 3	dry (1) to wet (3)
Color	1 - 5	white (1) to black (5)

Lichen species were analyzed using the environmental factors listed in Table 7 (including the percent cover of vascular plants and mosses within the 10 x 10 cm^2 subquadrat). Initially species data for quadrats were entered in a Cornell condensed format used with the CANOCO program. This format was converted to a Lotus file to be used with the PCORD program.

PLANT GROUP ENVIRONMENTAL VARIABLES

Plant species were analyzed initially without lichen species, using DCA and CCA to determine possible functional groups that could act as an environmental variables with lichens. The plant groups were used as environmental data together with the lichen species to determine any correlations between plant species and lichen species. Plant functional or structural groups have been used by McCune and Antos (1981) for comparing compositional patterns. These groups have been successfully employed when discussing lichens in terms of community groups (Barkman, 1958, 1973; James et al.

(1977). Plant groups were entered as presence/absence data. Plant categories for structural groups are listed in Appendix E and Table 14.

NUMERICAL ANALYSES

Species composition at each site (average percent cover and species richness of lichens and plants) was determined using PCORD 2.0 (McCune and Mefford, 1995). Average lichen percent cover and species richness (number of species) for each site were calculated at the quadrat level by totaling all quadrat values and dividing by the number of quadrats per site. Standard error was calculated for the average species richness at each site (Figure 9).

Ordinations are used to organize species and quadrat data to produce a summary of the community data. This provides an indication of the source of variation within the lichen assemblages found in the alpine (Kent & Coker, 1992). Ordinations also can provide information leading to the comparison of different communities or sites by examining the composition of quadrats. By further including measurable environmental variables to the ordination to constrain the analysis, relationships can be shown between those variables and the species and quadrats (ter Braak, 1986, 1987; Okland, 1996).

Ordination analyses of alpine lichen species with abiotic environmental factors and plant groups were performed with the package Canonical Community Ordination (CANOCO, ter Braak, 1988). Within this program two analyses were used to clarify the distribution of lichens in the six alpine sites. Detrended Correspondence Analysis (DCA) is an indirect mathematical method used to analyze data. DCA uses weighted averaging to correlate species to species and quadrats to quadrats based on quadrat composition. It then "detrends" the ordination to avoid the arch effect of data on the second axis that is seen in correspondence analysis (CA) (Hill & Gauch, 1980; Gauch, 1982). Quadrat scores are derived from species scores and species scores are derived from quadrat scores (Palmer, 1993; Kent & Coker, 1992). Canonical correspondence Analysis (CCA) is an direct method of analyzing the data (species and quadrats) allowing for the inclusion of environmental variables, chosen *a priori*, to be correlated with species and quadrats (Kent & Coker, 1992). Ordinations summarize the lichen community data relating quadrats to similarities in species composition and to environmental gradients. It also provides a summary of the variation observed along a transect and between transects and sites. In CCA the axes of the ordination are constrained by the environmental variables (ter Braak and Prentice, 1988; ter Braak, 1986, 1994). Values for interset correlations between environmental variables and ordination axes range between 0 and ± 1. The closer the value is to ± 1, the more important the environmental factor is for the distribution of species (ter Braak, 1987). Environmental vectors aligning with one of the axes suggests that that factor has a strong relationship with that axis. If the angle between the vector and axis is small (Figure 17, elevation and axis two), then there is a strong relationship with that environmental factor and the axis.

Environmental vectors in the CCA analyses point in the direction of the maximum value of that factor from the axes intersect. The position of the end of the vector depends on the eigenvalues and interset correlations. These vectors represent axes in the diagram that are relationships between the environmental variables and the linear coefficient correlations (ter Braak, 1987; Palmer, 1993; McCune, 1997). Long vector lines in the ordination are more strongly coordinated with the environmental axes than short vector lines (ter Braak, 1988). The species that are close to a given vector have been ranked by weighted averages with respect to that environmental variable. The CCA biplot ordination in the CANOCO program is based on linear-combination scores. The results of these ordinations can be misleading if there is considerable "noise" in the environmental data (McCune, 1997).

By drawing a perpendicular line from the lichen species to the vector, a determination can be made of the measure of correlation between species and environmental variables (ter

Braak, 1986). A lichen species which is close to a vector is highly correlated with that environmental variable.

In some of the ordinations, lichen species percent cover was square root or log transformed in the ordination, to down-weight the value of dominant species (van Tongeren, 1987). These transformations can be useful to obtain higher eigenvalues for the ordination. Eigenvalues range from 0 to 1.0, indicating the amount of dispersion of species scores on the ordination axis (a measure of the importance of the axis). Those eigenvalues close to 0 show no strong relationship between the dispersion of species in the graph and the ordination axes. Eigenvalues greater than 0.3 are common in ecological analyses and those higher than 0.5 suggest a good separation of species along the axis (ter Braak, 1988). The first ordination axis (x-axis) has the largest eigenvalue, the second axis (y-axis) has the next largest value, continuing on with the third and fourth axes becoming lower each time. The purpose of the transformations is to ensure a better fit of the data in an analysis (van Tongeren, 1987). This can be done by emphasizing a rare species and giving less weight to a dominant species (square root and logarithmic transformations).

Each site was analyzed with the abiotic factors of elevation, slope, aspect, soil pH, substrate, substrate stability, and moisture class. The one biotic factor for this set of data was total percent vegetation cover derived from the subquadrat and converted to the quadrat level (see Chapter 2, collection methods). DCA and CCA analyses were performed for each site to include quadrats, species and environmental variables. The ordination analyses were performed to determine trends in species and quadrat distributions.

To determination the influence of plant functional groups on lichen distributions, saxicolous species (those found on rock) were removed from the ordination analysis.

Monte Carlo permutation tests were performed on all ordinations to determine if the distributions were statistically significant. Monte Carlo tests "use the exchangeability of the residuals of the species after fitting covariables and environmental variables" (ter Braak, 1990). This randomization test determines the significance of the first axis and an overall trace.

Forward Selection is a method in the CANOCO program for determining the minimal set of variables that explain the species data (ter Braak, 1990). The process involves a series of steps where, at each step, a variable is selected that best explains the variance of species data. The variance explained in the process is a straight sum of squares regression. By means of a Monte Carlo permutation, the significance of a variable on the ordination can be tested. The sum of the constrained eigenvalues for each of the variables equals the variance explained by all variables. This is also the sum of all canonical eigenvalues seen in the ordination summary.

Transect data were converted from twenty quadrats to an average value for each transect. This value represented species and environmental variables (plant groupings excluded) for the sites to compare similarities and differences between sites. The transect data reduced the number of data points on the ordination graph to visualize the relationship between transects and sites (Figure 15).

Transect data were used to classify sites and species (Figures 19 and 20) based on their similarity. [Transect data refers to an averaging of the species found along the twenty quadrats of each transect.] This was done with cluster analyses to determine if the groupings of sites and species observed in the ordinations were supported in a classification analysis. With some classification analyses, a phenomenon called "chaining" may occur. This is the process by which new groups are created in the analysis by adding small groups or individuals to an existing group (McCune & Mefford, 1995; Pielou, 1984). Chaining is a problem in cluster dendrograms and therefore should be avoided. For the cluster analysis of transects, the best dendrogram resulted from using Ward's Method (UPGMA - unweighted pair grouping mathematical averaging) and a relative Euclidean distance (Figure 19, 20).

RESULTS

ABIOTIC FACTORS AND VEGETATION COVER

From the DCA ordination of the transect data (representing sites) there is a clear distinction between the Olympic sites and North Cascades sites (Figure 15). This analysis is based on species present in each quadrat. A separation of transects in the ordination supports the original observation that the species composition of the two mountain ranges are different. Exceptions to this are the four tundra transects from Slate Peak (A, E, G, H) and two transects from Skyline Divide (F, I) that have species composition very similar to what is seen in the northeast Olympic sites and group with those locations on the ordination (for transect numbers see Appendix C). The DCA ordination has an eigenvalue of 0.520 on the first axis and 0.338 for the second axis (Table 8). These values imply that a separation of species along the axes should occur (ter Braak, 1987, 1988). The first axis (x-axis) appears to represent a gradient of increased moisture and vegetation cover to the right. The left side of the ordination includes sites that are drier and contain a higher percentage of gravel and rocks. The second axis suggests increasing altitude, limited lichen soil community development (possibly due to perturbation from human trampling or snow patch areas), and exposed sites on the left side of the ordination. Deer Park has the lowest elevation in the Olympics and is located close to the first axis which represents sites at lower elevations. Slate Peak and Tatie Peak have the highest elevations of the six sites and they are located at the top of the ordination graph. In general, the North Cascades sites are more mesic from snowmelt run-off, have a higher altitude, and face north to northeast. Therefore, those sites are located on the right side of the ordination graph.

Species groupings for the DCA ordination follow the same pattern (Figure 16). The clustering of species in the transect ordination similarly indicate a moisture gradient along the first axis with this factor increasing to the right of the graph, along with soil and pH gradients. Elevation, exposure (ridge-top and open areas), and vegetation seemed to be the major gradients affecting the second axis with rock crust species clustering in the upper left of the ordination and stable soil species clustering on the lower right. Lichen species from saxicolous communities and exposed ridgetops are in the upper left section of the ordination. Lichens from xeric tundra sites and on loose substrates occur on the left side of the ordination graph. Species from the xeric tundra locations, associated with vegetation, group on the lower center portion of the ordination.

Table 9. Transect DCA - summary

TRANSECT DCA

Axes		1	2	3	4	Total Inertia
Eigenvalues	:	.520	.338	.123	.077	2.773
Lengths of gradient	:	3.435	3.345	1.823	1.587	
Cumulative percentage variance of species data	:	18.8	31.0	35.4	38.2	
Sum of all unconstrained eigenvalues						2.773

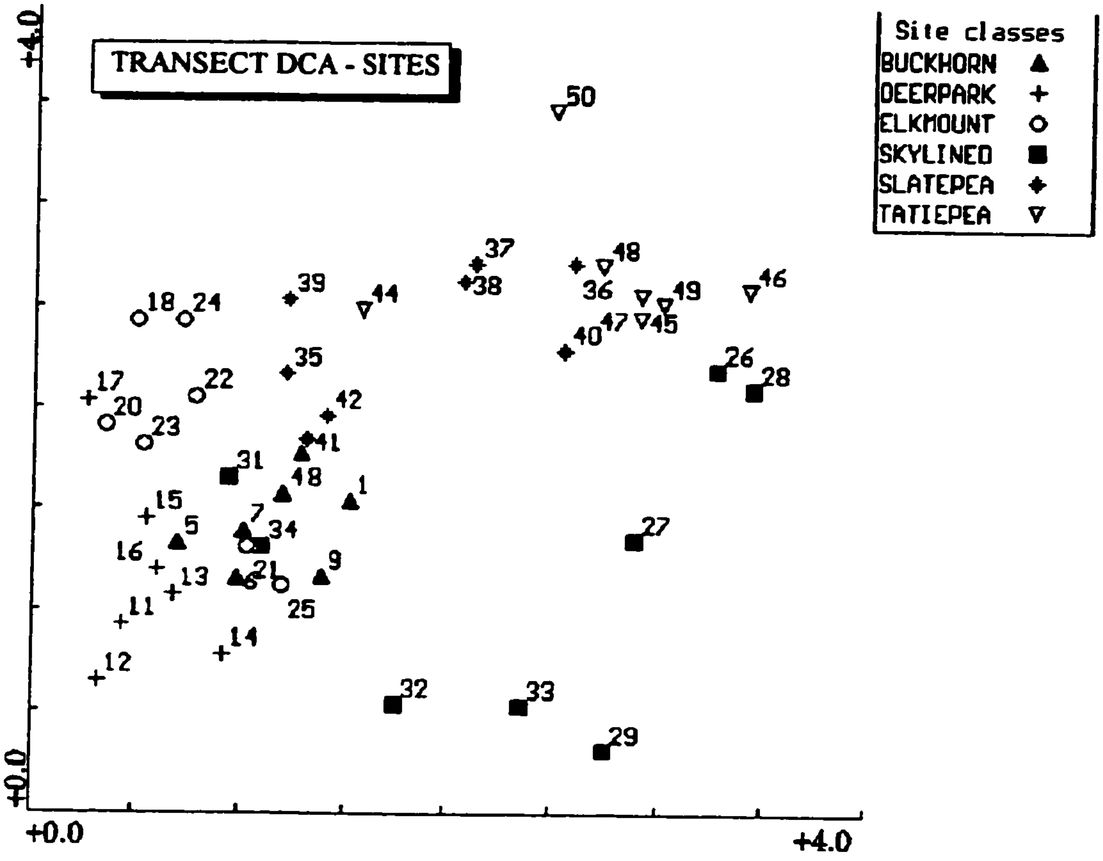

Figure 15. Detrended Correspondence Analysis of transects from the six alpine sites.

Transect number: Buckhorn, 1-9; Deer Park, 10-17; Elk Mountain, 18-25; Skyline Divide, 26-34; Slate Peak, 35-42; Tatie Peak, 43-50. The *x* axis is DCA-1 (horizontal); the *y* axis is DCA-2 (vertical). (For a thorough explanation of sites see Appendix A).

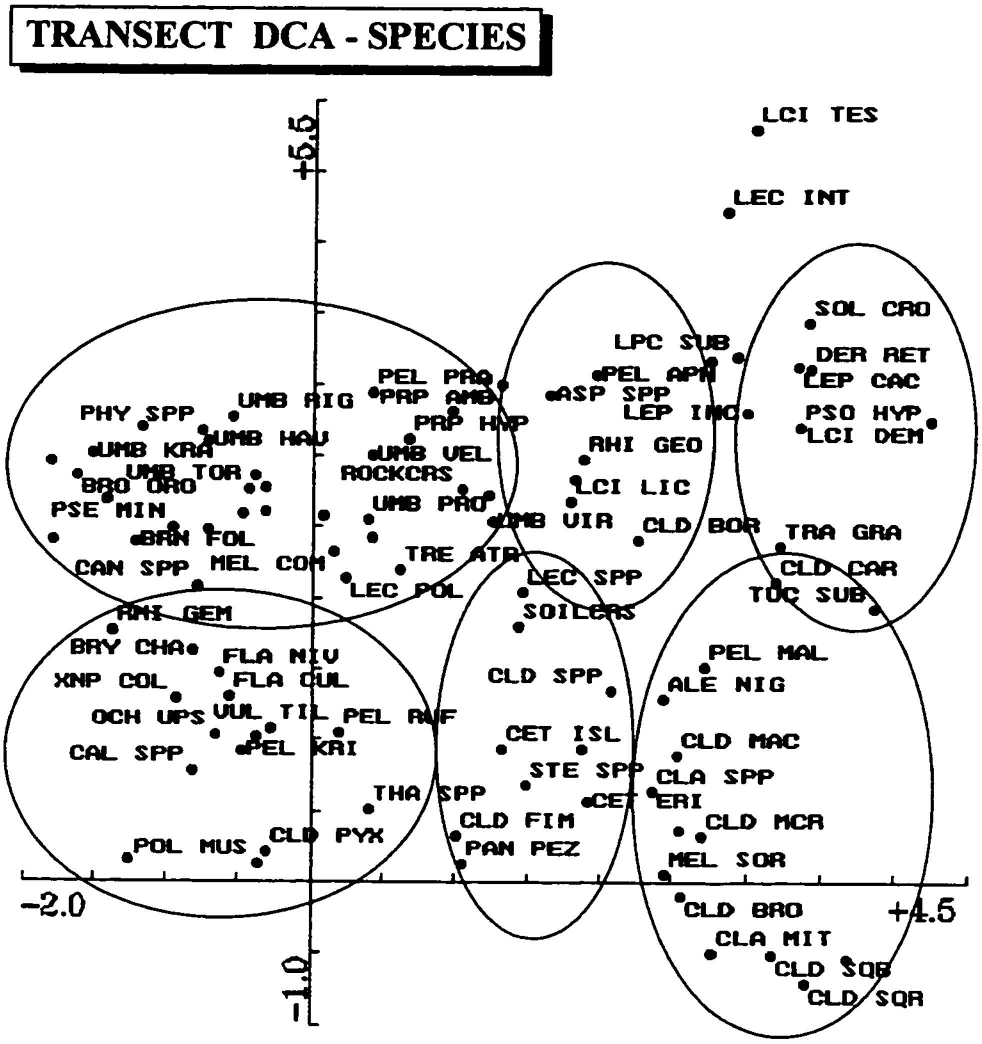
TRANSECT DCA - SPECIES

Figure 16. DCA ordination of species from the six alpine sites.
The *x* axis is DCA-1; the *y* axis is DCA-2. Species codes are found in Appendix D.

The CCA analysis of the transects has an eigenvalue of 0.450 with a species environment correlation of 0.943 for the first axis and 0.836 for the second axis (Table 9). The cumulative percentage variance of the species data for all four axes is 33.0% and for the species-environment relation 85.4%. The first axis eigenvalue was tested for significance with the Monte Carlo randomization test and resulted in a significance level of $p < 0.01$ for the first axis and overall trace result.

Table 10. Transect CCA - summary

TRANSECT CCA

Axes		1	2	3	4	Total Inertia
Eigenvalues	:	.450*	.240	.151	.074	2.773
LC-WA correlations	:	.943	.836	.833	.603	
Cumulative percentage variance						
of species data	:	16.2	24.9	30.3	33.0	
of species-environment data	:	42.0	64.4	78.5	85.4	
Sum of all unconstrained eigenvalues						2.773
Sum of all canonical eigenvalues						1.070

* $p < 0.01$ by Monte Carlo LC-WA = linear combination-weighted average scores

The interset correlations of environmental variable indicate that moisture class (.907) and soil pH (.889) have the strongest importance on the first axis (Table 11). This can be seen on the ordination graph with the mesic sites on the right hand side of the graph (Figure 17). They also have the lowest pH, which would put them in the opposite direction of the pH vector pointing to the left indicating the highest pH values. These two variables are significant in explaining the species data (using forward selection) with $p < 0.01$ for moisture class and $p < 0.05$ for soil pH (Table 12). On the species graph (Figure 18) lichens associated with moist environments and lower soil pH (*Tuckermannopsis*

Table 11. Abiotic variables and percent vegetation cover.

ABIOTIC FACTORS and PERCENT VEGETATION COVER

Sites	Eigenvalue	Species Cumulative % variance Axis 1	Species Cumulative % variance Axis 2	Species - Env. Cumulative % variance Axis 1	Species - Env. Cumulative % variance Axis 2	Transformation
Buckhorn Cirque, O.M.	0.241*	6.8	9.7	49.0	69.9	square root
Deer Park, O.M.	0.351*	8.0	11.5	42.8	61.7	square root
Elk Mountain, O.M.	0.271*	6.4	8.9	48.1	64.2	square root
Skyline Divide, N.C.	0.607*	10.1	17.9	37.3	66.0	none
Slate Peak, N.C.	0.497*	6.2	9.2	38.2	56.3	none
Tatie Peak, N.C.	0.444*	7.2	10.6	41.6	61.5	none
Transects	0.450*	16.2	24.9	42.0	64.4	none

* significant at $p < 0.01$

Table 12. Interset correlations of environmental variables and axes.
(Values are multiplied by 1000.)

INTERSET CORRELATIONS OF ENVIROMENTAL VARIABLES WITH AXES ABIOTIC AND % VEGETATION

Variable	**BC axis 1**	**BC axis 2**	**DP axis 1**	**DP axis 2**	**EM axis 1**	**EM axis 2**	**SD axis 1**	**SD axis 2**	**SP axis 1**	**SP axis 2**	**TP axis 1**	**TP axis 2**	**TR axis 1**	**TR axis 2**
elevation	-178	-125	209	-739	-293	342	527	-348	-520	96	265	-341	21	-704
slope	-114	-152	196	-368	-162	336	-193	256	-540	-199	538	161	-102	-85
aspect			227	193			223	-110	-683	-254	-227	19	-285	329
% vegetation	-546	25	-735	-189	726	157	-702	-177	640	-256	-438	139	720	60
soil pH	80	-617	444	-490	-80	316	618	196	-598	-190	269	72	-889	114
% soil	-770	123	-711	-325	763	-14	-819	-305	617	-340	-750	-38	752	182
stability	-673	53	-598	-258	-316	408	-517	-511	461	-124	-206	17	605	-163
moisture class	-330	108	-347	-255	443	-16	-824	22	673	25	-644	-113	907	-109

Table 13. Forward Selection tests for significance of Abiotic and % Vegetation Environmental Variables.

Variable	BC eigen-value	BC †% ex-plained	DP eigen-value	DP % ex-plained	EM eigen-value	EM % ex-plained	SD eigen-value	SD % ex-plained	SP eigen-value	SP % ex-plained	TP eigen-value	TP % ex-plained	TR eigen-value	TR % ex-plained
elevation	.02	4.2	.16**	19.5	.06**	10.7	.31**	19.0	.21**	16.2	.16**	15.0	.19**	17.8
slope	.06**	12.5	.05*	6.1	.06**	10.7	.31**	19.0	.14**	10.8	.15**	14.0	.06	6.0
aspect			.04*	4.9			.09**	5.5	.39**	30.0	.06	5.6	.09*	8.4
% vegetation	.05**	10.4	.27**	32.9	.06**	10.7	.13**	8.0	.09*	6.9	.11**	10.3	.04	3.7
soil pH	.10**	20.8	.05*	6.1	.06**	10.7	.12**	7.4	.07	.38**	.07	6.5	.08*	7.5
% soil	.22**	45.8	.09**	11.0	.23**	41.1	.54**	32.5	.26**	20.0	.38**	35.5	.12**	11.2
stability	.02	4.2	.12**	14.6	.06**	10.7	.05**	3.1	.05	3.8	.05	4.7	.06	6.0
moisture class	.02	4.2	.04*	4.9	.03	5.4	.07**	4.3	.10*	13	.09*	8.4	.42**	39.3
Total	.48	100	.82	100	.56	100	1.63	100	1.30	100	1.07	100	1.07	100

*significant at $p < 0.05$ † - % explained variance

**significant at $p < 0.01$

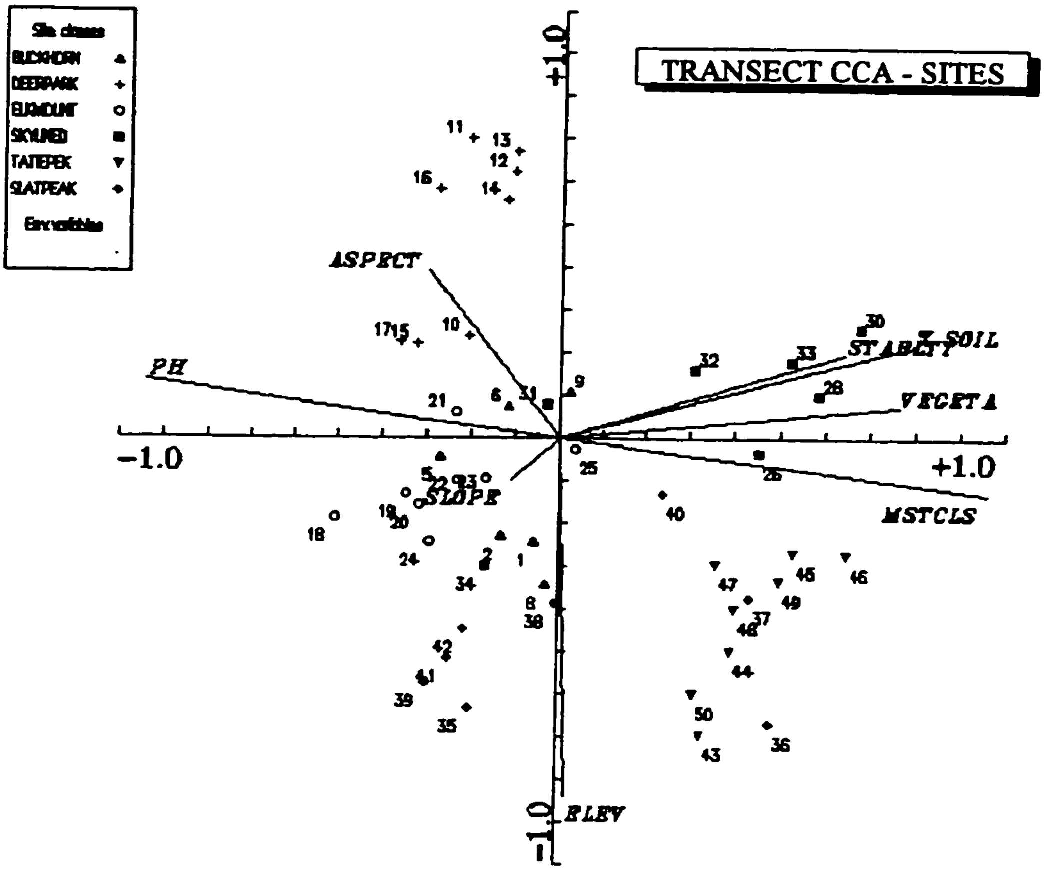

Figure 17. Canonical Correspondence Analysis of transects (linear combination scores) of abiotic factors and percent vegetation cover as environmental variables.

Transect number: Buckhorn, 1-9; Deer Park, 10-17; Elk Mountain, 18-25; Skyline Divide, 26-34; Slate Peak, 35-42; Tatie Peak, 43-50. The *x* axis is CCA-1; the *y* axis is CCA-2. Environmental variables codes are: Elevation (ELEV); Slope (SLOPE); Aspect (ASPECT); % Vegetation cover (VEGETA); Soil pH (pH); % Soil (% SOIL); Stability (STABLTY); Moisture Class (MOISTCLS). (For a thorough explanation of sites see Appendix A)

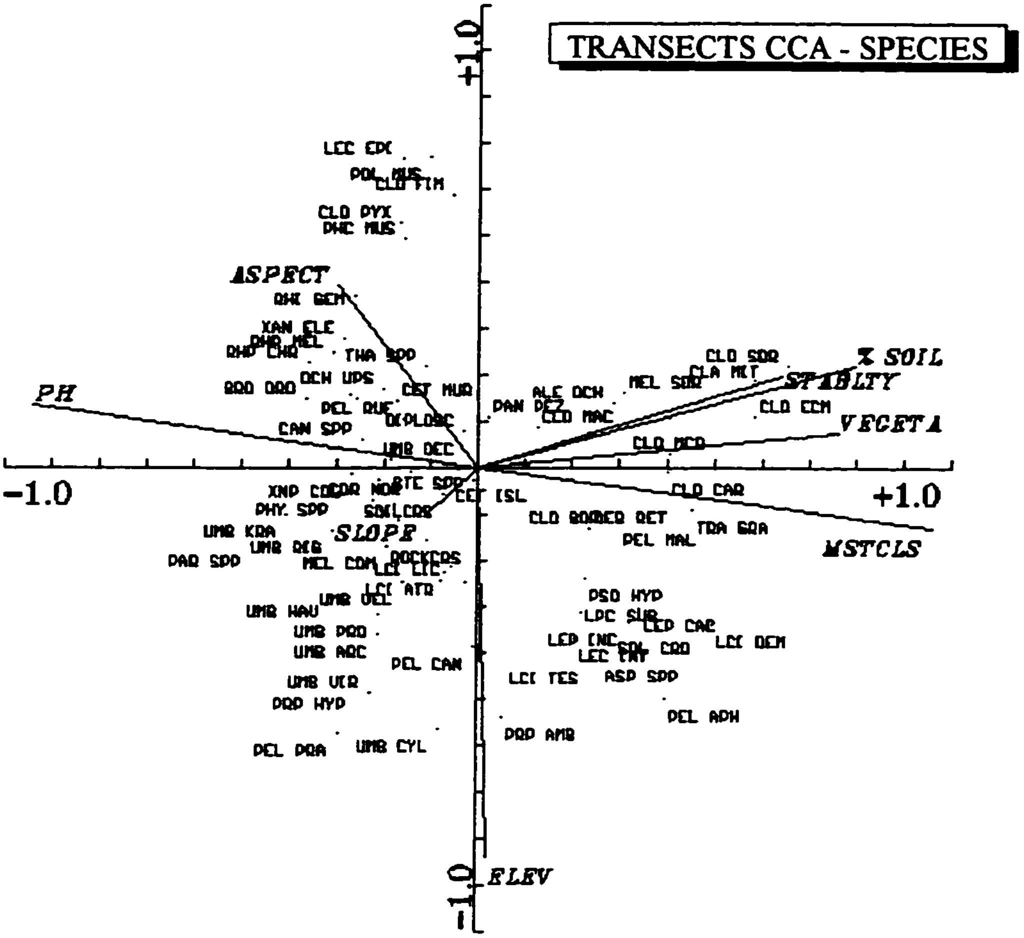

Figure 18. Canonical Correspondence Analysis of transect species from the six alpine sites.

The *x* axis is CCA-1; the *y* axis is CCA-2. Environmental variables codes are: Elevation (ELEV); Slope (SLOPE); Aspect (ASPECT); % Vegetation cover (VEGETA); Soil pH (pH); % Soil (% SOIL); Stability (STABLTY); Moisture Class (MOISTCLS). Species codes can be found in Appendix D.

subalpina, *Trapeliopsis granulosa*, *Cladonia ecmocyna*, *C. squamosa*, and *Cladina mitis*) are aligned with those vectors.

Elevation (.704) and aspect (.329) contribute the most to the second axis (Table 11) (significance at $p < 0.01$ and $p < 0.05$ respectively, Table 12). In this ordination, transects from sites with higher elevations (Slate Peak and Tatie Peak) are located at the bottom of the graph, aligning with the elevation vector, and transects from lower elevations (Deer Park) are at the top of the graph. Lichen species from higher elevations are those that were associated with ridgetops. At many of the sites these ridge-top areas are rocky, windblown areas, and in the North Cascades can include some krummholz vegetation. Associated species: Species found at higher elevations along ridge-tops - *Parmeliopsis ambigua*, *P. hyperopta*, *Umbilicaria cylindrica*, *U. arctica*, *U. virginis*, *U. proboscidea*, *U. krascheninnikovii*, *U. rigida*, *U. havaasii*, *U. vellea*, *Peltigera praetextata*, *Lecidea tessellata*, *L. atrobrunnea*, *Aspicilia* spp., *Bellemerea* spp., *Lecanora polytropa*, and *Parmelia saxatilis*.

The transects with more southerly aspects are aligned with the aspect vector (a higher ordinal value for that aspect Table 7). This includes all sites at Deer Park and Elk Mountain; transects A (35), E (39), G (41), and H (42) on Slate Peak; transects F (31), G (32), and H (33) on Skyline Divide. These sites contain dry tundra lichens such as the cetrarioids, *Thamnolia* spp., stereocaulons, *Cladina mitis*, *Cladonia macrophyllodes*, *C. pyxidata*, *C. pocillum*, *C. carneola*, and *C. macroceras*.

Transect I (number 34) on Skyline Divide is unusual for the tundra sites because it is the only transect in xeric tundra areas with a northern exposure (Figure 17). In both the DCA and CCA ordinations Skyline Divide transect I is found among Olympic sites, most likely because it contains many of the same lichens as those sites, with the addition of *Solorina crocea*. This is the only tundra study site with that lichen, although it is reported from Maiden Peak, east of Elk Mountain (Fonda & Rhoades, unpublished). In this study

Solorina crocea is more typically associated with mesic sites and can be found at lower elevations along trails in moist areas that have been moderately disturbed.

For two of the site ordinations, Elk Mountain and Buckhorn Cirque, the aspect vector does not appear on the ordinations as an environmental factor (Figure 21 and 23). This is because within these sites all transects have the same aspect. Thus, aspect did not appear in the CCA ordinations for the sites. But when the site transects are analyzed together, the influence of aspect can be seen on the ordination (Figure 17), with the aspect vector showing an increased value representing aspects with southerly exposures (Table 7). These sites include Elk Mountain, Deer Park, Slate Peak (transects A-35, E-39, G-41, and H-42), and Skyline Divide (transects F-31, G-32, and H-33). Those sites that face north or northeast, Tatie Peak, Slate Peak (transects B-35, C-36, D-37, and F-38), and Skyline Divide (transects A-26 and I-31), are found in the ordination in the opposite direction of the aspect vector, on the lower right portion of the ordination. Aspect is an important factor at Slate Peak explaining 30% of the variation seen in the ordination with a significance of $p < 0.01$. Associated species: Southern most exposure: *Thamnolia* spp., *Rhizocarpon geographicum*, *Lecanora polytropa*, *Candelariella* spp., *Brodoa oroarctica*, *Cetraria muricatum*, *Peltigera rufescens*, *Flavocetraria cucullata*, *F. nivalis*, and *Ochrolechia upsaliensis*. Northern and easterly most exposure: *Peltigera aphthosa*, *Lecidoma demissum*, *Solorina crocea*, *Lepraria incana*, *Lepraria cacuminum*, *Leprocaulon subalbicans*, and *Psoroma hypnorum*.

In general, the parent rock of the Olympics has a pH that is more basic (6.0) than the North Cascades sites (4 - 5.5). This may be due to the exposed rocky ridges and outcrops in Olympics, which have a more neutral pH than the areas with higher vegetation cover. The Olympic sites also have some calcareous deposits originating from oceanic crust. This would account for some of the higher pH values. Ericaceous plants in North Cascades generate a thin acidic duff or humus layer on top of rocks creating the lower pH at these sites. Soil pH is an important factor in the Olympic sites with interset correlations ranging between .316 to .617 on the second axes of the ordinations (Table 11). This variable is significant at all three sites (Table 12). For the North Cascades sites the correlation values range from .269 to .618 on the first axis, explaining 6 - 21% of the species variation. Soil pH is an important factor at Skyline Divide and Slate Peak, where there is a wider range in habitat and soil conditions, but only significant at Skyline Divide (Table 12). In the transect CCA, pH is closely aligned with the first axis with a correlation value of -.889. The Tatie Peak ordination does not demonstrate a high correlation value for pH since the soil pH is consistently low, lacking variation between transects.

Soil pH clearly affects species groups. In this study rock communities tend to have a substrate pH of 6.0 or higher, but rarely more than 7. Many of the lichen species in this community (*Umbilicaria*, *Physcia*, *Melanelia*, *Lecanora*, *Lecidea*, *Pseudephebes*, and *Rhizocarpon*) are more commonly found on acid rocks (Thomson, 1979, 1984). Even though rocky sites have the higher pH values, they are still considered acidic to neutral, confirming the fact that these lichens prefer acid rocks. Most of the transects with pH values between 4.0 and 5.5 are not rocky habitats, but areas with high ericaceous or graminoid cover generating humus or duff with these lower pH values, as seen at the North Cascades sites. Associated species: With higher pH values *Umbilicaria* sp., *Melanelia commixta*, *M. stygia*, *Cornicularia normoerica*, *Brodoa oroarctica*, *Pseudephebe minuscula*, *P. pubescens*, *Xanthoria elegans*, and *Lecidea atrobrunnea*.

Most transects show the vectors representing environmental factors of moisture class, stability, % soil and % vegetation cover, and a lower soil pH closely aligned (Table 11, Figures 17, 21, 22, 24, 25, and 26). Many of the quadrats that contain a high vegetation cover also have stable soils and retain more moisture than exposed areas with little vegetation. Elk Mountain does not reflect this clustering. Here, stability is associated with elevation, slope, and pH. Ridgetops at this location tend to be stable due to large rock outcrops and rock stripes, unlike the soil and gravel areas on steeper slopes which are less stable. Associated species: *Cladonia bellidiflora*, *C. borealis*, *C. ecmocyna*, *C.*

singularis, *C. squamosa*, *Lecidoma demissum*, *Trapeliopsis granulosa*, *Tuckermannopsis subalpina*, *Peltigera malacea*, and *Leprocaulon subalbicans*, *Lepraria cacuminum*.

For Buckhorn Cirque, Elk Mountain, Skyline Divide, and Tatie Peak, % soil explains the greatest percentage of variance for the species distributions (Table 12). This factor has high interset correlation values and is significant ($p < 0.01$) for all the sites. For Deer Park, % vegetation cover accounts for 32.9% of the variance, this being the most important factor for the species distributions at the site. In the Transect ordinations, moisture class (39.3%) and elevation (17.8%) together explained 57.1% of the total variance for the ordination. These factors are both significant and when comparing all sites strongly influence species distributions. This is seen in the CCA transect ordinations of sites and species, figures 17 and 18.

The stability vector is missing from Tatie Peak CCA species ordination of abiotic factors (Figure 26). This is because the stability vector (-206, 17) is closely aligned with the aspect vector (-227, 19) (Table 11). The graphics portion of CANOCO was not able to display both of these vectors simultaneously.

In most ordinations the cetrarioid lichens and *Thamnolia* spp. cluster toward the center of the ordination. These species are rarely associated with any of the abiotic or biotic (% vegetation, plant groups) factors in the ordinations, yet they are most typically associated with tundra environments in arctic-alpine habitats. *Cetraria islandica*, *C. ericetorum*, *C. muricatum*, *Thamnolia vermicularis*, *Flavocetraria cucullata* and *F. nivalis* along with *Cladina mitis*, which could be found at all sites, may have broader environmental tolerances, since they can be found in both dry and moist tundra habitats (Thomson, 1984; Appendix C). Even though the first four are primarily associated with arctic-alpine environments, they may be found occasionally at lower elevations as well (pers. observation, McCune and Geiser, 1997).

Few lichens positively associate with a high slope value. As the steepness of a slope increases at a site, lichen diversity decreases, except for saxicolous crustose species which can easily exist on a vertical surface. Also, most of the steeper slopes are less stable, affecting lichen establishment and growth. Many macrolichens have a negative association with slope, decreasing in richness as the steepness of the slope increases. As the slope becomes closer to 0° more foliose and fruticose lichens are able to establish themselves within the vegetation or soils (pers. observation; Link & Nash, 1984). Associated species: positive correlations with slope: certain rock crusts (*Lecanora polytropa*, *Candelariella vitellina*), *Umbilicaria* sp. negative correlations with increasing slope: *Thamnolia* spp., *Cetrarioid* sp., *Flavocetraria* sp., *Vulpicida tilesii*, *Tuckermannopsis subalpina*, *Trapeliopsis granulosa*, *Lepraria cacuminum*, *Cladonia* sp., *Lecidoma demissum*, *Peltigera malacea*, *Solorina crocea*, and *Stereocaulon* sp.

Cluster analyses: Cluster analyses of the transects and species (Figures 19 and 20) show the same trends with environmental factors. In these cluster analyses the Olympic sites are separated from the North Cascade sites, with the exception of the transects from Skyline Divide that have tundra conditions and species similar to the Olympic sites (Figure 19). Also seen is a distinction between mesic and dry tundra sites. Species results display similar clusters to what is seen in the DCA ordination. These clusters are saxicolous species seen at dry tundra locations, saxicolous species found at all sites, soil lichens from dry tundra sites, soil lichens from mesic sites, the cetrarioid and *Thamnolia* spp. assemblage (typical alpine species from all sites), and lichens associated with mesic vegetation (Figure 20).

ALPINE TRANSECT CLUSTER

Percent chaining = 2.33

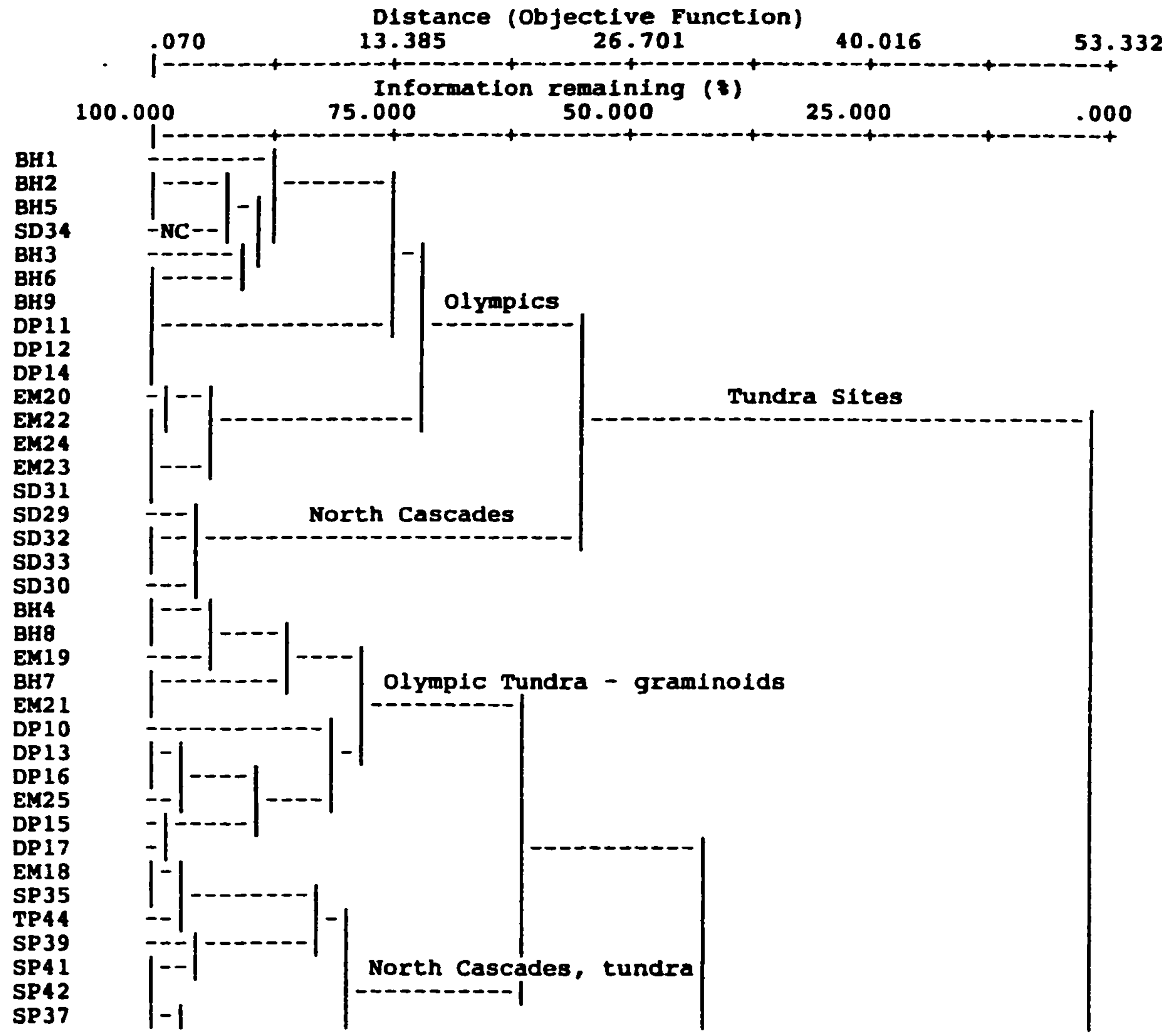

Figure 19. Cluster Analysis of sites represented by transects.

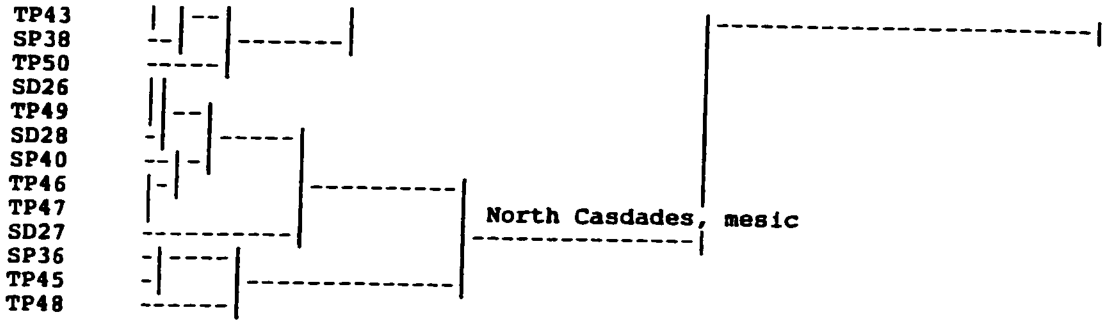

Figure 19 (continued). Cluster Analysis of sites represented by transects.

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TRANSECT SPECIES CLUSTER

Percent chaining =   6.02

Cannot log transform distance less than or equal to zero.
Dendrogram scaled normally.
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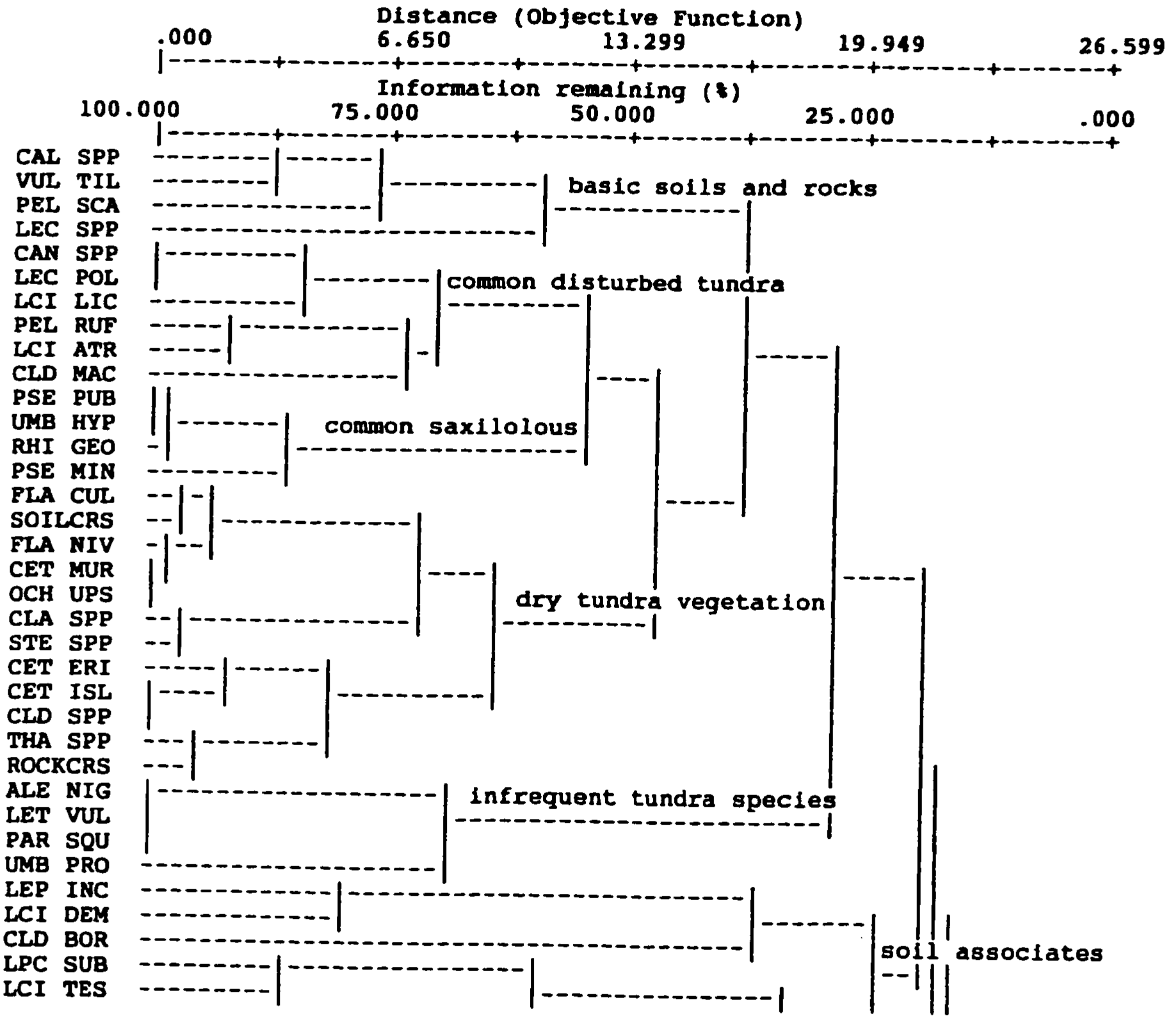

Figure 20. Cluster Analysis of species from site transects.

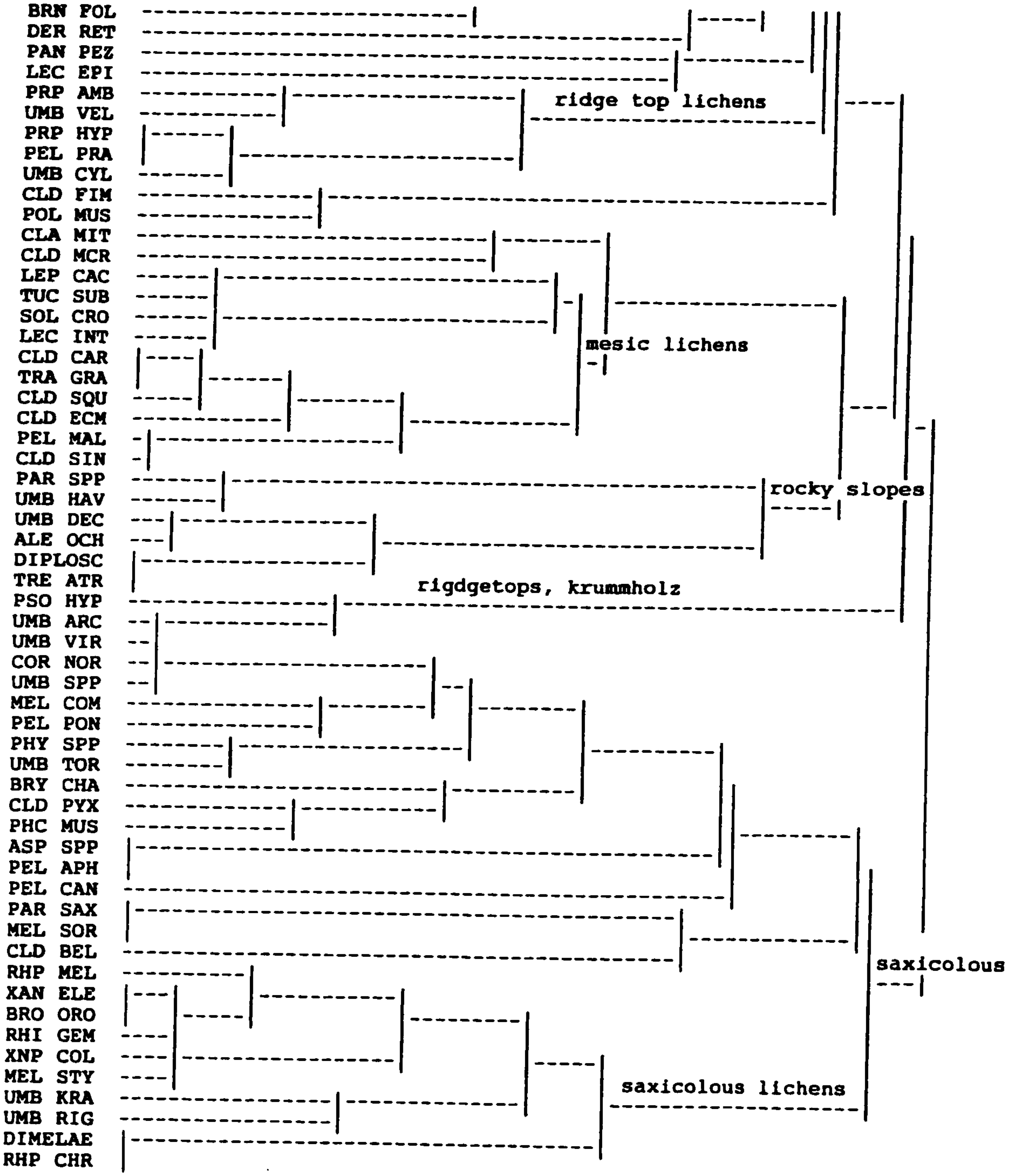

Figure 20 (continued). Cluster Analysis of species from site transects.

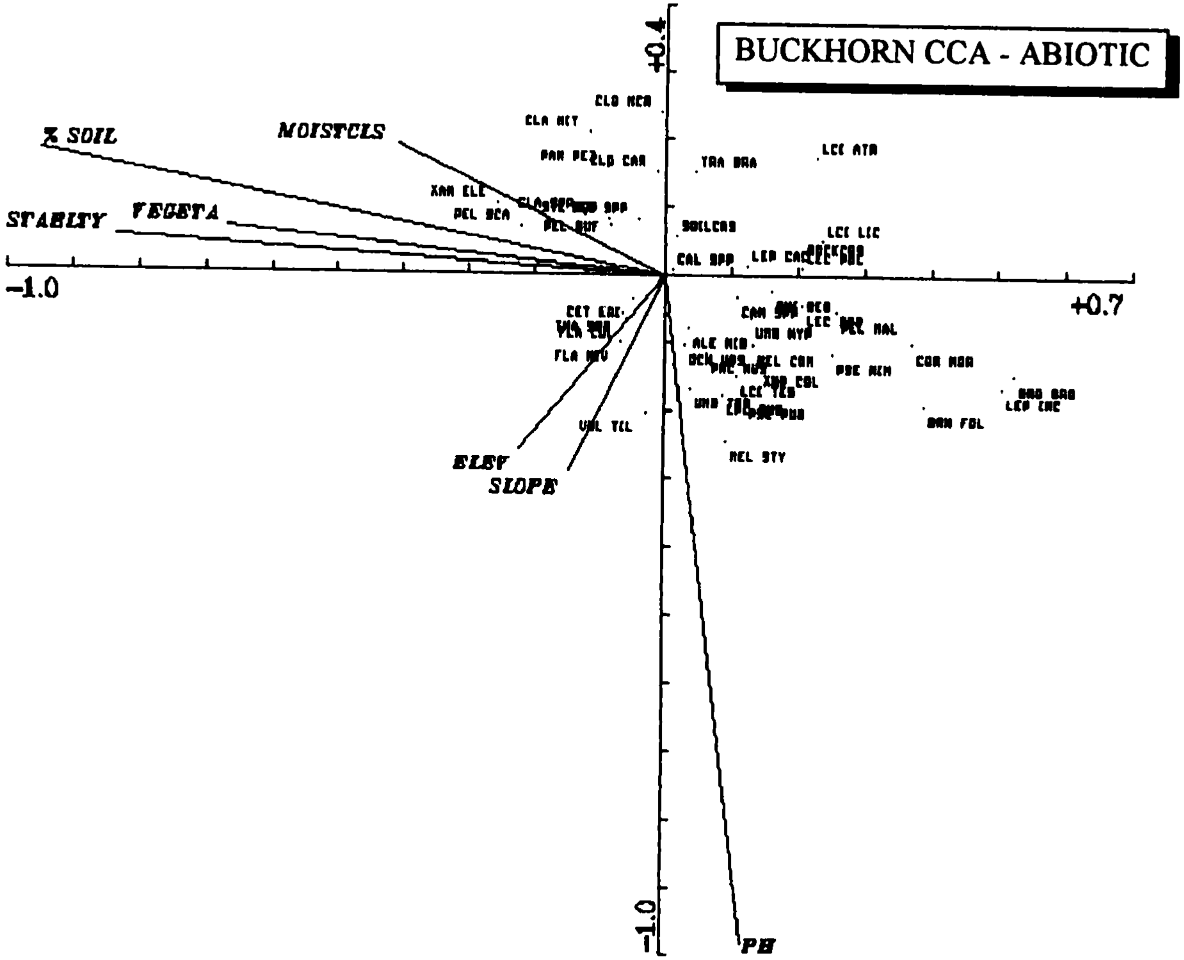

Figure 21. Buckhorn Cirque. Canonical Correspondence Analysis of individual species (linear combination scores). The *x* axis is CCA-1; the *y* axis is CCA-2. Environmental variables codes are: Elevation (ELEV); Slope (SLOPE); Aspect (ASPECT); % Vegetation cover (VEGETA); Soil pH (pH); % Soil (% SOIL); Stability (STABLTY); Moisture Class (MOISTCLS). Species codes can be found in Appendix D.

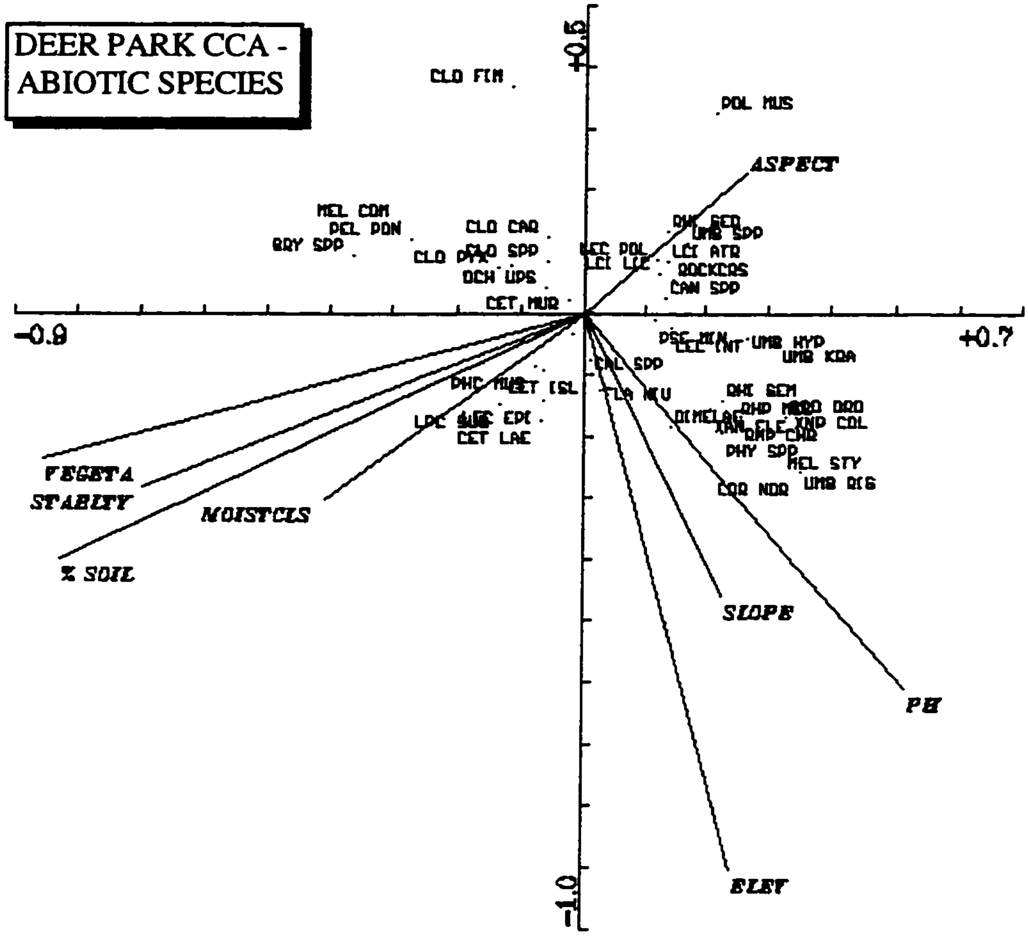

Figure 22. Deer Park ordination of abiotic factors.

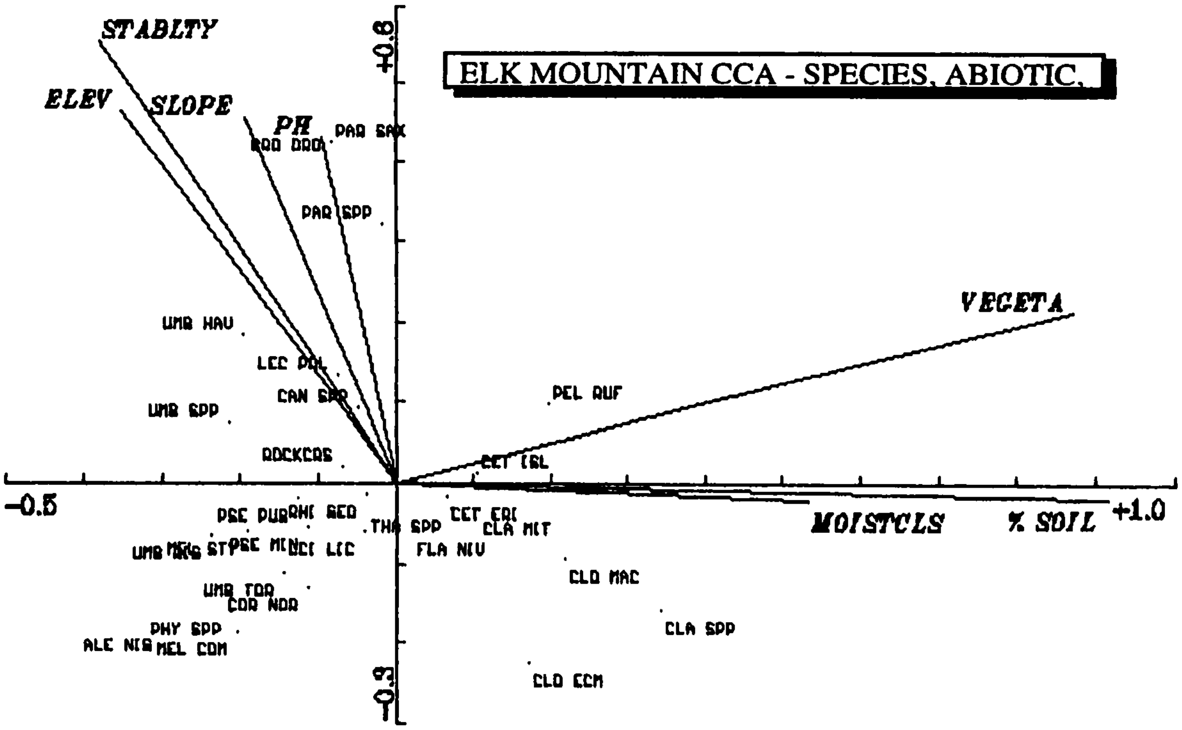

Figure 23. Elk Mountain ordination of abiotic factors.

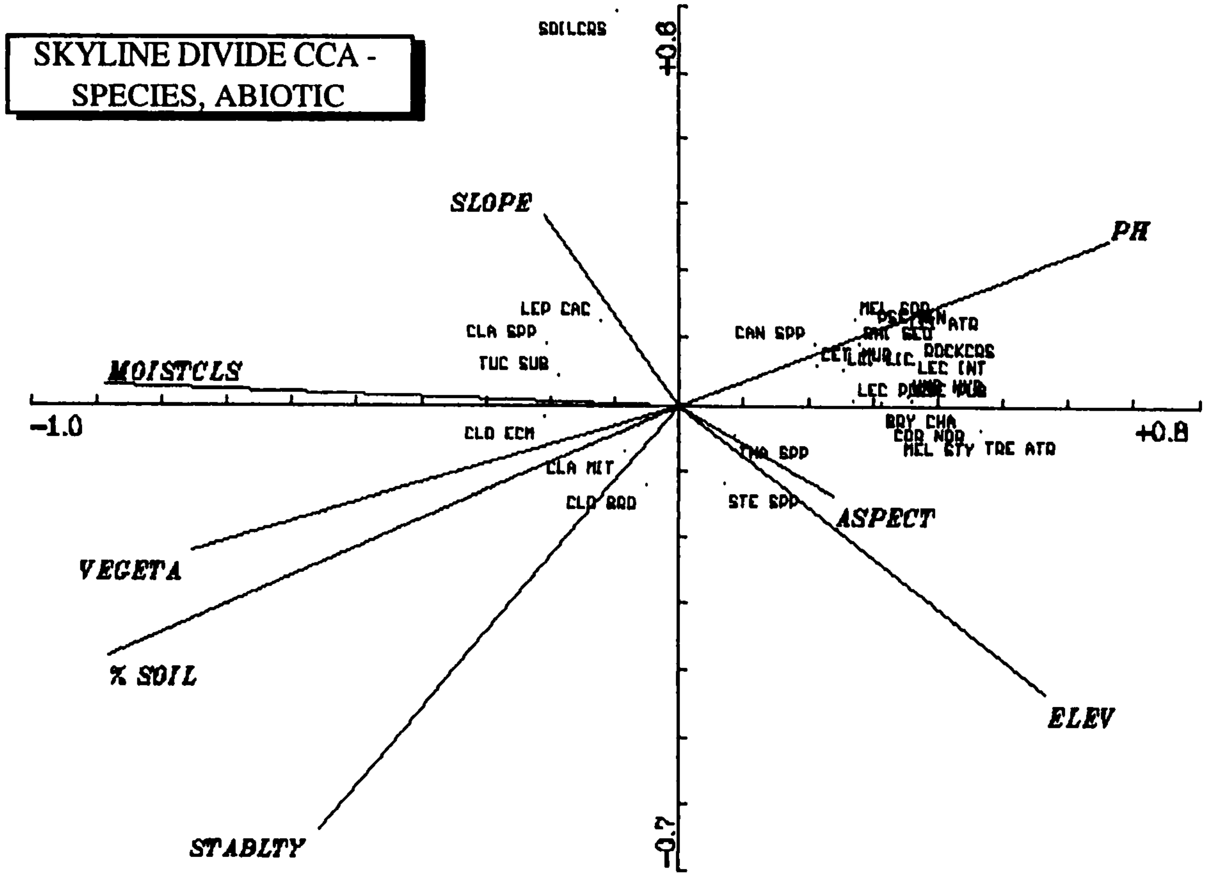

Figure 24. Skyline Divide ordination of abiotic factors.

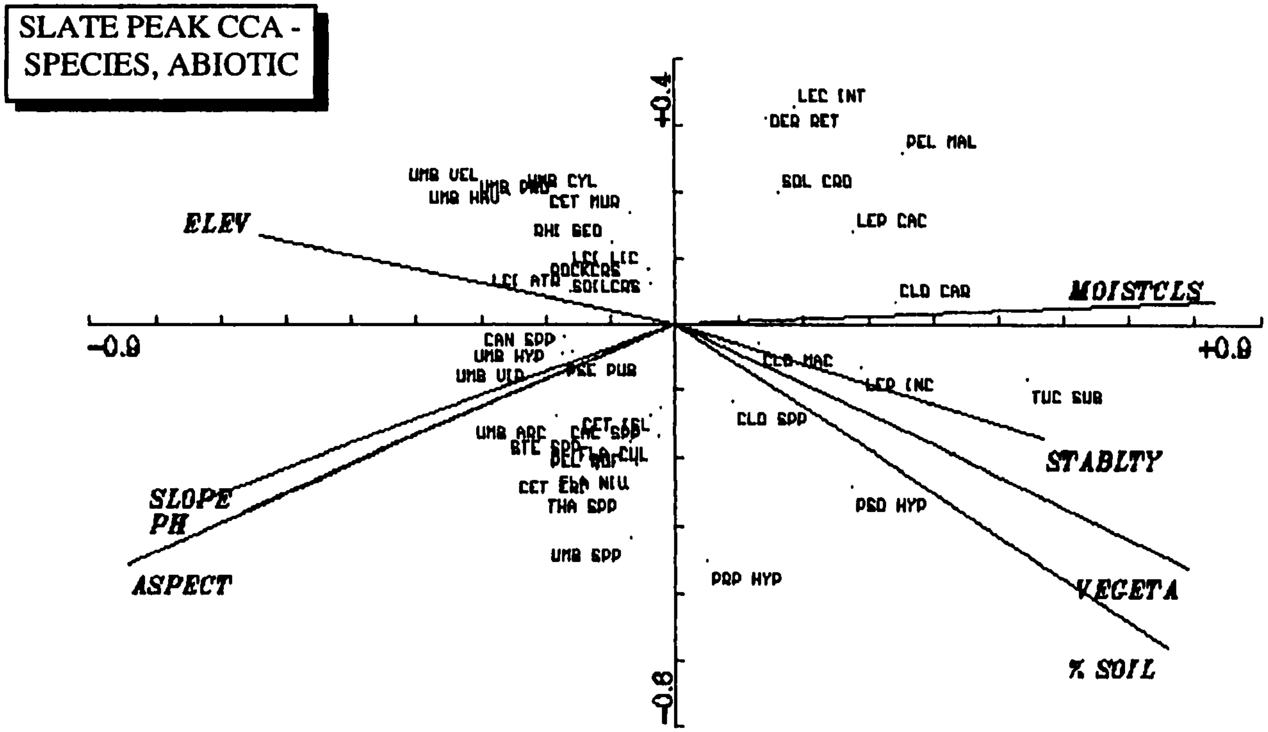

Figure 25. Slate Peak ordination of abiotic factors.

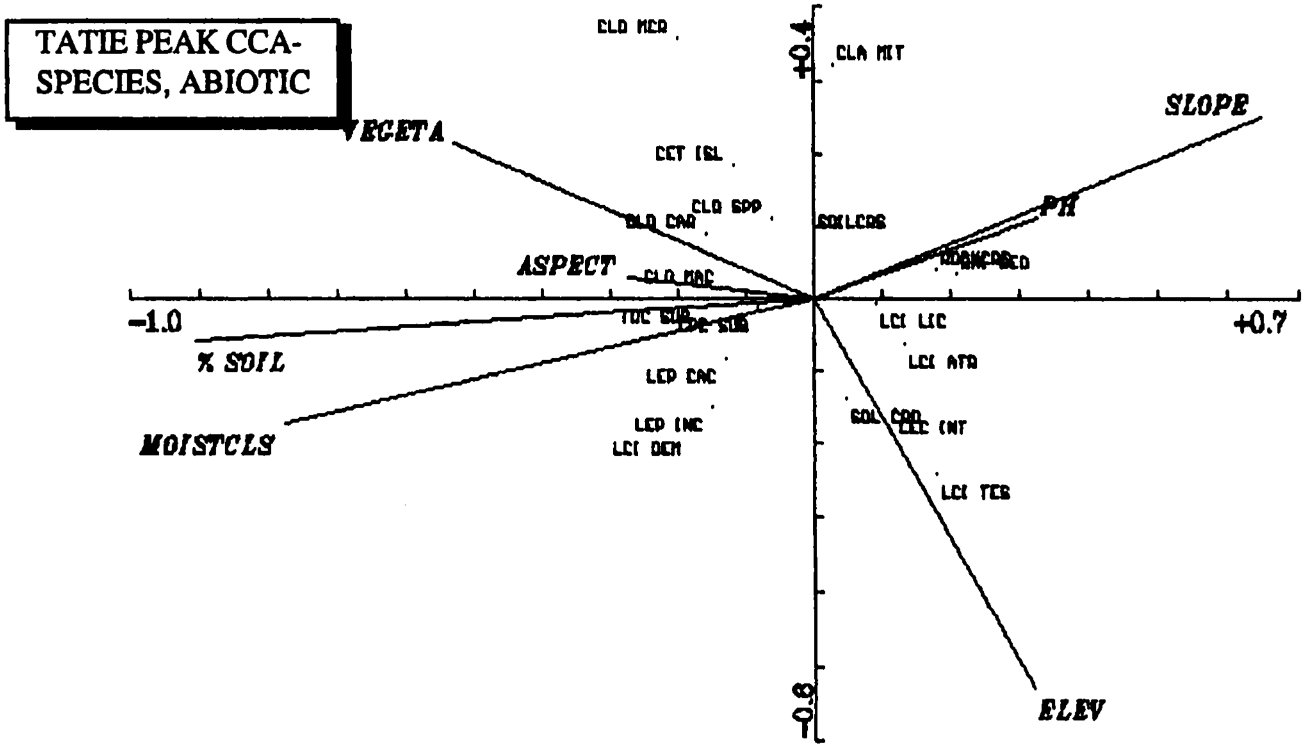

Figure 26. Tatie Peak ordination of abiotic factors.

GENERAL VEGETATION COMMUNITIES

Previous ordinations results from this study show that sites including vegetation fall into two major categories: dry tundra and mesic snow bank communities. These are broad categories with considerable variation.

Dry Tundra Lichen Communities

The dry tundra lichen communities tend to occur on windswept ridges or exposed areas and are represented by all Olympic sites, three Skyline Divide transects and four Slate Peak transects. These include saxicolous (rock), terricolous (soil), and vegetation communities found within each site. Most of the transects from these areas have a south, southwest or northwest aspect and an average soil pH of 5.5 - 6.7. On Elk Mountain, Deer Park, and Slate Peak the vegetation and lichens are patchy and not continuous across the landscape. At Buckhorn Cirque and Skyline Divide, the dry tundra has a more continuous vegetation and lichen cover. Lichens are most dominant on slopes with a south/southwestern aspect. At Deer Park, Elk Mountain, Slate Peak and the dry tundra areas of Skyline Divide, slopes range between 0° - 30°, averaging 18°. In contrast, the gradual slope of Buckhorn Cirque provides a tundra-like terrain, where lichen growth is continuous and not broken up by bare patches (of rock or gravel) or areas of vascular plants. Dominant vascular plants are *Phlox diffusa*, *P. hendersonii*, *Lupinus lepidus*, *Achillea millefolium*, *Arenaria capillaris*, *A. obtusiloba*, *A. rubella*, *Selaginella wallacei*, and sedges (*Carex spectabilis*, *C. phaeocephala*). *Dryas octopetala* is a common herb mat on Slate Peak but not seen at the Olympic sites. The lichen vegetation is very similar at all dry tundra sites, although the vascular plant species can be different depending on the mountain range. Common lichens are *Thamnolia vermicularis*, *T. subuliformis*, cetrarioid lichens (*Cetraria islandica*, *C. ericetorum*, *C. muricatum*, *Flavocetraria nivalis*, *F. cucullata*, *Peltigera* spp. (mainly *Peltigera rufescens*), and *Cladina mitis*.

Mesic Communities

The mesic lichen communities develop in snow bank areas where snow patches linger well into July and areas may be snow free for less than 90 days each year. These sites (all Tatie Peak transects, five Skyline Divide transects, and four Slate Peak transects) tend to have north, northeast or eastern exposures, slopes ranging from 10° - 20°, and an average soil pH of 4.6 - 5.0. These communities also can be segregated into saxicolous (not well developed at the study sites), terricolous (mainly lichen soil crust communities), and lichens with vegetation, some species being epiphytic. Dominant vascular plants are *Phyllodoce empetriformis*, *P. glanduliflora*, *Cassiope mertensiana*, *Vaccinium deliciosum*, *Luzula piperi*, *Luetkea pectinata*, *Antennaria lanata*, and *Veronica cusickii*. Common lichens are *Tuckermannopsis subalpina*, *Cetraria islandica*, *Lepraria cacuminum*, *Cladonia* spp. (mainly *C. ecmocyna*, and *C. carneola*), and *Solorina crocea*.

PERCENT COVER: COMPARING LICHENS TO VEGETATION

A comparison between all sites was made to examine patterns seen with vegetation and lichen percent cover at the quadrat level (Figure 8). Percent cover of lichens, compared to percent cover of all plants, is approximately equal in the Olympic Mountain sites and the tundra transects from Skyline Divide and Slate Peak (Figure 8). In the mesic snow bank sites, the combined vascular plant and cryptogam cover (other than lichens) is greater than the lichen cover.

Sites and transects influenced by a maritime climate (Elk Mountain, Deer Park, Buckhorn Cirque and Skyline Divide) have lichen populations with greater species richness than sites on the east side of the Cascade Mountains (Figure 11). Dry tundra sites, in general, have a greater species richness, compared to mesic snow bank communities. This can be seen in comparing the xeric transects on Mount Baker and Slate Peak with the two eastern Cascade snow bank sites (Figure 11). The Tatie Peak site on the eastern slopes of the Cascades has the lowest lichen and vascular plant diversity of all sites.

To illustrate the effect of vascular plant and cryptogam cover on lichen cover, two sites were chosen and compared for each quadrat within the site. Tatie Peak represented the mesic snow-bank sites and Deer Park represented dry tundra sites. Raw data of the percent cover were statistically compared (Figures 27 and 32). The vertical axis is percent cover and the horizontal axis is the quadrat numbers. Both lichen and vegetation cover are compared together to show relationships between the two types of alpine vegetation.

The Tatie Peak site (Figure 32) shows a strong negative correlation between percent cover of lichens to vascular plants and cryptogams (other than lichens) in the snow bank communities. Where plant cover is high, the percent cover of lichens decreases. Lichen cover appears to increase only in quadrats where vegetation cover is low. A simple regression was performed, resulting in an r value of -0.5, significant at $p < 0.001$ (Table 13).

However, on the xeric tundra site at Deer Park, a positive correlation exists between lichens cover and cover of other vegetation (Figure 28). At this site the plant community is very patchy, surrounded by loose gravel. The smaller patches do not contain many lichen species. As the plant community increases in size, the lichen community within the patch also enlarges. At this site, the regression value for r was +0.31 with a significance of $p < 0.001$ (Table 13).

The other sites also are compared (Figures 27, 29, 30, and 31) for lichen cover in relation to plant cover, but regressions do not demonstrate the high significance as ins the previous sites (Table 13). Buckhorn (Figure 27) has a regression value of +0.14 with $p < 0.055$, which is marginally significant. However, when quadrats 81 - 180 (transects I - M) are compared, there is a positive correlation of +0.34 between lichens and plants, statistically significant at $p < 0.001$. For Elk Mountain (Figure 29), there is a general negative correlation for lichens and plant cover of -0.27, significant at $p < 0.001$. This is probably due to the rock outcrops and lichens covered rock stripes, with no plant development. Skyline Divide (Figure 30) has a general negative correlation between lichen cover and plant cover of -0.57 and $p < 0.001$ for all quadrats. When only the mesic transects for Skyline are compared the regression value is slightly lower of -0.48 and $p < 0.001$, while tundra transects are not statistically significant with a regression value of -0.14. Slate Peak (Figure 31) has an overall regression value of -0.12 which is not statistically significant.

Table 14. Regression values for comparing lichen percent cover to vegetation percent cover. (See also Appendix H)

Site	**r value**
Buckhorn Cirque (all quadrats)	+ 0.14*
Buckhorn Cirque (quadrats 81-180)	+ 0.34**
Deer Park	+ 0.31**
Elk Mountain	- 0.27**
Skyline Divide (all quadrats)	- 0.57**
Skyline Divide (mesic transects)	- 0.48**
Skyline Divide (tundra transects)	- 0.14
Slate Peak	- 0.12
Tatie Peak	- 0.5**

* significant at $p < 0.055$

* *significant at $p < 0.001$

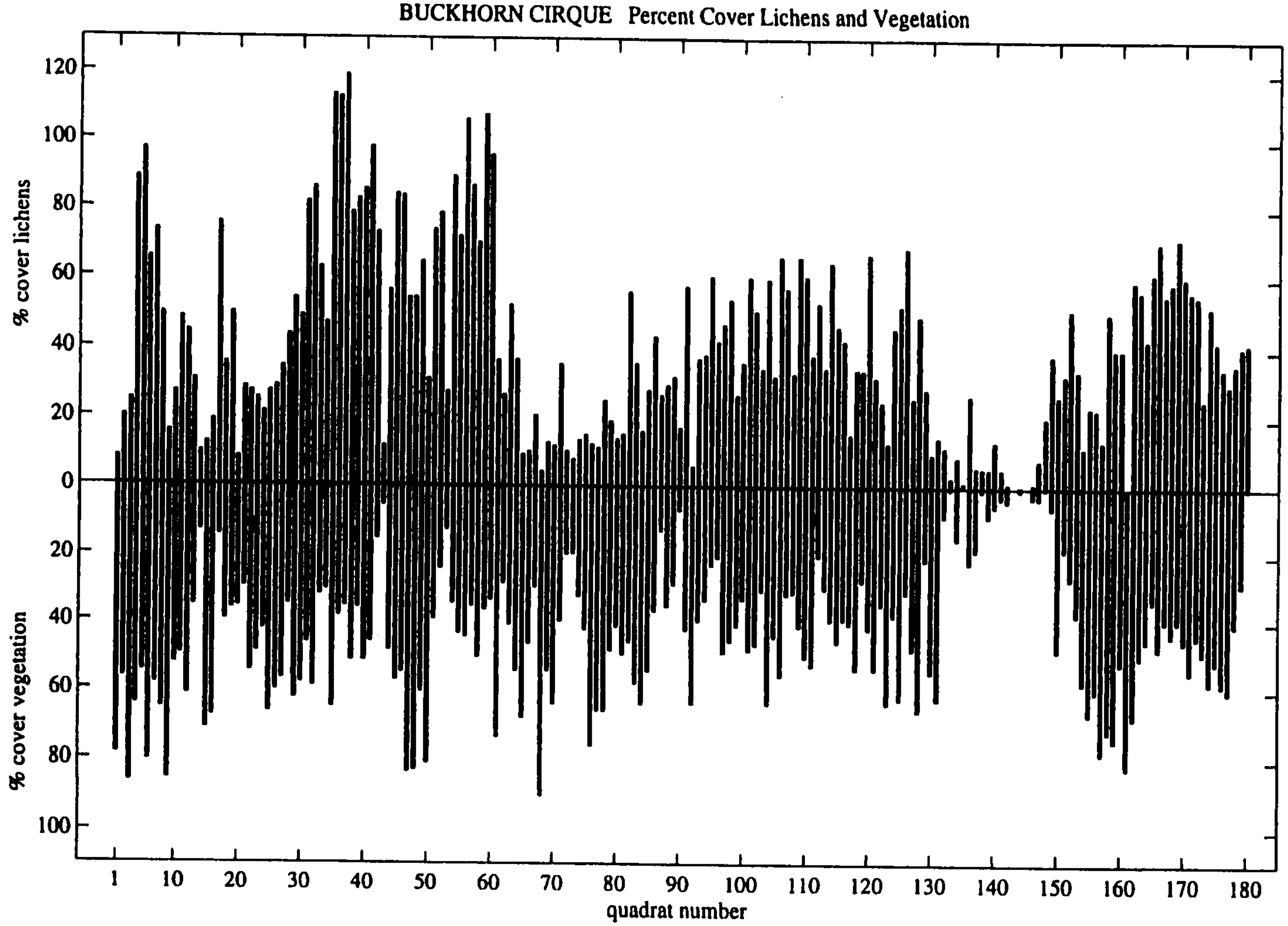

Figure 27. Buckhorn Cirque. Comparison of percent cover of lichens and vegetation for each of the six sites. Lichen cover is on the top half of the graph. Vegetation cover is on the lower half of the graph.

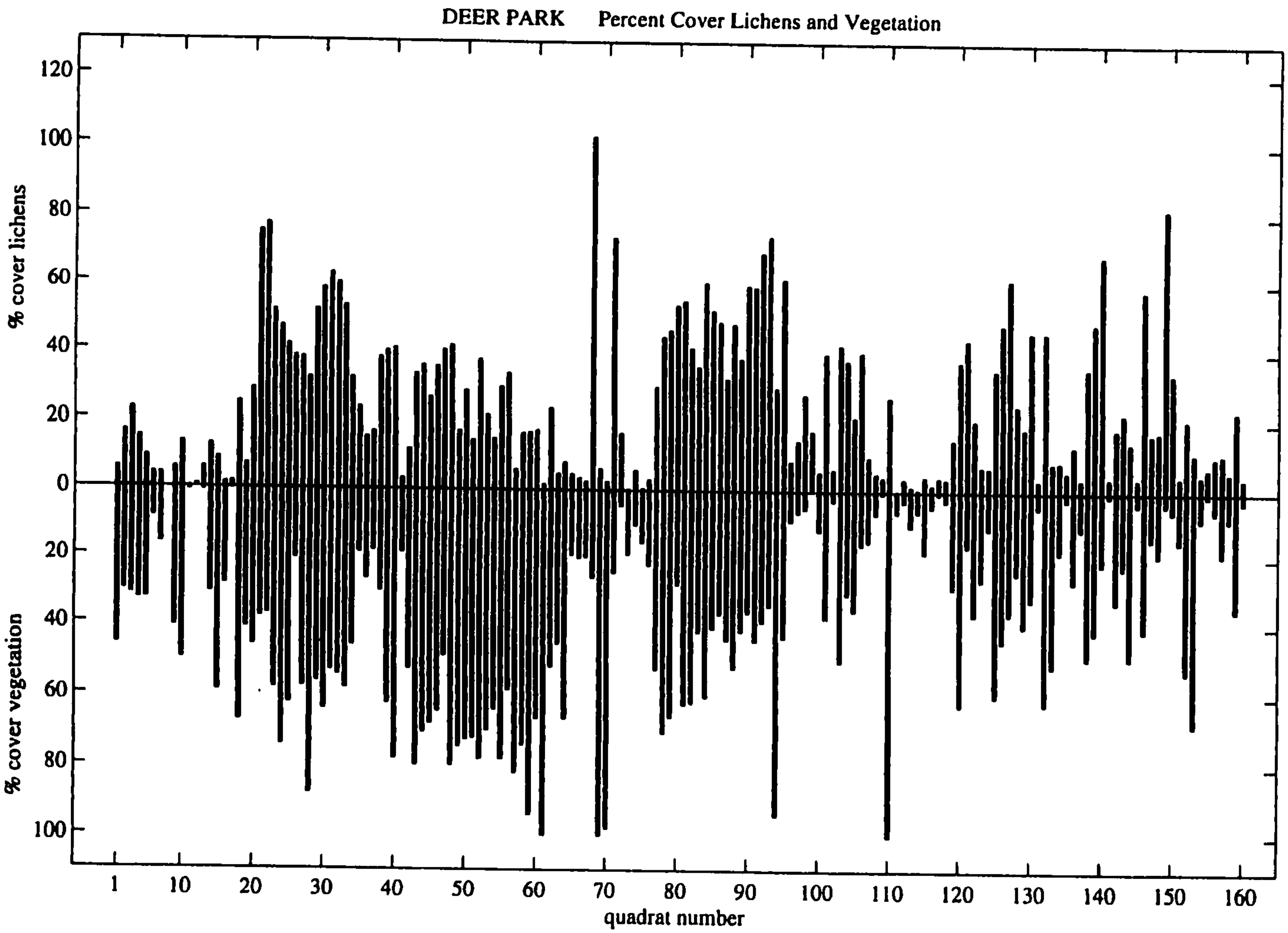

Figure 28. Deer Park. Comparison of percent cover of lichens and vegetation for each of the six sites. Lichen cover is on the top half of the graph. Vegetation cover is on the lower half of the graph.

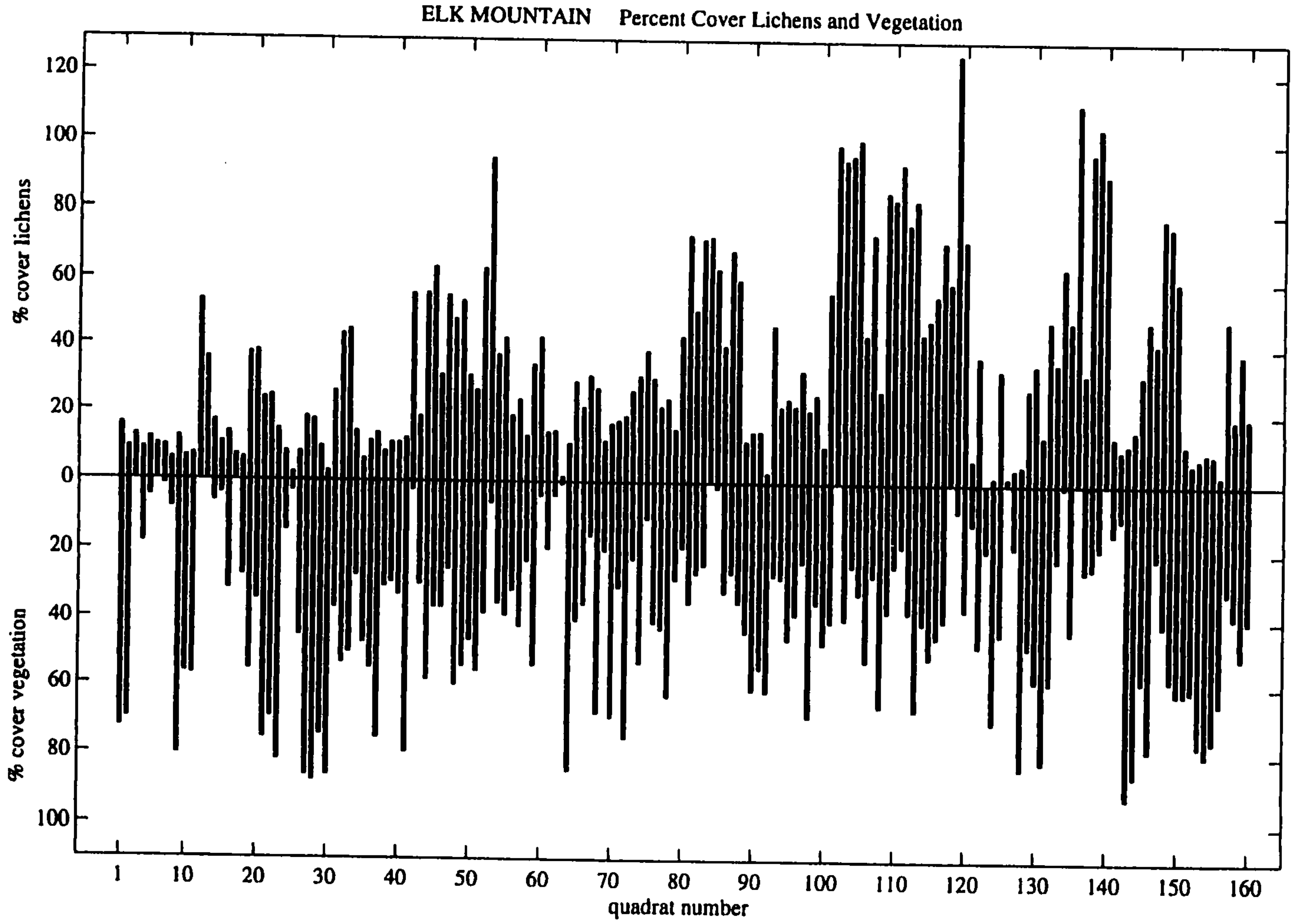

Figure 29. Elk Mountain. Comparison of percent cover of lichens and vegetation for each of the six sites. Lichen cover is on the top half of the graph. Vegetation cover is on the lower half of the graph.

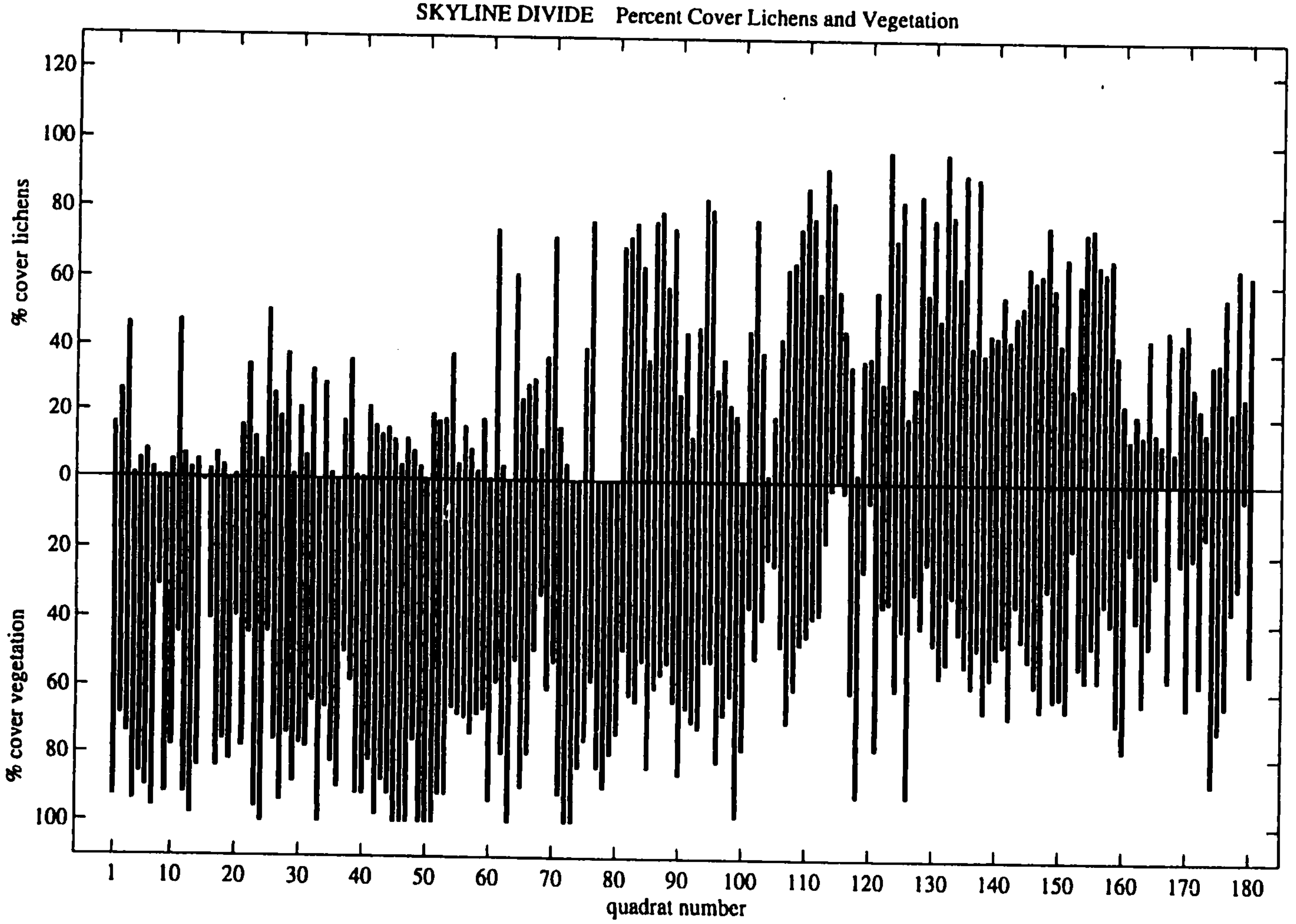

Figure 30. Skyline Divide. Comparison of percent cover of lichens and vegetation for each of the six sites. Lichen cover is on the top half of the graph. Vegetation cover is on the lower half of the graph.

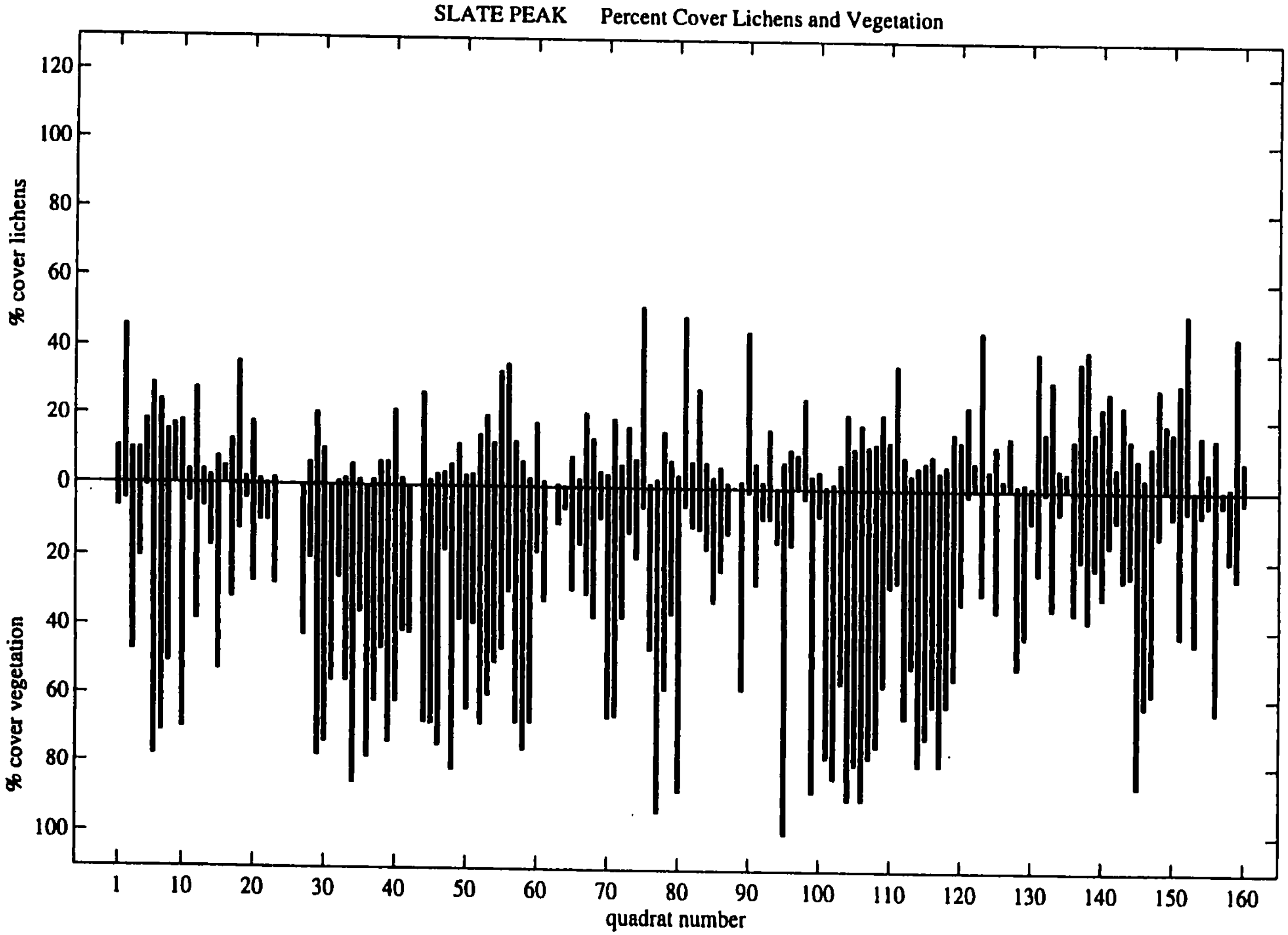

Figure 31. Slate Peak. Comparison of percent cover of lichens and vegetation for each of the six sites. Lichen cover is on the top half of the graph. Vegetation cover is on the lower half of the graph.

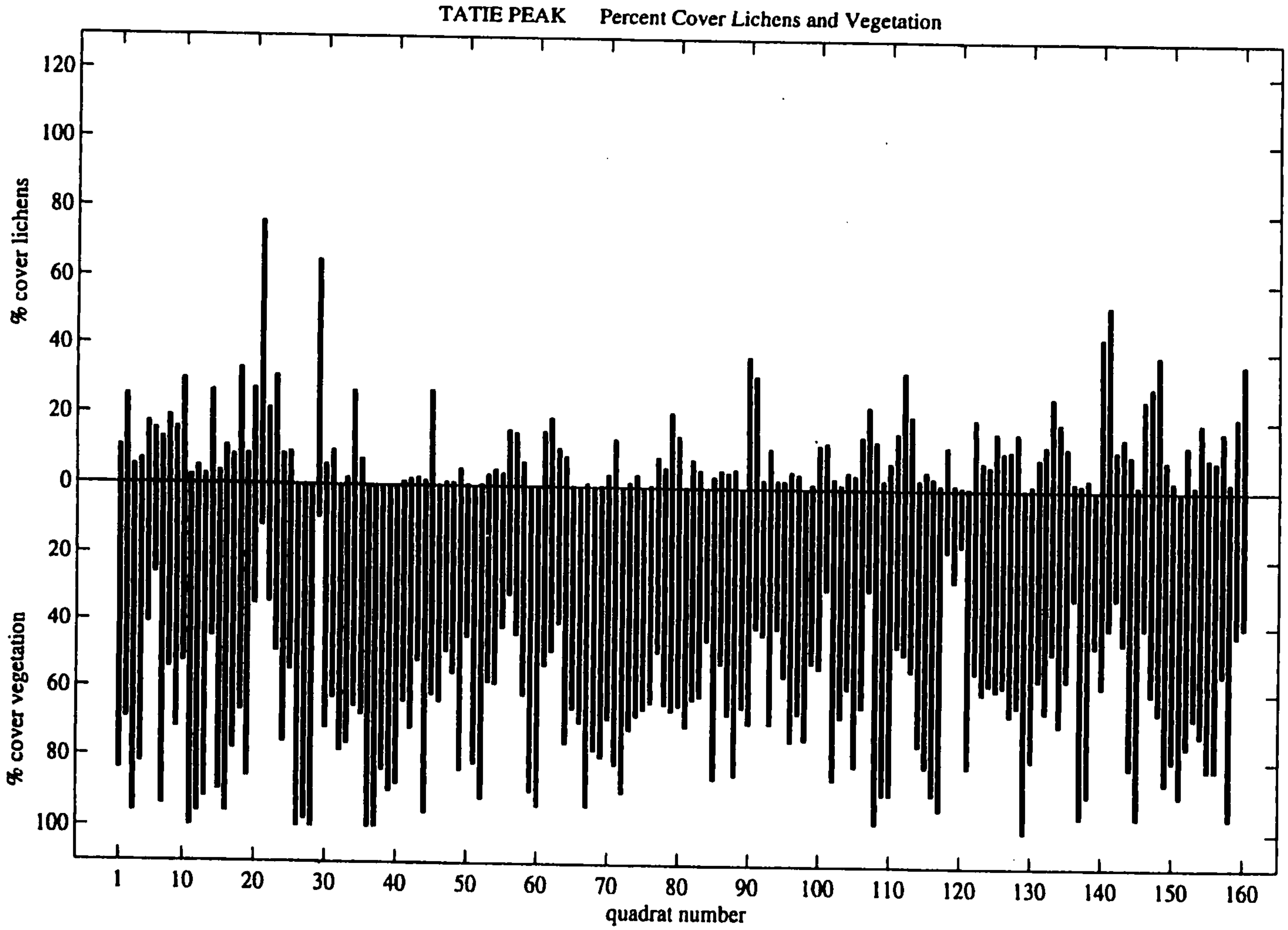

Figure 32. Tatie Peak. Comparison of percent cover of lichens and vegetation for each of the six sites. Lichen cover is on the top half of the graph. Vegetation cover is on the lower half of the graph.

PLANT FUNCTIONAL GROUPS

Vascular plants were converted into functional groups to determine if lichens were more likely to be associated with plants as a substrate (Table 14). From previous ordinations using DCA and CCA, it was determined that individual plant species as environmental variables do not have a significant influence on lichen species' distributions.

The CCA biplot of the Tatie Peak site (Figure 38) shows a high presence of ericaceous plants (Table 14), common in the more mesic snow bank areas. Lichen species are represented by a six letter code derived from the genus and species names (Appendix D). The first and second axes represent environmental gradients that correlate with the linear combinations of environmental vectors included in the CCA analysis (ter Braak, 1987). At this site, woody shrubs and ground cover are a major determinant of axis 1 ($p < 0.01$), with ericaceous ground cover and herbs also important ($p < 0.05$). These four variables explain 56.6% of the variance seen in the ordination. Axis 2 represents associations with ericaceous woody shrubs, cryptogams, and secondarily with woody ground cover and shrubs (Tables 16 and 17).

The vector lines found on the graph represent the environmental variables of the plant structure groups with maximum value pointing away from the axes intersect (Figure 38). Lichen species found closer to the terminus of the vector are positively affected by that environmental variable, such as *Peltigera malacea* with woody shrubs. *Tuckermannopsis subalpina* has a negative correlation with woody shrubs. The longer the vector, the more important it is in affecting the distribution patterns of the lichens (ter Braak, 1987, 1988, 1994; John, 1989; John & Dale, 1990). A "long" vector with a high correlation value may represent a variable that was only found in a few

Table 15. Plant structural groups: Codes are given first for plant groupings

Code	Group Descriptions
CRYPTOG	cryptogams - mosses (*Tortula ruralis* (Hedw.) Gaertn. et al., *Polytrichum piliferum* Hedw., *Ceratodon purpureus* (Hedw.) Brid., as examples), *Selaginella wallacei*, *Lycopodium sitchensis*
GRAMIN	graminoids - *Carex* sedges (*Carex spectabilis*, *C. phaeocephala*, *Luzula piperi*, *L. spicata*, *Festuca idahoensis*, *Juncus parryi*, grasses
CUSHION	cushions - *Silene aucaulis*, *Phlox diffusa*, *Phlox hendersonii*, *Arenaria rubella*, *A. obtusiloba*
WOODYGC	woody - *Juniperus communis*, *Luetkea pectinata*, *Empetrum nigrum*, *Salix nivalis*
HERB	herb (simple) - *Erigeron aureus*, *E. compositus*, *E. peregrinus*, *Achillea millefolium*, *Allium cernuum*, *A. crenulatum*, *Veronica cusickii*, *Antennaria lanata*
HRB-ROS	herb-rosettes - *Antennaria rosea*, *A. alpina*, *Campanula rotundifolia*
HRB-MAT	herb-mats - *Synthris pinnatifida* Wats., *Cerastium arvense*, *Lupinus lepidus*, *Eriogonum ovalifolium*, *E. pyrolifolium* Hook., *Sibbaldia procumbens*, *Dryas octopetala*
HRB-TFT	herb-tufts - *Arenaria capillaris*, *Oxytropus campestris*, *Geum triflorum*
EWOODMT	ericaceous dense mats - *Cassiope mertensiana*, *Phyllodoce empetriformis*, *P. glanduliflora*
ERIGC	ericaceous (woody) ground cover - *Cassiope stellariana*
ERWDSHB	vertical shrub - *Vaccinium deliciosum*, *V. scoparium*
HRB-SHB	herb-shrub - *Haplopappus lyallii*
WOODSHB	low - medium woody shrubs - *Potentilla fruticosa*, *Salix cascadensis*
KRUMMH	krummholz - *Abies lasiocarpa*, *Laryx lyallii*, *Picea engelmannii*, *Pinus albicaulis*
PERGC	perennial - *Sedum lanceolatum*

quadrats. Vector length does not represent the frequency or high value of an environmental variable. Interset correlations of environmental variables and axes are given in Table 16. The eigenvalue for the Tatie Peak site is 0.276 with $p < 0.05$ determined with the Monte Carlo test (Table 15). On the ordination (Figure 38) *Tuckermannopsis subalpina* aligns with the vector for ericaceous woody shrubs. *Cladonia carneola*, *Cladonia* spp., *Trapeliopsis granulosa*, and *Cetraria islandica* are frequently found at the base of krummholz, ericaceous woody mats and ground cover. *Cetraria islandica* is more closely associated with ericaceous ground cover but is at times mixed with *Tuckermannopsis subalpina*. *Cladina mitis*, *Peltigera aphthosa*, and *P. malacea* have a high correlation with woody shrubs and herb-tufts, producing colonies at the base of plants. *Lepraria cacuminum* is found with herbs in areas were there is exposed ground. *Lecidoma demissum*, *Solorina crocea* and *Cladonia ecmocyna* tend to be mixed in with graminoids, between tussocks and herb-mats. *Cladonia macrophyllodes* is found around woody ground cover, cushion plants and graminoids.

The ordination for Deer Park (Figure 34) has an eigenvalue of 0.144 (Table 15). This is very low but a Monte Carlo simulation showed that the first axis is significant at $p < 0.01$. Axis 1 in this ordination is determined by the environmental variables of herb-mats, herb-tufts, and woody shrubs. Woody shrubs are significant at $p < 0.01$, explaining 36.1% of the variance. Cushion plants, woody ground cover, and herb-shrubs are the main determinants of axis 2 (Table 16). Herb-shrubs being significant at $p < 0.05$ and explaining 13.9% of the variance (Table 17).

From the ordination graph and weighted species scores *Cladonia* spp. (C. *macrophyllodes*, *C. carneola*, and others) and *Cladina mitis* are associated with the base of herbs, herb-shrub, cryptogams and woody ground cover, where there is sheltered space between the plants. *Flavocetraria cucullata* and *F. nivalis*, indicate herbaceous vegetation and graminoids. *Physconia muscigena*, *Thamnolia vermicularis*, and *T.*

subuliformis occur with graminoids, cushion plants, and herb-tufts, which are found on soil or cryptogams in between the vascular plants.

Field observations indicate that *Peltigera malacea* and *P. rufescens* tend to be epiphytic on vegetation, such as *Empetrum nigrum* and *Juniperus communis*. This was seen at Skyline Divide and Elk Mountain. While recording species within a quadrat, these lichens were found deep in the vegetation, close to the ground, yet definitely attached to these ground covers.

The other ordinations for Buckhorn Cirque, Elk Mountain, Skyline Divide, and Slate Peak (Figures 33, 35, 36, and 38 respectively) show slightly different variations of lichen species with plant groups. Herbs (including the rosettes, tufts, and mats) and graminoids are usually associated with the cetrarioid lichens, *Thamnolia* spp., *Cladina mitis* and stereocaulons. *Tuckermannopsis subalpina* and *Trapeliopsis granulosa* are highly associated with ericaceous plants. Interset correlations for environmental variable and axes for each site are listed in Table 15. Eigenvalues for these ordinations (.144 to .538) are comparable to those observed with abiotic factors (.241 to .607, Tables 10 and 15). Buckhorn Cirque and Deer Park have very low eigenvalues (.181 and .144) even though their first axes were shown to be significant. Elk Mountain and Slate Peak have higher eigenvalues for the plant functional groups ordinations than the abiotic factors and vegetation cover. At these sites the vegetation functional groups may have more of an influence on species distributions than the abiotic factors. The species-environment cumulative percent variance are fairly similar for all sites ranging between 49.0% (Slate Peak) to 64.8% (Skyline Divide) for the first two axes.

Cushion plants, woody ground cover, and herbs are the most important factors affecting species distributions at Buckhorn Cirque on the first axis (Figure 33). Combined they accounted for 53.5% of the variance and all are significant ($p < 0.01$). The herb groups of tufts, rosettes, and mats along with graminoids are the next most important factors

Table 16. Plant Functional Group Factors

PLANT FUNCTIONAL GROUP FACTORS

Sites	Eigenvalue	Species Cumulative % variance Axis 1	Species-Env. Cumulative % variance Axis 2	Species-Env. Cumulative % variance Axis 1	Species-Env. Cumulative % variance Axis 2	Transformation
Buckhorn Cirque, O.M.	0.181*	6.7	9.6	41.7	60.2	none
Deer Park, O.M.	0.144*	6.4	9.0	39.6	55.9	log
Elk Mountain, O.M.	0.416*	8.6	12.3	40.8	51.2	none
Skyline Divide, N.C.	0.377*	7.2	12.5	37.1	64.8	none
Slate Peak, N.C.	0.583*	7.2	11.4	30.8	49.0	none
Tatie Peak, N.C.	0.276**	4.9	7.9	31.8	50.6	square root

* significant at $p < 0.01$

** significant at $p < 0.05$

affecting the ordination with graminoids and herb-mats being secondarily important along the second axis (Tables 16 and 17).

At Elk Mountain (Figure 35) there are several lichens associated with herb-mats: *Flavocetraria cucullata*, *F. nivalis*, *Physconia muscigena*, *Thamnolia* spp., *Stereocaulon* spp., *Cetraria muricatum*, and *Ochrolechia upsaliensis*. This is a very important variable for the site having a correlation value of -.619 with the first axis, and significance of $p < 0.01$, explaining 27.5% of the species distributions. The herb-shrub, herb-tuft and graminoid groups have *Peltigera ponojensis*, *P. malacea*, *P. rufescens* and *Cladina mitis* aligned with these vectors. *Lecanora cacuminum* and *Cladonia macrophyllodes* have negative associations with cushion plants, woody shrubs herbs, and perennial ground covers.

The ordination for Skyline Divide (Figure 36) shows a good separation of lichen species with the eigenvalue at 0.377 and a species-environment cumulative % variance at 64.8%. Here the herb-rosettes and cushion plants are found in association with the cetrarioid lichens, *Thamnolia* spp., *Ochrolechia upsaliensis*, *Bryoria chalybeiformis*, *Alectoria ochroleuca*, and *Peltigera rufescens*. *Cladonia ecmocyna*, *C. squamosa*, *C. bellidiflora*, and *Cetraria islandica* are found among the woody shrubs. Around ericaceous woody mats are *Lepraria cacuminum Solorina crocea*, soil crusts, *Leprocaulon subalbicans*, *Alectoria nigricans*, and *Lepraria incana*. These lichens are consistently found among ericaceous plants and woody ground covers at all sites. Herb mats had a strong correlation with the first axis of -.298, as well as cushion plant (-.546) and ericaceous woody shrubs with the second axis, -.677, accounting for 56.1% of the variance. All three of these variables are significant ($p < 0.01$) (Tables 16 and 17).

Slate Peak's first axis (Figure 37) is strongly influenced by ericaceous woody mats (.671), ericaceous ground cover (.515) and woody ground cover (.411). These factors are both significant at $p < 0.01$, accounting for 39.6% of the variance. For the second axis

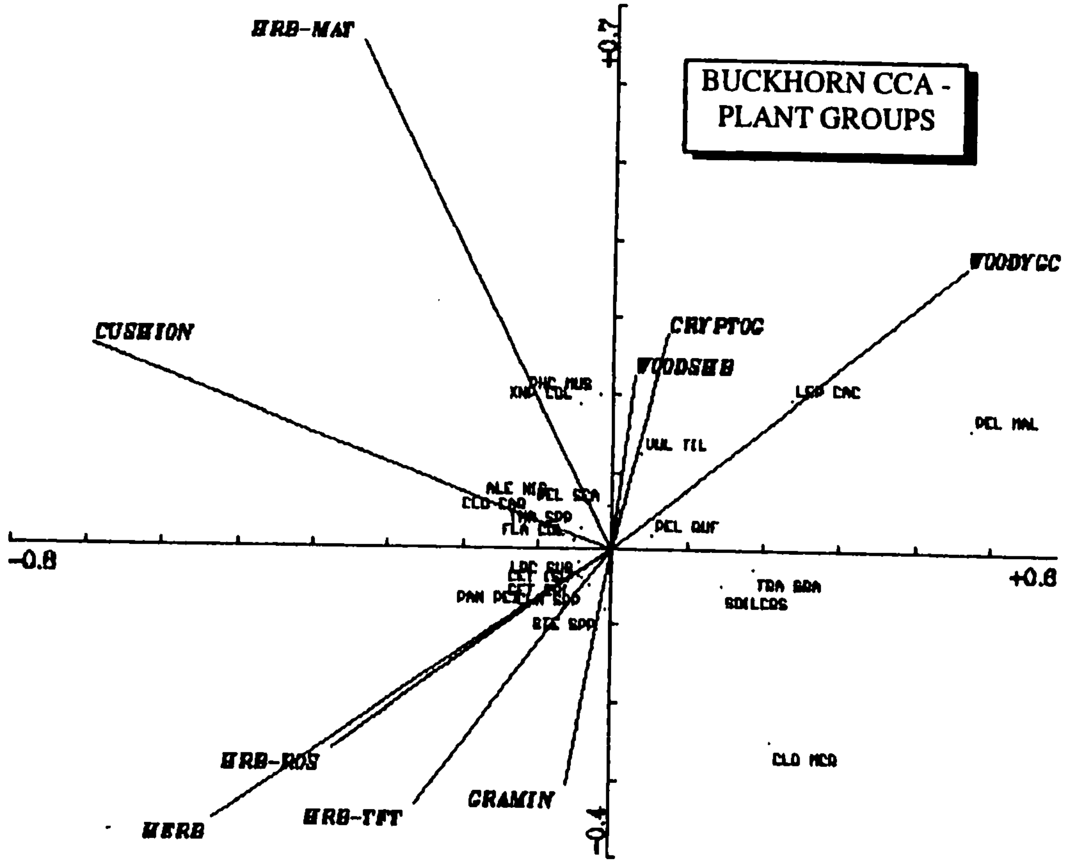

Figure 33. Buckhorn Cirque. Canonical Correspondence Analysis of species and plant functional groups.
The x axis is CCA-1; the y axis is CCA-2. Environmental variables codes are: Cryptogams (CRYPTOG); Graminoids (GRAMIN); Cushion (CUSHION); Woody ground cover (WOODYGC); Herb (HERB); Herb-rosette (HRB-ROS); Herb-mat (HRB-MAT); Herb-tuft (HRB-TFT); Ericaceous woody mat (EWOODMT); Ericaceous ground cover (ERIGC); Ericaceous woody shrub (ERWDSHB); Herb-shrub (HRB-SHB); Woody shrub (WOODSHB); Krummholz (KRUMMH); Perennial ground cover (PERGC). Species codes can be found in Appendix D.

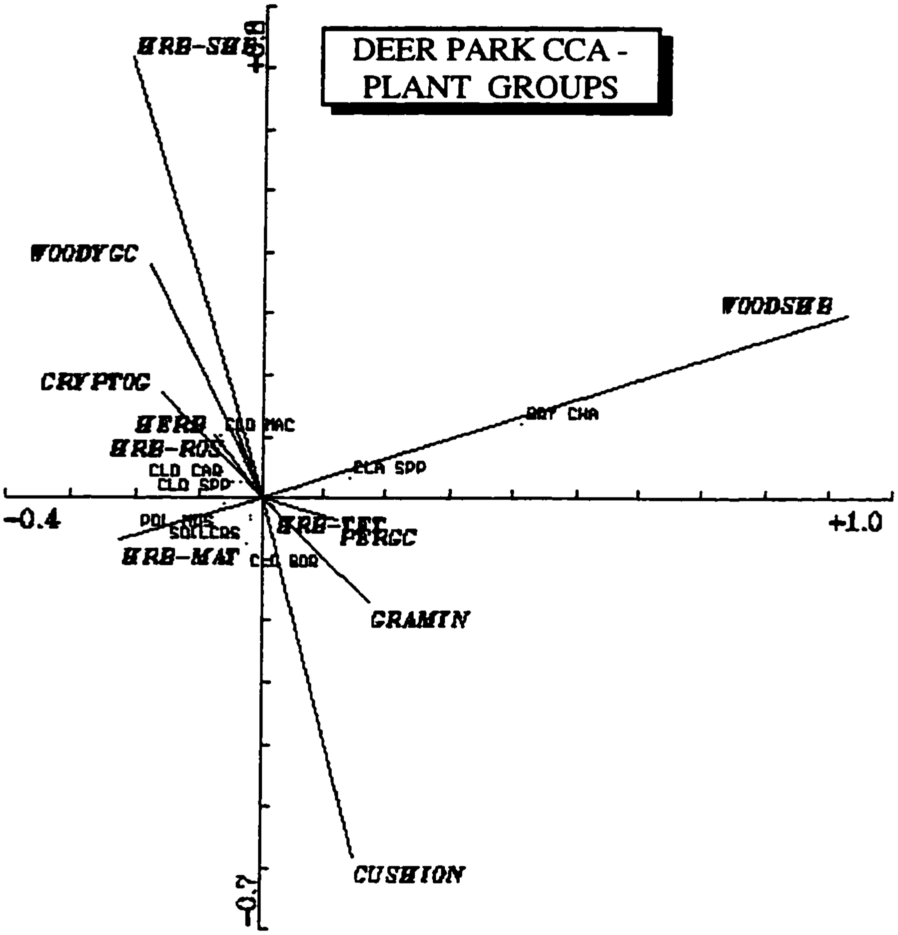

Figure 34. Deer Park. Canonical Correspondence Analysis of species and plant functional groups.

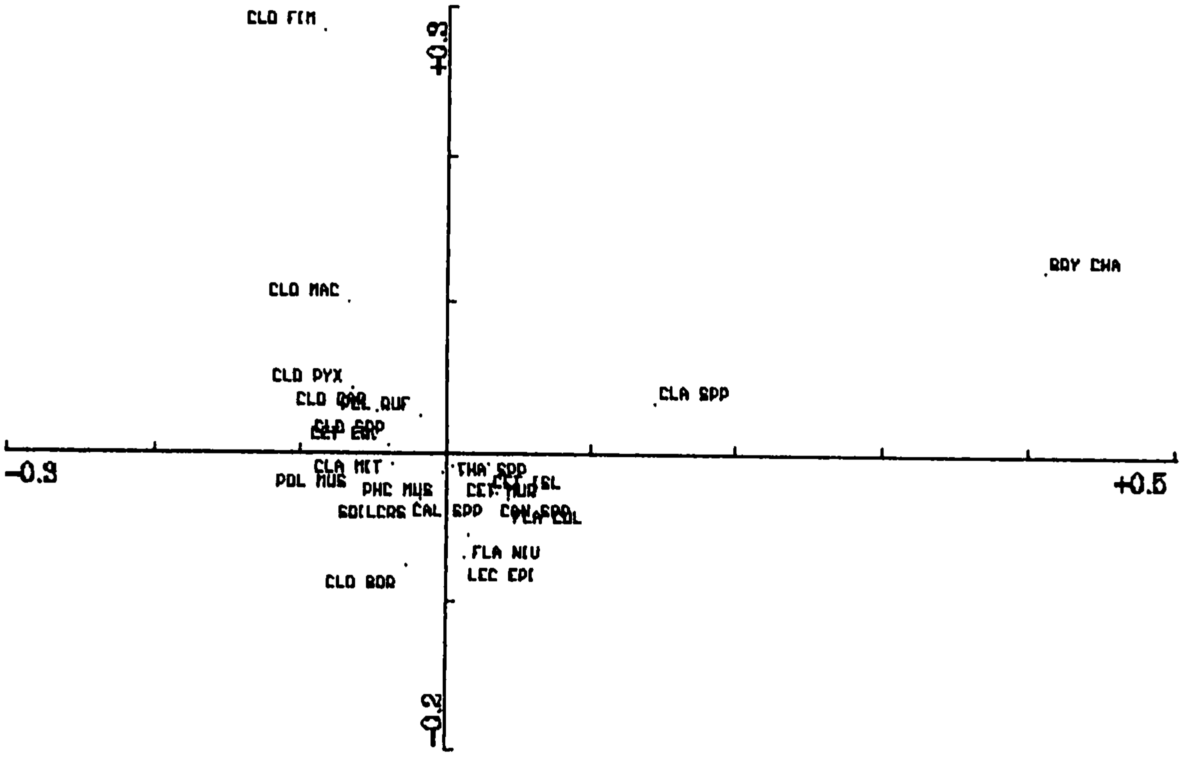

Figure 34 (continued). Deer Park. Canonical Correspondence Analysis of species and plant functional groups.

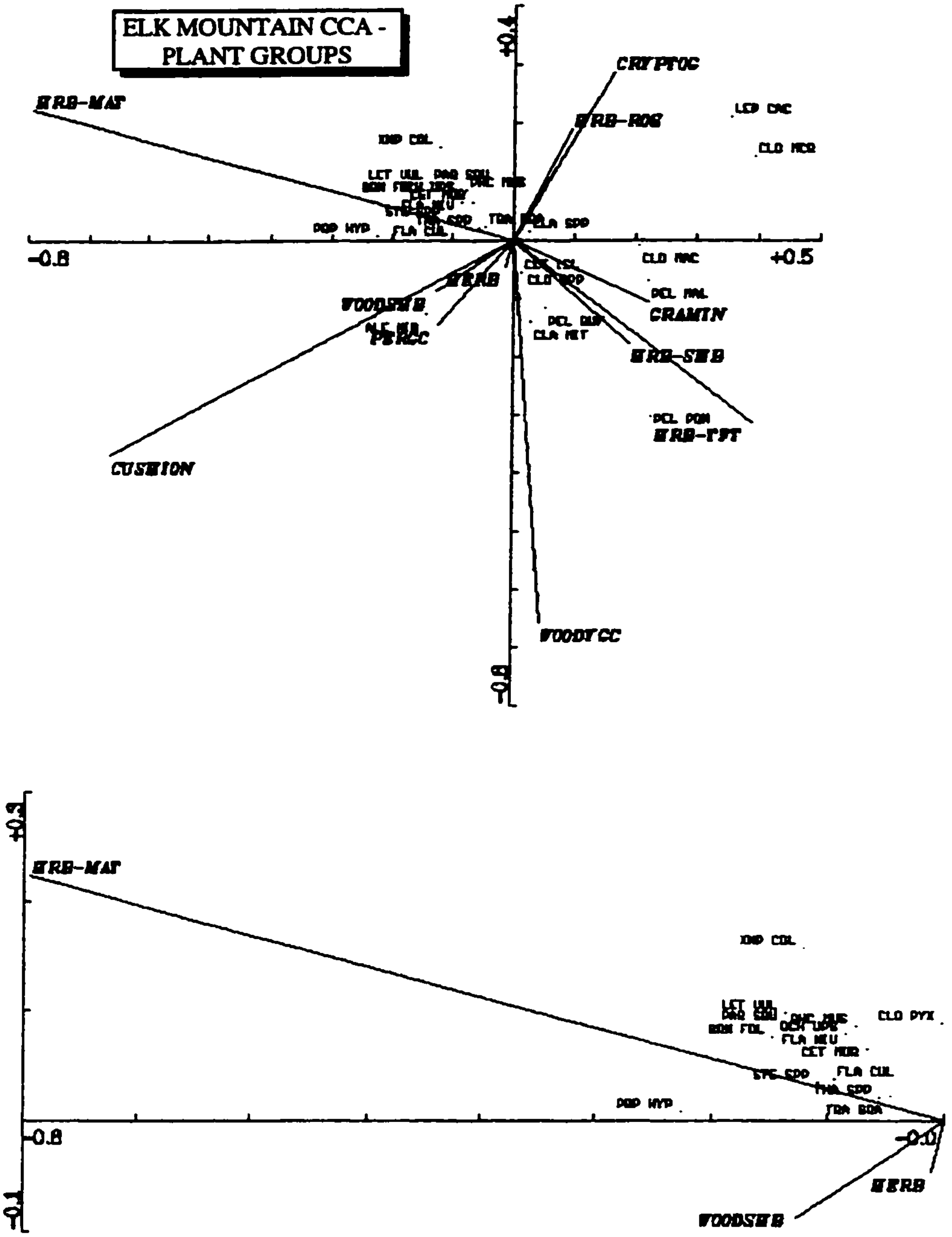

Figure 35. Elk Mountain. Canonical Correspondence Analysis of species and plant functional groups.

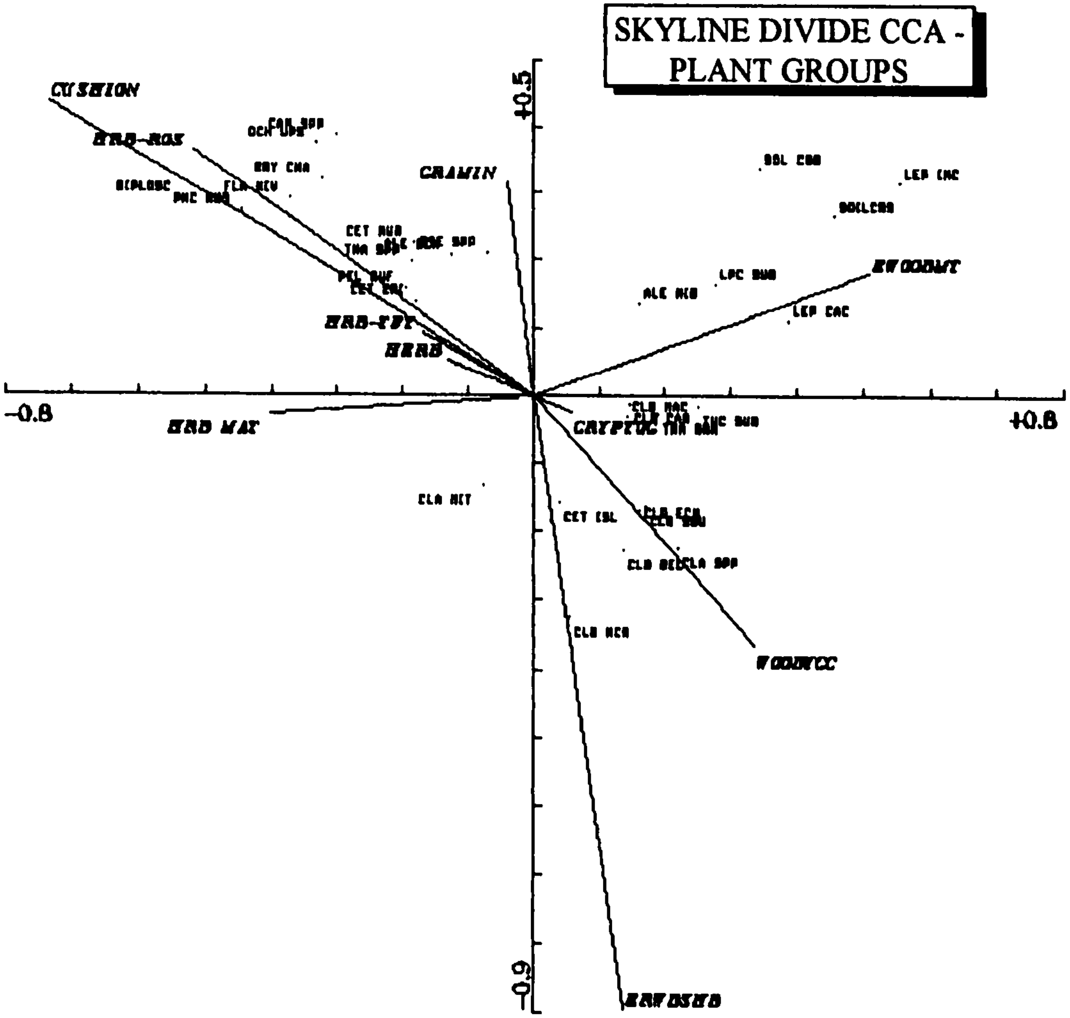

Figure 36. Skyline Divide. Canonical Correspondence Analysis of species and plant functional groups.

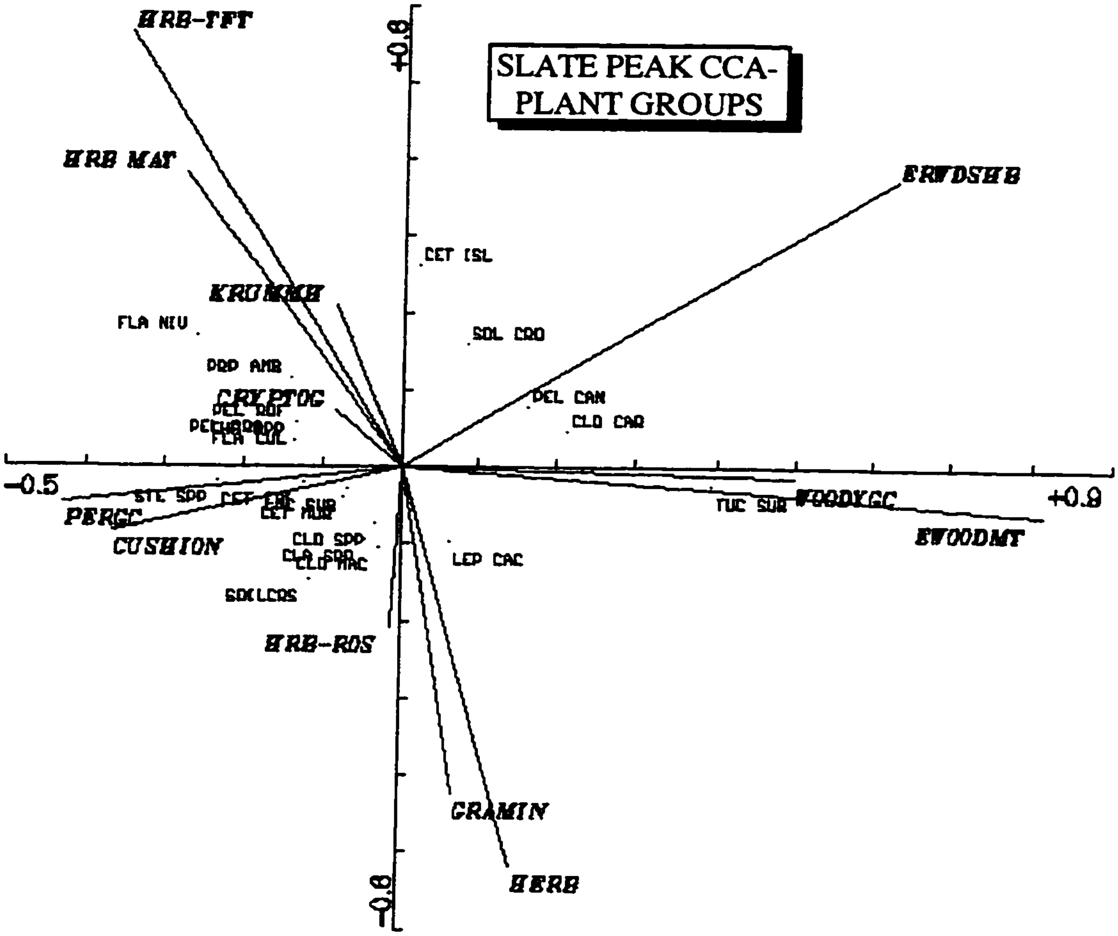

Figure 37. Slate Peak. Canonical Correspondence Analysis of species and plant functional groups.

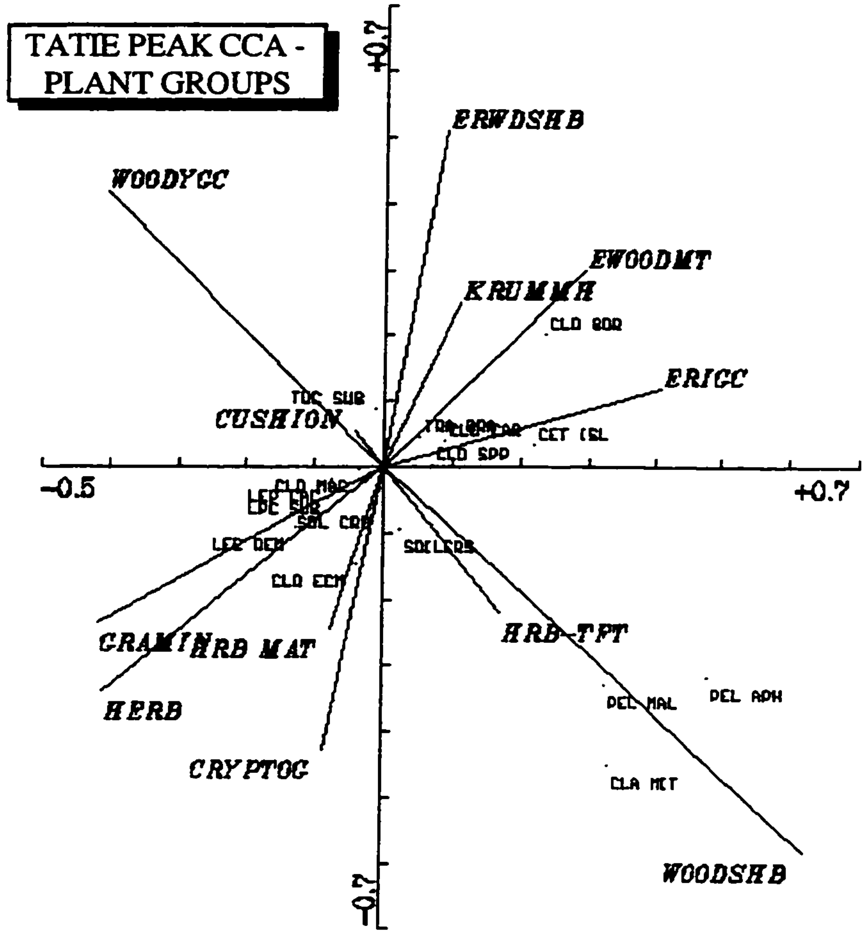

Figure 38. Tatie Peak. Canonical Correspondence Analysis of species and plant functional groups.

Table 17. Interset correlations of environmental variables and axes. (Values are multiplied by 1000.)

INTERSET CORRELATIONS OF ENVIROMENTAL VARIABLES WITH AXES PLANT FUNCTIONAL GROUPS.

Variable	BC axis 1	BC axis 2	DP axis 1	DP axis 2	EM axis 1	EM axis 2	SD axis 1	SD axis 2	SP axis 1	SP axis 2	TP axis 1	TP axis 2
CRYPTOG	50	160	-123	89	127	191	43	-19	-71	57	-61	-260
GRAMIN	-35	-179	135	-88	173	-68	-28	238	59	-330	-311	-144
CUSHION	-461	149	118	-302	-516	-234	-546	332	-302	-66	-30	33
WOODYGC	311	213	-136	197	37	-417	250	-277	411	-10	-304	255
HERB	-352	-204	-60	54	-8	-30	-96	40	122	-402	-305	-207
HRB-ROS	-248	-151	-32	57	75	120	-386	276	-10	-162		
HRB-MAT	-227	376	-172	-35	-619	141	-298	-19	-228	297	-55	-149
HRB-TFT	-174	-192	15	-7	304	-198	125	70	-286	439	126	-133
EWOODMT							380	136	671	-47	216	182
ERIGC											302	73
ERWDSHB							103	-677	515	290	65	311
HRB-SHB			-159	373	147	-111						
WOODSHB	20	128	-707	155	-99	-55					465	-356
KRUMMH									-71	163	81	153
PERGC			96	-18	-96	-91			-353	-38		

Table 18. Forward Selection test of significance for Plant Functional Groups Environmental Variables.

RESULTS of FORWARD SELECTION for ENVIRONMENTAL VARIABLES PLANT FUNCTIONAL GROUPS

Variable	BC eigen-value	BC % ex-plained	DP eigen-value	DP % ex-plained	EM eigen-value	EM % ex-plained	SD eigen-value	SD % ex-plained	SP eigen-value	SP % ex-plained	TP eigen-value	TP % ex-plained
CRYPTOG	.03**	7.0	.03*	8.3	.10**	9.8	.03	3.0	.13**	6.9	.05	5.7
GRAMIN	.04**	9.3	.04*	11.1	.03	2.9	.03	3.0	.08	4.2	.06	6.9
CUSHION	.10**	23.3	.03	8.3	.15**	14.7	.27**	26.7	.16**	8.5	.01	1.0
WOODYGC	.08**	18.6	.01	2.8	.09*	8.8	.11**	10.9	.12**	6.3	.09**	10.3
HERB	.05**	11.6	.01	2.8	.05	4.9	.07**	6.9	.12*	6.3	.11*	12.6
HRB-ROS	.04**	9.3	.03**	8.3	.07**	6.9	.04	4.0	.13*	6.9		
HRB-MAT	.04*	9.3	.02	5.6	.28**	27.5	.07**	6.9	.16**	8.5	.03	3.5
HRB-TFT	.03*	7.0	.01	2.8	.09**	8.8	.03	3.0	.15**	7.9	.07*	8.1
EWOODMT							.14**	13.9	.42**	22.2	.08	9.2
ERIGC											.11*	12.6
ERWDSHB							.23**	22.8	.21*	11.1	.04	4.6
HRB-SHB			.05*	13.9	.06	5.9						
WOODSHB	.02*	4.7	.13**	36.1	.06	5.9					.18**	20.7
KRUMMH									.11	5.8	.04	4.6
PERGC			.01	2.8	.04	3.9			.09*	4.8		
Total	.43	100	.36	100	1.02	100	1.01	100	1.89	100	.87	100

*significant at $p < 0.05$ **significant at $p < 0.01$

graminoids (-.330), herbs (-.402), and herb-tufts (.439) are major determinants of the axis, with herbs ($p < 0.05$) and herb tufts ($p < 0.01$) significant.

DISCUSSION

ABIOTIC FACTORS AND VEGETATION COVER

This study shows that the major factors influencing lichen communities in alpine areas are 1) substrate type, which can define a community (Thomson, 1984; Creveld, 1981); 2) moisture availability to the lichens, which is most useful as atmospheric humidity (Blum, 1973; Ascaso, 1978; Canters et al., 1991; Nash, 1996); 3) the amount and kind of vegetation in an area (Petzold and Mulhern, 1987), and 4) the pH of a substrate (See & Bliss, 1980). Not only can these factors influence lichen species, but they can be limiting factors as well. Too much moisture and a low pH reduces the lichen diversity of an area. If the substrate becomes rocky and stable, cetrarioid lichens, *Thamnolia* spp., stereocaulons and *Cladina mitis* are absent from the community and replaced by saxicolous crusts, umbilicarias, melanelias, and pseudephebes.

Areas with scattered vegetation and low cover give certain fruticose lichens opportunities to become established within a community. Where the soil is exposed, soil lichen crusts communities can develop. At Buckhorn Cirque there are two layers of lichens. The macrolichens that are common to all alpine sites, covering wide areas within the site, and the crustose lichens on the soil, which displayed a wide species diversity of lichens. These lichen crusts were much more sensitive to the substrate and appeared to be selected for within a much narrower environmental range than the macrolichens. Adequate testing of this phenomena this was beyond the scope of this study but has been examined in range land areas (Rosentreter, 1989; Thomas & Rosentreter, 1992; Eldridge & Tozer, 1997). Ahti and Oksanen (1990) noted the importance of these crustose species and as indicator species, which are easily overlooked in ecological studies.

Initial examination of ordinations and classification indicate that edaphic factors such as substrate and moisture regimes dictate the structure of alpine lichen communities (See & Bliss, 1980; Carleton, 1990; Canters et al., 1991). However, this is more complicated when determining interactions between environmental factors. Substrate includes pH, texture, water retention of the surface, exposure to the sun and weather, or if it is mineral soil or vegetation. Moisture affects the vegetation (other than lichens) more than the lichens themselves. If the vegetation is thick and lush from sufficient moisture, then lichens cannot "compete" as well as in areas where they can be opportunistic and occupy available space not used by vascular plants and bryophytes (Ahti & Oksanen, 1990; Carleton, 1990; Hoffman & Kazmierski, 1969). It was observed on the ordinations of abiotic factors that for several of the sites the vectors of % soil, stability, moisture, and % vegetation cover grouped together as indicators of specific groups of lichens that are frequently found associated with these conditions. Extending the vectors in the opposite direction of the ordination, includes environments that are rocky, loose, dry, and limited in vegetation. In this area of the ordination are lichens that are inversely affected by the environmental vectors: soil, stability, moisture, and vegetation. These lichens are the dry tundra lichens that are more commonly found in alpine areas on rock and solifluction zones.

Few environmental. variables represent clear gradients that can stand alone in ecology studies. Many variables may work together to create an environment that determines which lichens will develop in a particular area. In this study *Solorina crocea* appeared to be an indicator of mesic conditions, as observed in the ordination graphs (Figures 18, 25) and in the cluster analysis where it groups with other hydrophilic lichens. However, for *S. crocea*, aspect seems to be the main factor influencing where the lichen grows, always being on north, northeastern slopes or in areas shaded by ridges. It is highly correlated with snow patches and seepage areas in the alpine. These northerly aspects tend to be the more mesic sites (Whittaker, 1960), where the snow lingers into the summer, the last areas to melt. The northern slopes receive less insolation from the sun, making them cooler locations. In this study where *S. crocea* was found in a more exposed dry tundra site, it was a slope with a northern aspect, indicating that this is a seepage area from a late snowbank.

John (1989, 1990) and John & Dale (1990), examined saxicolous lichen communities in Jonas Rock Slide, and found that no single environmental factor determined the assemblage of lichens within a community. Many of the factors act together to determine the affect of the site or microsite as a whole on a lichen community. This is certainly the case with this study when examining the effects abiotic factors and vegetation on alpine lichen communities. And in the case of Elk Mountain where stability aligns with the factors of slope, pH, and elevation, the geology and topography of the site dictates the structure of the community and the species included.

PLANT FUNCTIONAL GROUP ORDIANTIONS

The observations and analyses of data support the hypothesis that vegetation in alpine areas can have a profound effect on the lichen species richness. Plants can affect the pH and stability of the substrate, and the substrate, in turn, influences lichen establishment (Glew, 1994). Plants also can provide support for lichen attachment or create small clearings between plants where lichens can establish themselves in the soil, as in the case of Cladonias and soil crusts (Kunze, 1980). And, as vegetation decays, it develops into substrate for certain species of lichens such as *Ochrolechia upsaliensis*, *Trapeliopsis granulosa*, and *Lecanora epibryon* (Thomson, 1979; Kunze, 1980; Eversman, 1995).

Both the dry tundra and mesic snow bank sites share some alpine lichen species, such as *Cetraria islandica*, *Stereocaulon glareosum*, and *Cladonia ecmocyna*. But overall the appearance and composition of these two communities are very different for both lichens and vegetation. In these two communities lichen species are determined, to a certain degree, by the presence and type of vegetation. The amount of moisture retained within a community and the solar radiation received also affects both the plants and lichens found in the community (Kunze, 1980; Glew, 1998).

In general, mesic alpine communities have a lower lichen species richness and abundance (percent cover) than the drier tundra sites (Figures 8 and 11; Flock, 1978; Kunze, 1980; Petzold and Mulhern, 1987). This also was reported for forested areas of the Olympic Peninsula (Hoffman, 1971) and boreal Canada in northeast Ontario and western Quebec (Carleton, 1990). Plants in mesic communities may have a competitive advantage over lichens because they are able to grow and reproduce at a faster rate (Kunze, 1980; Carleton, 1990).

This study suggests that luxuriant growth of ericaceous plant suppress lichen communities from developing into a more extensive area. Within the snow bank community, the high vascular plants cover and low lichen cover suggests that lichens do not flourish in these areas. In addition, lichen diversity is lower in these areas compared to the tundra sites. However, some lichen species found in these locations may simply be better able to grow dense vegetation and would not form large colonies in a less competitive community. Kärnefelt (1979) noted that *Tuckermannopsis subalpina* does not do well above tree line in open terrestrial areas where it has to compete with *Cetraria islandica*, and thus remains in the subalpine. *Tuckermannopsis subalpina* depends on vegetation since it is epiphytic. When its substrate is not longer present, the lichen also disappears. *Tuckermannopsis subalpina* is usually restricted to snow bank communities where ericaceous plants, certain woody ground covers (*Luetkea pectinata*), and krummholz trees occur. In this study, *Cetraria islandica* is less abundant in krummholz communities with ericaceous plants, but flourishes and becomes dominant when ericaceous plants are not longer part of the community.

At the Deer Park site, lichen cover increases with vascular plant cover (Figure 28; Kunze, 1980). Most of the lichens found with the vascular plants are fruticose species. Lichens become stabilized in the community, becoming entangled with the vegetation. *Thamnolia* spp. and cetrarioid species can be seen moving about on the bare tundra, under windy conditions (pers. observation). Eventually they are blown into a vegetation patch, where they become established. In some areas of Deer Park and Buckhorn Cirque, these lichens develop into large colonies of a single species that may be 20-30 cm in diameter. These large colonies seem to have some attachment to the humus layer, which further stabilizes them. Even though both of the ordinations for the sites have low eigenvalues for plant group (Deer Park 0.144 and Buckhorn Cirque 0.181) they have significantly positive correlations between lichen cover and plant cover. It may be assumed that the lichens found at these sites have no particular associations with plant groups or species but that the low tundra vegetation provides a foundation or structure in which the lichens become established. This also can be seen for the soil crusts that become established around the base of plants and cryptogams. The soil lichen development seen at Buckhorn Cirque is the highest of all the sites, with over 4% of the total cover as soil crusts.

As the environment becomes exposed and dry in tundra areas, vascular plant cover decreases while lichen cover increases. Lichens acquire moisture from the atmosphere (Blum, 1973), in contrast to vascular plants that are more dependent on soil moisture than lichens (Flock, 1978; Kunze, 1980). It is possible that lichens are abundant in extreme environments because they are better adapted to areas where vascular plants do not prosper, such as dry tundra communities (Carleton, 1990). Lichens are able to establish themselves on bare stable substrates and can occupy much of the available space. Furthermore, many of the dry tundra areas are predominately rock, limiting suitable substrate for vascular plants. In these communities lichen cover will increase, especially saxicolous lichen species, adapted to establishing themselves on rock surfaces.

Ordination analyses were performed with lichens to include individual plant species as environmental data. Because there are so many plant species at each site (25-50), this analysis proved to be complicated, revealing a decrease in correlation values between ordination axes and environmental variables (plant species variables). A potential problem occurs with a large number of environmental variables. Occasionally large values of a correlation coefficient will appear, when in reality, there may be no fundamental biological significance to the number (McCune & Mefford, 1995). Placing the plants into functional categories reduced the number of variables, increased correlation values and diminished the probability of deceiving analyses.

Phyllodoce empetriformis, *P. glanduliflora*, *Cassiope mertensiana* and *Vaccinium deliciosum*, are dominant plants in the mesic snow bank communities, forming mats and woody shrub structures. These ericaceous plants form dense mats that can prevent lichen establishment. However, from the CCA analysis (Figures 36, 37, 38), *Tuckermannopsis subalpina*, *Trapeliopsis granulosa*, *Solorina crocea*, *Lepraria cacuminum*, *Leprocaulon subalbicans*, *Cladina mitis*, *Cladonia squamosa*, *C. bellidiflora*, *C. ecmocyna* and *Cladonia* spp. are commonly found among these plants. These lichens and plants typify the vegetation found in acidic, mossy, and moist (water shedding areas from late-melting snow banks) communities that have north-northeast facing aspects. The plant functional groups from these areas appeared to have a higher association with certain lichen groups than the dry tundra sites.

The xeric tundra sites are more likely to have lichens such as *Thamnolia vermicularis*, *T. subuliformis* and cetrarioid lichens entangled in the vegetation. In Washington's alpine locations, these lichens rarely appear on the landscape unless some kind of vegetation has developed (Figures 33, 34, 35). Some of the matted or tufted vascular plants, such as *Phlox diffusa*, *P. hendersonii*, *Lupinus lepidus*, *Eriogonum ovalifolium*, *E. pyrolifolium*, *Synthris pinnatifida*, *Selaginella wallacei* and *Arenaria capillaris*, provide substrate support for lichen fragments to establish themselves. Where this occurs, lichen abundance follows plant patterns demonstrating a positive relationship between the two groups (Figures 27, 28; Kunze, 1980). From this study there does not appear to be a strong association between most lichen species and individual plant species at the tundra sites. In addition, lichen communities also are independent of the plant species used for support, but are dependent on certain structural groupings of plants that provide a foundation in which the lichens can become established. Thus, lichen communities do not always follow the same patterns as plant communities. This study shows that when plant species and communities change along the landscape, but the structure of the plants remains the same, the lichen community is able to remain constant without changing its composition.

Cladina mitis and *Peltigera* spp., found at both mesic snow bank sites and dry tundra sites, occur more in open spaces between plants and in areas where the soil is stable. Frequently other lichens, such as soil crusts or *Cladonia* spp. assist with the stability of the soil. These soil crusts in turn can aid in the prevention of soil erosion (St. Clair and Johansen, 1993; Rosentreter, 1995) and vascular plant seedling establishment (St. Clair and Johansen, 1993).

Unquestionably abiotic factors such as aspect, slope, elevation, moisture, and substrate pH are important in determining the composition of alpine lichen communities. It is less clear how soil pH may influence which species of epiphytic lichens are found on plants. Lichen communities have specific requirements that determine their development. Not only are abiotic factors important in determining lichen distributions, but the structure of vegetation within a community has a dramatic effect on lichen distributions as well. Lichen communities, their diversity, and abundance are greatly influenced by the structure of vascular plant community. In addition to examining the influence of a single plant or group of plants on lichen communities, the plant community as a whole needs to be studied in detail. This includes the edaphic factors of the soil, climate, geology, age of the area, as well as lichens interactions with each other. These factors will aid in the determination of how plant structure influences the composition of lichens found within a community.

CHAPTER 5: CONCLUSIONS

This study has significantly advanced the knowledge of alpine lichens in Washington state. Over 170 lichen species comprising 71 families were identified from approximately 1500 collections made over a period of nine years. A number of species, especially the crustose forms, are yet to be determined. No doubt some additional species will be discovered at the sites. Taxonomic documentation of the Washington alpine lichen flora provides information for future taxonomic studies. It is clear from this investigation that the diverse habitats of Washington alpine areas have influenced the species found at each site, as well as their frequency and abundance.

Although the number of alpine sites in this study was relatively small, the detailed research done at the site level improved our knowledge of alpine lichen communities. Lacking from previous studies has been information on the abundance of specific lichens by site and the impact of moisture regimes on alpine lichen communities. Also included here is the frequency of lichens found based on transects. This coupled with analyses of environmental factors has provided information indicating factors that are important at the site and quadrat level. For example, elevation is important at the site level in relation to distance above treeline and climatic influences such as snow levels. At the transect level, substrate and aspect are factors affecting the lichens found within the sites. The associated vegetation also influences the lichens found along these transects. South and southwest facing slope were more typically fell fields with higher lichen species richness. Distributions within the quadrat demonstrate that microhabitat preferences (i.e. soil vs. rock, soil/rock pH, stability of the substrate) exist for many lichens, especially the soil crusts (Ahti & Oksanen, 1990; Canters et al.; Hammer, 1996).

The type of vegetation within a site affects the species composition found in lichen communities, as well as the percent cover of lichens. Two major assemblages of vegetation predominated in the alpine, dry tundra communities and mesic snow bank communities. Lichen communities found in the mesic areas tended to have a much lower species richness and cover. In the dry tundra communities, lichens displayed a higher diversity and percent cover. Vegetation and rock outcrops at the drier sites provided more microhabitats that increased the diversity. Some of the low lichen diversity in the mesic areas was related to the well-developed ericaceous mats and shrubs that seemed to lower lichen richness and cover.

Substrate appeared to be a main factor influencing lichen communities within the sites. Certainly the preference for lichens to occur on rock or soil was evident, as was the positive association of certain lichens with plant cover. Buckhorn Cirque and Deer Park were areas where lichens became established once the plant communities or patches were established in the area. Other sites, Tatie Peak and Skyline Divide mesic transects, had a negative correlation between lichens and other vegetation. These latter sites also displayed a lower lichen diversity that seemed to be related to the high cover of the vascular plants.

It is noteworthy that in Scandinavian countries, where lichens and ericaceous plants coincide, the vascular plants do not seem to be a detriment to lichens (Ahti & Oksanen, 1990). For example, heathers are part of the lichen communities, and at the more northern latitudes, may grow more slowly or are not as dense as seen in the North Cascades sites. Therefore, these mats are not directly competing for space with the lichens, as seen in Washington's alpine area.

Within the lichen communities it was observed that macrolichens cover broader areas than vascular plant species. This can be seen both within a site and between sites. Even though the lichen assemblages for the dry tundra sites are fairly consistent in both the Olympic and North Cascade Mountains, the vascular plant species can be quite different. This indicates that the species of plants associated with lichens may not be as important as the assemblage of plants found in these areas. Plant form may provide structural support for some lichens, allowing lichen communities to develop once they become entangled or attached to the plants.

Information from this study indicates that microlichens, are more specific regarding edaphic factors, reflecting the microhabitat conditions of the soil and parent rock material. Microlichens may be more sensitive to variations in edaphic factors than macrolichens (Carleton, 1990; Canters et al., 1991). Microlichens, such as *Ochrolechia upsaliensis* and *Lecanora epibryon* (often on alkaline soils), are frequently omitted from the community studies (Ahti & Oksanen, 1990). These soil crusts may be important indicator species of soil conditions.

This study supports the idea that oceanic influences and continentality affect lichen distributions. It was observed that some lichen species, especially within the genus *Umbilicaria*, were found more often, if not exclusively, in either the Olympic or North Cascades sites. Species richness also appears to be influenced by maritime conditions. Those sites with oceanic affinities had higher species richness and cover than those sites found on the eastern slopes of the Cascade Mountains. Additional sites in the Cascade and Olympic Mountains are in need of investigation to determine if this observation holds true.

Historical factors, including geological events, are likely to be important. Both the Cascade and Olympic Mountains are relatively young in comparison to the Rocky Mountains and had less time to develop alpine lichen communities. The small size of the alpine areas in Washington (compared to the Rocky Mountains) also restricts the diversity of lichens within the communities. In addition, the existence of refugia in the northeastern Olympic Mountains may explain the complexity of these lichen communities compared with the North Cascades sites. Olympic sites that were not covered with ice had undoubtedly more time to develop lichen communities than the North Cascades sites. Unlike the Rock Mountains that have connections to arctic communities, the mountain ranges in Washington have little contact with those lichens with arctic affinities. Those alpine areas of the state that were exposed in the last ice age would have remnant populations to contribute to the diversity found at those sites.

Some of the limitations of the study revolve around the analyses of the data and the selection and measurement of environmental factors. For example, abiotic factors were determined *a priori* and were based on alpine studies dealing mainly with vascular plants. Hence, factors determining lichen distributions may not be the same as those influencing the occurrence of vascular plants. Direct gradient analyses (CCA) perform better with measurable factors (McCune, 1997). In addition, some environmental factors such as historical events cannot easily be accounted for in these analyses (McCune & Allen, 1985). Other factors are difficult to measure or may require equipment that is cumbersome to bring into the field.

The information provided here contributes basic knowledge useful in future studies involving Washington's alpine lichens. Lichen populations and communities provide important information about our environment in terms of air quality and edaphic conditions. With global warming becoming a major concern, monitoring alpine communities is essential. Many of the lichens found at higher elevations could be eliminated if temperatures increased. Examining any turnover or changes in lichen species composition in these communities could indicate significant global climate changes. More work needs to be done in alpine regions to provide better understanding of the conditions that affect lichen site selection and the development of lichen species composition within an alpine community.

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APPENDIX A: TRANSECT DATA

Location	Transect Series	Direction of transect line	Aspect	Slope (degrees)	Elevation (meters)	Mountain Range	pH
Buckhorn Cirque	E	120 SE x 300 NW	NW	2.5--5	1965 - 1980	Olympics	5.9
Buckhorn Cirque	F	110 SE x 290 NW	NW	8--15	1980 - 2000	Olympics	6
Buckhorn Cirque	G	120 SE x 300 NW	NW	15	2000 - 2025	Olympics	6.5
Buckhorn Cirque	H	121 SE x 300 NW	NW	2	1965 - 1980	Olympics	5.9
Buckhorn Cirque	I	122 SE x 300 NW	NW	8--10	1980 - 2000	Olympics	6.3
Buckhorn Cirque	J	123 SE x 300 NW	NW	10 (15)	2000 - 2015	Olympics	6
Buckhorn Cirque	K	124 SE x 300 NW	NW	0	1980	Olympics	5.2
Buckhorn Cirque	L	125 SE x 300 NW	NW	(1) 12	1980 - 2000	Olympics	5.7
Buckhorn Cirque	M	126 SE x 300 NW	NW	12-15 (20)	2000 - 2015	Olympics	5.8
Deer Park, Blue Mt.	A	270 W x 90 E	W	20	1815 - 1830	Olympics	6.7
Deer Park, Blue Mt.	B	230 SW x 50 NE	SW	20	1800 - 1815	Olympics	6.5
Deer Park, Blue Mt.	C	130 SE x 310 NW	SE	17	1785 - 1700	Olympics	6.6
Deer Park, Deer Ridge	D	210 SW x 30 NE	SW	25 (20,5)	1680 - 1710	Olympics	6
Deer Park, Deer Ridge	E	260 W x 80 E	W	17.5	1740 - 1770	Olympics	6
Deer Park, Deer Ridge	F	180 S x 360 N	S	15	1740 - 1755	Olympics	6.3
Deer Park, Deer Ridge	G	170 S x 350 N	S	10	1710 - 1720	Olympics	6.3
Deer Park, Blue Mt.	H	210 SW x 30 NE	SW	20	1815 - 1800	Olympics	7
Elk Mountain	G	180 S x 360 N	S	22	2030 - 2060	Olympics	6.6
Elk Mountain	H	180 S x 360 N	S	23	2000 - 2030	Olympics	6.3
Elk Mountain	I	200 S x 20 N	S	12	1980 - 2000	Olympics	6.5
Elk Mountain	J	180 S x 360 N	S	12	1955 - 1980	Olympics	6.4
Elk Mountain	K	160 S x 340 N	S	5	2030 - 2045	Olympics	6.3
Elk Mountain	L	180 S x 360 N	S	16.5	1950 - 1980	Olympics	6.4
Elk Mountain	M	200 S x 20 N	S	1, 25	1980 - 2010	Olympics	6.5
Elk Mountain	N	170 S x 350 N	S	17.5, 8	1965 - 1980	Olympics	6

Location	Transect Series	Direction of transect line	Aspect	Slope (degrees)	Elevation (meters)	Mountain Range	pH
Skyline Divide	A	100 E x 280 W	E	20	1815 - 1830	North Cascades	5
Skyline Divide	B	280 W x 100 E	W	20	1905 - 1920	North Cascades	4.6
Skyline Divide	C	60 NE x 240 SW	NW	5, 10, 5	1920	North Cascades	4.6
Skyline Divide	D	300 NW x 120 SE	NW	15	1875 - 1890	North Cascades	4.3
Skyline Divide	E	20 NE x 200 SW	NW	0	1875	North Cascades	4.3
Skyline Divide, tundra	F	170 S x 350 N	S	15, 3	1980 - 1995	North Cascades	5.2
Skyline Divide, tundra	G	240 SW x 60 NE	SW	20	1980 - 1995	North Cascades	5
Skyline Divide, tundra	H	210 SW x 30 NE	SW	20	1980 - 1995	North Cascades	4.8
Skyline Divide, tundra	I	0 N x 180 S	N	10	1935 - 1950	North Cascades	5.9
Slate Peak, ridge	A	320 NW x 140 SE	W, SW	30	2165	North Cascades	6.2
Slate Peak	B	44 NE x 226 SW	ENE	27	2135 -2165	North Cascades	5.1
Slate Peak	C	80 E x 260 W	E	11	2120 - 2135	North Cascades	4.6
Slate Peak	D	320 NW x 140 SE	NW	6	2165	North Cascades	5.2
Slate Peak, ridge	E	320 NW x 140 SE	W, SW	30	2165	North Cascades	6.1
Slate Peak	F	10 N x 190 S	NE	8	1965 - 1980	North Cascades	5.2
Slate Peak, ridge	G	240 SW x 60 NE	SW	30	2120 - 2135	North Cascades	5.9
Slate Peak, ridge	H	250 W x 70 E	SW	25	2150 - 2165	North Cascades	5.9
Tatie Peak, ridge	A	10 N x 190 S	N	30, (20,25)	2090 - 2105	North Cascades	4.8
Tatie Peak	B	30 N x 210 S	N	25	2040 - 2060	North Cascades	4.9
Tatie Peak	C	40 NE x 220 SW	NE	20, 10	2040 -2055	North Cascades	4.6
Tatie Peak	D	110 ESE x 290 WNW	NE	10	2045	North Cascades	4
Tatie Peak	E	90 E x 270 W	E	0, 30	2075 - 2090	North Cascades	5.3
Tatie Peak	F	330 NW x 150 SE	NW	5	2040	North Cascades	5.1
Tatie Peak	G	30 NE x 210 SW	NE	(15) 5	2075	North Cascades	4.8
Tatie Peak, ridge	H	280 W x 100 E	N	20	2100	North Cascades	4.9

Location	Transect Series	Transect number	Latitude and Longitude	
			high point	low point
Buckhorn Cirque	E	1	47°49'33"N 123°07'41"W	47°49'36"N 123°07'48"W
Buckhorn Cirque	F	2	47°49'32"N 123°07'40"W	47°49'33"N 123°07'41"W
Buckhorn Cirque	G	3	47°49'30"N 123°07'38"W	47°49'32"N 123°07'40"W
Buckhorn Cirque	H	4	47°49'35"N 123°07'46"W	47°49'38"N 123°07'45"W
Buckhorn Cirque	I	5	47°49'32"N 123°07'37"W	47°49'35"N 123°07'46"W
Buckhorn Cirque	J	6	47°49'30"N 123°07'38"W	47°49'32"N 123°07'37"W
Buckhorn Cirque	K	7	47°49'31"N 123°07'43"W	47°49'34"N 123°07'48"W
Buckhorn Cirque	L	8	47°49'29"N 123°07'44"W	47°49'31"N 123°07'43"W
Buckhorn Cirque	M	9	47°49'27"N 123°07'42"W	47°49'29"N 123°07'44"W
Deer Park, Blue Mt.	A	10	47°57'19"N 123°15'35"W	47°57'20"N 123°15'38"W
Deer Park, Blue Mt.	B	11	47°57'17"N 123°15'36"W	47°57'17"N 123°15'39"W
Deer Park, Blue Mt.	C	12	47°57'17"N 123°15'32"W	47°57'14"N 123°15'28"W
Deer Park, Deer Ridge	D	13	47°56'57"N 123°15'04"W	47°57'53"N 123°15'06"W
Deer Park, Deer Ridge	E	14	47°56'55"N 123°14'44"W	47°55'54"N 123°14'50"W
Deer Park, Deer Ridge	F	15	47°56'54"N 123°14'57"W	47°56'53"N 123°14'56"W
Deer Park, Deer Ridge	G	16	47°57'00"N 123°15'24"W	47°56'59"N 123°15'22"W
Deer Park, Blue Mt.	H	17	47°57'15"N 123°15'36"W	47°57'14"N 123°15'36"W
Elk Mountain	G	18	47°55'30"N 123°21'09"W	47°55'25"N 123°21'05"W
Elk Mountain	H	19	47°55'23"N 123°21'05"W	47°55'26"N 123°21'13"W
Elk Mountain	I	20	47°55'25"N 123°21'28"W	47°55'24"N 123°21'25"W
Elk Mountain	J	21	47°55'24"N 123°21'35"W	47°55'22"N 123°21'37"W
Elk Mountain	K	22	47°55'29"N 123°21'42"W	47°55'33"N 123°21'43"W
Elk Mountain	L	23	47°55'28"N 123°21'42"W	47°55'25"N 123°21'42"W

Location	Transect Series	Transect number	Longitude and Latitude	
			high point	low point
Elk Mountain	M	24	47°55'34"N 123°22'13"W	47°55'29"N 123°22'13"W
Elk Mountain	N	25	47°55'29"N 123°22'13"W	47°55'28"N 123°22'16"W
Skyline Divide	A	26	48°51'11"N 120°50'59"W	
Skyline Divide	B	27	48°50'39"N 121°51'18"W	
Skyline Divide	C	28	48°50'38"N 121°51'20"W	
Skyline Divide	D	29	48°50'29"N 121°51'13"W	
Skyline Divide	E	30	48°50'29"N 121°51'13"W	
Skyline Divide, tundra	F	31	48°50'15"N 121°51'15"W	48°50'12"N 121°51'15"W
Skyline Divide, tundra	G	32	48°50'17"N 121°51'21"W	
Skyline Divide, tundra	H	33	48°50'31"N 121°51'30"W	
Skyline Divide, tundra	I	34	48°50'07"N 121°51'11"W	48°50'02"N 121°51'10"W
Slate Peak, ridge	A	35	48°44'08"N 120°40'38"W	48°44'11"N 120°40'40"W
Slate Peak	B	36	48°44'08"N 120°40'38"W	48°44'13"N 120°40'32"W
Slate Peak	C	37	48°44'34"N 120°40'41"W	48°44'30"N 120°40'33"W
Slate Peak	D	38	48°44'08"N 120°40'38"W	48°44'11"N 120°40'40"W
Slate Peak, ridge	E	39	48°44'08"N 120°40'38"W	48°44'11"N 120°40'40"W
Slate Peak	F	40	48°44'16"N 120°40'25"W	48°44'13"N 120°40'20"W
Slate Peak, ridge	G	41	48°44'17"N 120°40'44"W	48°44'20"N 120°40'45"W
Slate Peak, ridge	H	42	48°44'08"N 120°40'40"W	48°44'09"N 120°40'48°"W
Tatie Peak, ridge	A	43	48°41'45"N 120°41'14"W	
Tatie Peak	B	44	48°41'37"N 120°42'26"W	
Tatie Peak	C	45	48°41'33"N 120°42'22"W	
Tatie Peak	D	46	48°41'33"N 120°42'22"W	
Tatie Peak	E	47	48°41'34"N 120°42'22"W	

Location	Transect Series	Transect number	high point Longitude and Latitude low point
Tatie Peak	F	48	48°40'32"N 120°43'05"W
Tatie Peak	G	49	48°41'34"N 120°42'22"W
Tatie Peak, ridge	H	50	48°41'44"N 120°41'14"W

APPENDIX B: LICHEN SPECIES FOUND BY SITE

SPECIES	**EM**	**BC**	**DP**	**SD**	**TP**	**SP**
Acarospora fuscata (Schrader) Arnold	X		X	X	X	
Adelolecial pilati (Hepp) Hertel & Hafellner	X					
Ahtiana sphaerosporella (Müll. Arg.) Goward*		X			X	X
Alectoria nigricans (Ach.) Nyl.	X	X	X	X	X	
Alectoria ochroleuca (Hoffm.) A. Massal.			X	X		
Alectoria sarmentosa (Ach.) Ach.*			X	X		
Alectoria sarmentosa subsp. *vexillifera* (Nyl.) D. Hawksw.						X
Allantoparmelia alpicola (Th. Fr.) Essl.	X			X		
Arthrorhaphis citrinella (Ach.) Poelt				X		
Aspcilia caesiocinerea (Nyl. *ex* Malbr.) Arnold	X	X	X	X	X	
Aspcilia candida (Anzi) Hue					X	
Aspicila cf. contorta(Hoffm.) Kremp.	X					
Bellemerea alpina (Sommerf.) Clauzade & Roux			X	X	X	X
Bellemerea cinereorufescens (Ach.) Clauzade & Roux		X	X	X	X	X
Bellemerea subsorediza (Lynge) R. Sant.				X	X	X
Brodoa oroarctica (Krog) Goward	X	X	X	X	X	
Bryoria capillaris (Ach.) Brodo & D. Hawksw.*						X
Bryoria chalybeiformis (L.) Brodo & D. Hawksw.	X	X	X	X		
Bryoria fremontii (Tuck.) Brodo & D. Hawksw.*					X	X
Bryoria fuscescens (Geylnik) Brodo & D. Hawksw.*		X	X			
Bryoria glabra (Mot.) Brodo & D. Hawksw.*			X			
Bryoria pseudofuscescens (Gyel.) Brodo & D. Hawksw.*						X
Bryoria trichodes (Michaux) Brodo & D. Hawksw.*			X			
Buellia geophila (Flörke *ex* Sommerf.) Lynge		X				
Caloplaca ammiospila (Wahlenb.) H. Olivier		X				
Caloplaca dispersa (Pers.) Sommerf.			X			
Caloplaca epithallina Lynge	X					
Caloplaca lamprocheila (D.C) Flag.			X			
Caloplaca jungermanniae (Vahl.) Th. Fr.						X
Caloplaca saxicola (Hoffm.) Nordin			X			
Caloplaca tiroliensis Zahlbr.	X	X	X			
Candelariella aurella (Hoffm.) Zahlbr.			X			
Candelariella terrigena Räsänen		X				

SPECIES	**EM**	**BC**	**DP**	**SD**	**TP**	**SP**
Candelariella vitellina (Hoffm.) Muell. Arg.	X	X	X	X		X
Catapyrenium					X	
Cetraria aculeatum (Schreber) Fr.	X	X		X		X
Cetraria ericetorum Opiz	X	X	X	X	X	X
Cetraria islandica (L.) Ach.	X	X	X	X	X	X
Cetraria muricatum (Ach.) Eckfeldt	X	X	X	X		X
Cladina arbuscula (Wallr.) Hale and Culb.	X	X				
Cladina mitis (Sandst.) Hustich	X	X	X	X	X	X
Cladonia bellidiflora (Ach.) Schaerer				X		
Cladonia borealis Stenroos			X			
Cladonia cariosa (Ach.) Spreng.		X				
Cladonia carneola (Fr.) Fr.	X		X	X	X	X
Cladonia chlorophaea (Flörke *ex* Sommerf.) Sprengel			X			X
Cladonia ecmocyna Leighton	X	X	X	X	X	X
Cladonia fimbriata (L.) Fr.						X
Cladonia gracilis (L.) Willd.	X			X		
Cladonia macroceras (Delise) Ahti	X	X		X	X	X
Cladonia macrophyllodes Nyl.	X	X	X	X	X	
Cladonia pleurota (Flörke) Schaerer				X		
Cladonia pocillum (Ach.) Grognot	X		X			X
Cladonia pyxidata (L.) Hoffm.	X		X			
Cladonia singularis Hammer				X		
Cladonia squamosa Hoffm.				X		
Coccocarpia sp.		X				
Cornicularia normoerica (Gunn.) Du Rietz	X		X	X		X
Dermatocarpon luridum (With.) J.R. Laundon †					X	X
Dermatocarpon reticulatum H. Magn.		X			X	X
Dermatocarpon rivulorum (Arn.) Dalla Torre & Sarnth.					X	X
Diploschistes muscorum (Scop.) Sant.				X		
Flavocetraria cucullata (Bellardi) Kärnefelt & Thell	X	X	X			X
Flavocetraria nivalis (L.) Kärnefelt & Thell	X	X	X	X		X
Hypogymnia austerodes (Nyl.) Räsänen	X					
Hypogymnia imshaugii Krog						X
Hypogymnia rugosa (G. Merr.) L. Pike*			X			
Lecanora bicincta Ramond	X	X	X		X	X
Lecanora cavicola Creveld					X	
Lecanora dispersa (Pers.) Sommerf.			X	X		
Lecanora epibryon (Ach.) Ach.		X				

SPECIES	EM	BC	DP	SD	TP	SP
Lecanora hagenii (Ach.) Ach.		X	X	X	X	
Lecanora intricata (Ach.) Ach.	?	?	?		?	?
Lecanora leucothallina Arnold	X					
Lecanora malaena (Hedl.) Fink	X					
Lecanora polytropa (Hoffm.) Rabenh.	X	X	X	X	X	X
Lecanora rupicola (L.) Zahlbr.	X	X	X			
Lecidea atrobrunnea (Ramond *ex* Lam. & DC.) Schaerer	X	X	X	X	X	X
Lecidea cf. atrobrunnea (*L. praenubila* Nyl.)	X					
Lecidea atromarginata H.Magn.						X
Lecidea cascadensis H. Magn.	X					X
Lecidea contraponenda (Arnold) Knoff. & Hertel				X		
Lecidea lapicida (Ach.) Ach.		X		X		
Lecidea leucothallina Arnold	X					
Lecidea tessellata Flörke	X	X	X		X	X
Lecidella wulfenii (Hepp) Körber		X				
Lecidoma demissum (Rutstr.) Gotth. Schneider & Hertel	X	X		X	X	
Lepraria cacuminum (Massal.) Lohtander	X	X	X	X	X	X
Lepraria incana (L.) Ach.						X
Lepraria neglecta (Nyl.) Erichsen	X			X		
Leprocaulon microscopium (Vill.) Gams *ex* D. Hawksw.					X	
Leprocaulon subalbicans (Lamb) Lamb & Ward	X			X	X	
Letharia columbiana (Nutt.) J.W. Thomson*		X			X	
Letharia vulpina (L.) Hue	X	X			X	X
Lobaria linita (Ach.) Rabenh.				X		
Massalongia carnosa (Dicks) Körber					X	
Megaspora verrucosa (Ach.) Haffelner and V. Wirth	X	X				
Melanelia commixta (Nyl.) Thell	X	X		X		X
Melanelia disjuncta (Erichsen) Essl.	X	X				
Melanelia exasperatula (Nyl.) Essl.	X			X		
Melanelia hepatizon (Ach.) Thell		X				X
Melanelia infumata (Nyl.) Essl.	X			X		
Melanelia panniformis (Nyl.) Essl.	X					
Melanelia sorediata (Ach.) Goward & Ahti	X	X		X		X
Melanelia stygia (L.) Essl.	X	X	X	X		
Mycobilimbia sabuletorum (Schreber) Hafellner		X				
Mycoblastus affinis (Schaerer) Schauer				X		
Mycoblastus sanguinarius (L.) Norman			X			
Nodobryoria abbreviata (Müll. Arg.) Commons & Brodo*		X			X	X

SPECIES	**EM**	**BC**	**DP**	**SD**	**TP**	**SP**
Ochrolechia upsaliensis (L.) A. Mass.	X	X	X	X		
Ophioparma lapponica (Räsänen) Hafellner & R. W. Rogers	X		X			
Pannaria pezizoides (Weber) Trevisan		X				
Parmelia saxatilis (L.) Ach.	X			X		
Parmeliopsis ambigua (Wulfen) Nyl.*						X
Parmeliopsis hyperopta (Ach.) Arnold*			X			X
Peltigera aphthosa (L.) Willd.			X			
Peltigera canina (L.) Willd.						X
Peltigera didactyla (With.) J.R. Laundon	X					
Peltigera kristinssonii Vitik.	X					
Peltigera lepidophora (Vainio) Bitter	X		X		X	
Peltigera malacea (Ach.) Funck	X	X		X	X	X
Peltigera ponojensis Gyelnik	X		X			X
Peltigera praetextata (Flörke *ex* Sommerf.) Zopf						X
Peltigera rufescens (Weiss) Humb.	X	X	X	X	X	X
Phaeophyscia sciastra (Ach.) Moberg	X					
Phaeorrhiza nimbosa (E. Fr.) Mayr. & Poelt		X				
Phylliscum demangeonii(Moug. & Mont.) Nyl.				X		
Physcia caesia (Hoffm.) Fürnr.			X	X		
Physcia callosa Nyl.				X		
Physcia dimidiata (Ach.) Nyl.			?			
Physcia dubia (Hoffm.) Lettau	X		X			
Physcia phaea (Tuck.) J.W. Thomson	X					
Physconia muscigena (Ach.) Poelt	X	X	X	X		
Placynthiella uliginosa (Schrader) Coppins & James	X	X		X		X
Platismatia glauca (L.) Culb. & Culb.*			X			
Polychidium muscicola (Sw.) Gray		X				
Porpidia contraponenda (Arnold) Knoph & Hertel				X		
Porpidia thomsonii Gowan				X		
Protoparmelia badia (Hoffm.) Haffelner					X	X
Pseudephebe minuscula (Nyl. *ex* Arnold) Brodo & D.Hawksw.	X	X	X		X	X
Pseudephebe pubescens (L.) Choisy	X	X	X	X	X	X
Psora globifera (Ach.) A. Massal.				X		
Psoroma hypnorum (Vahl) Gray						X
Rhizocarpon bolanderi (Tuck.) Herre	X		X			
Rhizocarpon disporum (Nägel *ex* Hepp) Müll. Arg.	X					
Rhizocarpon distinctum Th. Fr.						X
Rhizocarpon eupetraeum (Nyl.) Arnold						X

SPECIES	**EM**	**BC**	**DP**	**SD**	**TP**	**SP**
Rhizocarpon geographicum (L.) DC.	X	X	X	X	X	X
Rhizocarpon lecanorinum Anders	X		X			
*Rhizocarpon macrosporum*Räsänen	X					
Rhizocarpon obscuratum (Ach.) A. Massal				X		
Rhizocarpon polycarpum (Hepp) Th.Fr.				X		
Rhizoplaca chrysoleuca (Sm.) Zopf			X			
Rhizoplaca melanopthalma (DC.) Leuckert & Poelt	X	X	X		X	
Rimularia insularis (Nyl.) Rambold & Hertel	X				X	X
Solorina crocea (L.) Ach.		X		X	X	X
Sporastatia polyspora (Nyl.) Grummann				X		
Sporastatia testudinea (Ach.) A. Massal.	X	X		X	X	X
Staurothele drummondii (Tuck.) Tuck.			X		X	X
Staurothele fissa (Taylor) Zwackh						X
Staurothele spp.	X			X		
Stereocaulon alpinum Laur. *ex* Funck		X	X	X	X	X
Stereocaulon glareosum (Savicz) H. Magn.		X		X		X
Stereocaulon rivulorum H. Magn.		X				
Stereocaulon tomentosum Fr.		X				X
Stereocaulon spp.	X	X	X	X	X	X
Tephromela armeniaca (DC.) Hertel & Rambold					X	
Thamnolia subuliformis (Ehrh.) Culb.	X	X	X	X		X
Thamnolia vermicularis (Sw.) Ach. Schaerer	X	X	X	X	X	X
Trapeliopsis granulosa (Hoffm.) Lumbsch		X	X		X	X
Tremolecia atrata (Ach.) Hertel		X		X		
Tuckermannopsis chlorophylla (Willd.) Hale*			X			
Tuckermannopsis merrillii (Du Rietz) Hale*		X			X	X
Tuckermannopsis subalpina (Imshaug) Kärnefelt*		X		X	X	X
Umbilicaria arctica (Ach.) Nyl.				X	X	X
Umbilicaria cylindrica (L.) Delise *ex* Duby						X
Umbilicaria decussata (Vill.) Zahlbr.	X		X	X	X	X
Umbilicaria deusta (L.) Baumg.				X		
Umbilicaria havaasii Llano	X			X		X
Umbilicaria hyperborea (Ach.) Hoffm.	X	X	X	X	X	X
Umbilicaria krascheninnikovii (Savicz) Zahlbr.	X	X	X			X
Umbilicaria proboscidea (L.) Schrader			X	X	X	X
Umbilicaria rigida (Du Rietz) Frey	X	X	X			X
Umbilicaria torrefacta (Lightf.) Schrader	X	X		X		
Umbilicaria vellea (L.) Hoffm.				X		X

SPECIES	**EM**	**BC**	**DP**	**SD**	**TP**	**SP**
Umbilicaria virginis Schaerer		X		X		X
Vulpicida tilesii (Ach.) J.-E. Matts. & M.J. Lai		X				
Xanthoparmelia coloradoënsis (Gyelnik) Hale	X	X	X			
Xanthoparmelia wyomingica (Gyelnik) Hale	X	X	X			
Xanthoria fallax (Hepp.) Arnold			X			
Xanthoria elegans (Link) Th. Fr.	X	X	X	X	X	X
Total lichens at sites	80	81	73	81	50	72
* found in krummholz only						
% found along stream at lower elevation						

APPENDIX C: LICHEN PERCENT COVER AND FREQUENCY FOR EACH SITE

APPENDIX C: Lichen percent cover and frequency for each site. Standard deviation is listed ± after each percent cover value. Frequency is listed in parentheses under percent cover. Frequency is the number of quadrats in which the species occurred, out of 160 quadrats per site (180 quadrats for Buckhorn Cirque (BC) and Skyline Divide (SD)).

Lichen species	**BC**	**DP**	**EM**	**SD**	**SP**	**TP**
Alectoria nigricans			.001 ± .02 (1)	.001 ± .2 (1)		
Alectoria ochroleuca				.01 ± .08 (4)		
Aspicilia spp.			.01 ± .06 (1)			.01 ± .16 (1)
Brodoa oroarctica	.004 ± .06 (1)	.03 ± .22 (3)	.003 ± .04 (1)			
Brown foliose	.004 ± .05 (2)		.01 ± .11 (2)		.001 ± .02 (1)	
Bryoria chalybeiformis	.03 ± .18 (8)	.11 ± 1.44 (1)	.01 ± .05 (3)	.02 ± .16 (4)		
Caloplaca spp.	.22 ± 2.26 (26)	.03 ±.08 (30)	.02 ± .07 (22)		.01 ± .07 (4)	
Candelariella spp.	.31 ± .57 (89)	.46 ± 1.18 (110)	.40 ± .62 (113)	.02 ± .07 (12)	.04 ± .10 (32)	
Cetraria ericetorum	2.64 ± 4.95 (83)	.04 ± .20 (8)	.90 ± 1.79 (68)	2.94 ± 5.65 (78)	.52 ± 1.72 (31)	
Cetraria islandica	6.72 ± 9.82 (119)	1.06 ± 2.48 (63)	1.74 ± 2.85 (96)	1.86 ± 5.43 (46)	.77 ± 3.76 (46)	.50 ± 2.07 (20)
Cetraria muricatum (aculeatum)	1.36 ± 2.43 (78)	1.53 ± 2.59 (84)	1.02 ± 2.07 (67)	.30 ± 1.18 (27)	.04 ± .18 (12)	

Lichen species	BC	DP	EM	SD	SP	TP
Cladina mitis	1.98 ± 3.82 (100)	.92 ± 3.60 (25)	.72 ± 2.19 (46)	11.23 ± 16.54 (117)	.02 ± .15 (6)	.03 ± .29 (3)
Cladonia bellidiflora				.02 ± .18 (2)		
Cladonia borealis		.01 ± .07 (2)				.01 ± .10 (1)
Cladonia carneola	.01 ± .12 (2)	.03 ± .14 (11)	.02 ± .21 (2)	.38 ± 1.53 (47)	.04 ± .27 (13)	.05 ± .42 (7)
Cladonia ecmocyna				.62 ± 2.17 (27)		
Cladonia fimbriata		.01 ± .13 (2)				.001 ± .01 (1)
Cladonia macroceras	.04 ± .33 (5)		.37 ± 2.96 (5)	.62 ± 2.42 (16)		.23 ± 1.24 (10)
Cladonia macrophyllodes		.33 ± .95 (33)	.32 ± 1.04 (33)	.10 ± .48 (14)	.09 ± .43 (11)	.22 ± .59 (33)
Cladonia pyxidata		.17 ± .84 (17)	.01 ± .06 (2)	.01 ± .09 (1)		
Cladonia singularis				.33 ± 1.42 (18)		
Cladonia spp.	4.63 ± 6.89 (147)	1.82 ± 3.21 (80)	1.96 ± 2.71 (115)	2.71 ± 3.72 (126)	1.09 ± 1.94 (80)	.58 ± 1.29 (73)
Cladonia squamosa				.25 ± .77 (34)		
Cornicularia normoerica	.01 ± .06 (4)	.02 ± .23 (1)	.12 ± .54 (16)	.12 ± .71 (8)		

Lichen species	BC	DP	EM	SD	SP	TP
Dermatocarpon reticulatum					.002 ± .03 (1)	
Dimelaena sp.		.002 ± .03 (1)				
Diploschistes muscorum				.02 ± .19 (1)		
Flavocetraria cucullata	3.44 ± 6.84 (88)	.93 ± 2.52 (42)	1.50 ± 2.96 (64)		.03 ± .34 (5)	
Flavocetraria nivalis	1.27 ± 2.94 (84)	.08 ± .46 (10)	.76 ± 1.94 (58)	.03 ± .17 (11)	.02 ± .18 (4)	
Lecanora epibryon		.01 ± .07 (6)				
Lecanora intricata	.01 ± .11 (3)	.05 ± .20 (14)	.03 ± .24 (7)	.09 ± .33 (20)	.02 ± .18 (5)	.40 ± 1.43 (27)
Lecanora polytropa	.54 ± 1.22 (95)	.23 ± .42 (75)	.43 ± .58 (106)	.11 ± .38 (28)	.14 ± .29 (59)	.01 ± .16 (1)
Lecanora spp.	.12 ± .65 (17)		.01 ± .06 (3)		.01 ± .04 (5)	
Lecidea atrobrunnea	.62 ± 2.19 (40)	.29 ± .89 (33)	.30 ± .72 (42)	.06 ± .28 (9)	.92 ± 1.69 (71)	.32 ± .81 (36)
Lecidea tessellata	.004 ± .04 (2)	.01 ± .01 (2)	.004 ± .05 (1)			.09 ± .64 (7)
Lecideine lichens	.13 ± .42 (31)	.04 ± .21 (8)	.20 ± .57 (40)	.13 ± .47 (24)	.26 ± .60 (44)	.07 ± .48 (9)
Lecidoma demissum						.04 ± .41 (3)

Lichen species	BC	DP	EM	SD	SP	TP
Lepraria cacuminum	.26 ± 1.29 (15)		.28 ± 2.64 (15)	.62 ± 2.91 (42)	.89 ± 2.24 (46)	2.20 ± 3.85 (92)
Lepraria incana	.04 ± .53 (1)		.01 ± .07 (4)	.002 ± .03 (1)	.08 ± 1.00 (2)	.08 ± .49 (17)
Leprocaulon subalbicans	.12 ± .65 (5)	.002 ± .03 (1)		.01 ± .06 (5)	.02 ± .08 (17)	.03 ± .19 (10)
Letharia vulpina			.001 ± .02 (1)			
Melanelia commixta	.01 ± .12 (2)	.002 ± .03 (1)	.04 ±.27 (8)	.05 ± .46 (7)	.002 ± .03 (1)	
Melanelia soridiata				.01 ± .04 (2)		
Melanelia stygia	.03 ± .15 (9)	.16 ± 2.80 (3)	.03 ± .14 (11)	.02 ± .17 (4)		
Ochrolechia upsaliensis	1.16 ± 2.72 (74)	1.10 ± 2.95 (49)	.67 ± 1.67 (48)	.12 ± .74 (10)		
Pannaria peziziodes	.01 ± .07 (3)					
Parmelia saxatilis			.001 ± .02 (1)	.01 ± .06 (1)		
Parmelia spp.			.01 ± .12 (3)			
Parmelia squarrosa			.001 ± .02 (1)			
Parmeliopsis ambigua					.001 ± .02 (1)	.001 ± .01 (1)

Lichen species	BC	DP	EM	SD	SP	TP
Parmeliopsis hyperopta			.01 ± .06 (1)		.03 ± .22 (3)	
Peltigera aphthosa						.01 ± .13 (1)
Peltigera canina					.003 ± .04 (1)	
Peltigera kristiansonii	.04 ± .29 (3)		.02 ± .20 (2)			
Peltigera malacea	.02 ± .18 (3)		.04 ± .26 (5)	.21 ± .73 (24)	.06 ± .71 (1)	.001 ± .01 (1)
Peltigera ponojensis		.02 ± .22 (1)	.02 ± .18 (2)			
Peltigera praetextata					.02 ± .22 (1)	
Peltigera rufescens	.83 ± 1.57 (81)	1.53 ± 3.25 (72)	1.23 ± 2.49 (56)	.05 ± .27 (8)	.58 ± 2.03 (37)	
Physcia spp.		.20 ± 6.40 (8)	.01 ± .07 (3)			
Physconia muscigena	.01 ± .06 (8)	.16 ± .60 (25)	.02 ± .08 (10)	.01 ± .05 (3)		
Polychidium muscicola		.002 ± .03 (1)				
Pseudephebe minuscula	.004 ± .03 (3)	.21 ± .67 (24)	1.30 ± 3.78 (48)	.08 ± .43 (13)	.04 ± .22 (7)	.01 ± .05 (2)
Pseudephebe pubescens	.27 ± .95 (28)	.20 ± 1.53 (9)	1.43 ± 3.04 (55)	1.14 ± 3.89 (28)	.19 ± .70 (22)	

Lichen species	BC	DP	EM	SD	SP	TP
Psoroma hypnorum						.01 ± .05 (2)
Rhizocarpon geminatum (grande)		.04 ± .25 (9)			.02 ± .18 (2)	
Rhizocarpon geographicum	.47 ± 1.00 (82)	.16 ± .50 (42)	1.46 ± 2.20 (102)	.53 ± 1.39 (44)	1.29 ± 2.66 (84)	.90 ± 2.83 (48)
Rhizoplaca chrysoleuca		.005 ± .06 (1)				
Rhizoplaca melanopthalma	.003 ± .03 (3)	.09 ±.41 (22)	.01 ± .04 (3)	.002 ± .03 (1)		.001 ± .01 (1)
Rock crusts	4.49 ± 7.31 (120)	2.35 ± 4.05 (107)	8.28 ± 10.91 (135)	2.14 ± 5.56 (54)	3.10 ± 5.26 (97)	2.25 ± 6.44 (57)
Soil crusts	2.55 ± 4.39 (115)	.32 ± .89 (47)	1.43 ± 4.46 (75)	1.77 ± 18.05 (38)	.40 ± 1.81 (43)	.13 ± .71 (20)
Solorina crocea				.32 ± 1.72 (12)	.19 ± 1.00 (9)	.59 ± 2.85 (18)
Stereocaulon spp.	1.11 ± 3.17 (44)		.07 ± .50 (6)	1.05 ± 2.68 (59)	.22 ± 1.29 (18)	
Thamnolia spp.	5.09 ± 7.23 (109)	10.83 ± 11.38 (124)	4.32 ± 6.89 (91)	4.74 ± 7.50 (78)	.34 ± 1.64 (19)	
Trapeliopsis granulosa	.004 ± .06 (1)		.01 ± .09 (5)	.41 ± 1.39 (31)		.22 ± .94 (22)
Tremolechia atrata				.04 ± .22 (6)		
Tuckermannopsis subalpina				3.07 ± 5.94 (88)	.65 ± 2.81 (24)	1.47 ± 4.94 (55)

Lichen species	BC	DP	EM	SD	SP	TP
Umbilicaria arctica			.01 ± .05 (3)		.02 ± .19 (1)	
Umbilicaria cylindrica					.02 ± .10 (6)	.004 ± .04 (2)
Umbilicaria decussata				.01 ± .08 (1)		
Umbilicaria havaasii			.01 ± .08 (6)		.01 ± .07 (2)	
Umbilicaria hyperborea	.11 ± .53 (18)	.02 ± .14 (4)	2.14 ± 3.98 (75)	.53 ± 1.84 (25)	.20 ± .83 (19)	
Umbilicaria krascheninnikovii		.03 ± .29 (2)	.11 ± .42 (18)			
Umbilicaria proboscidea			.002 ± .02 (1)	.01 ± .06 (1)	.002 ± .03 (1)	
Umbilicaria rigida	.003 ± .03 (2)	.13 ± 1.68 (2)	.58 ± 3.23 (15)			
Umbilicaria spp.	.01 ± .07 (3)	.02 ± .22 (2)	.04 ± .20 (13)	.01 ± .07 (2)	.004 ± .04 (3)	
Umbilicaria torrefacta	.002 ± .03 (1)		.24 ±1.02 (18)	.03 ± .13 (9)		
Umbilicaria vellea				.002 ± .03 (1)	.002 ± .03 (1)	
Umbilicaria virginis					.02 ± .13 (9)	
Vulpicida tilesii	.21 ± .89 (31)					

Lichen species	BC	DP	EM	SD	SP	TP
Xanthoparmelia coloradoënsis	.12 ± .59 (12)	.02 ± .21 (3)	.01 ± .07 (4)			
Xanthoria elegans	.001 ± .01 (1)	.03 ± .13 (12)				

APPENDIX D: LICHEN CODES, GROWTH FORM AND SUBSTRATE

Lichen Codes, Growth Form and Substrate

Lichen Species	**Code**	**Colour**	**Growth Form**	**Substrate**
Acorospora fuscata		4	crustose	rock
Adelolecia pilati		1--2	crustose	rock
Ahtiana sphaerosporella		2	foliose	krummholz subalpine trees
Alectoria nigricans	ALE NIG	2--3	fruticose	vegetation, rocks
Alectoria ochroleuca	ALE OCH	2--4	fruticose	vegetation
Alectoria sarmentosa		2	fruticose	krummholz subalpine trees
Alectoria sarmentosa subsp. *vexillifera*		2	fruticose	soil
Allantoparmelia alpicola		4	foliose	rock
Arthroraphis citrinella		2	leprose	soil
Aspicilia caesiocinerea	ASP SPP	3	crustose	rock
Aspicilia candida		2	crustose	rock
Aspicilia cf. contorta		1--2	crustose	rock
Bellemerea alpina		3	crustose	rock
Bellemerea cinereorufescens		3	crustose	rock
Bellemerea subsorediza		3	crustose	rock
Brodoa oroarctica	BRO ORO	3--4	foliose	rock
Brown foliose	BRN FOL	3	foliose	rock, soil
Bryoria capillaris		4	fruticose	krummholz subalpine trees
Bryoria chalybeiformis	BRY CHA	4	fruticose	vegetation, rocks
Bryoria fremontii		4	fruticose	krummholz subalpine trees
Bryoria fuscescens		4	fruticose	krummholz subalpine trees
Bryoria glabra		4	fruticose	krummholz subalpine trees
Bryoria pseudofuscescens		4	fruticose	krummholz subalpine trees
Bryoria trichodes		4	fruticose	krummholz subalpine trees
Buellia geophila		1	crustose	soil
Caloplaca ammiospila	CAL.SPP	2	crustose	soil
Caloplaca dispersa		3	crustose	rock
Caloplaca epithallina		3	parasitic	on *Rhizoplaca* sp.
Caloplaca jungermanniae		2	crustose	soil
Caloplaca lamprocheila		3	crustose	rock

Lichen Species	**Code**	**Colour**	**Growth Form**	**Substrate**
Caloplaca saxicola		3	crustose	rock
Caloplaca tiroliensis		2	crustose	soil
Candelariella aurella.	CAN SPP	2	crustose	rock
Candelariella terrigena		2	crustose	soil
Candelariella vitellina		2	crustose	rock
Catapyrenium		3	suamulose	soil
Cetraria aculeatum		4	fruticose	vegetation
Cetraria ericetorum	CET ERI	4	fruticose	vegetation
Cetraria islandica	CET ISL	4	fruticose	vegetation
Cetratia muricatum	CET MUR	4	fruticose	vegetation
Cladina arbuscula		1	fruticose	vegetation, graminoids
Cladina mitis		1	fruticose	vegetation, graminoids
Cladina spp.	CLA SPP	1	fruticose	vegetation, graminoids
Cladonia bellidiflora	CLD BEL	2	fruticose	soil, sand, vegetation, humus
Cladonia borealis	CLD BOR	1--2	fruticose	thin soil
Cladonia cariosa		2	fruticose	thin soil, rich humus
Cladonia carneola	CLD CAR	1	fruticose	soil, rotten wood
Cladonia chlorophaea		2	fruticose	thin soil, organic
Cladonia ecmocyna subsp. *ecmocyna*		2	fruticose	thin soil
Cladonia ecmocyna subsp. *intermedia*	CLD ECM	2	fruticose	thin soil
Cladonia ecmocyna subsp. *macroceras*	CLD MCR	2--3	fruticose	soil
Cladonia fimbriata	CLD FIM	2	fruticose	soil, mossy rocks
Cladonia gracilis		2--3	fruticose	soil, decaying wood
Cladonia macrophyllodes	CLD MAC	1--2	fruticose	soil, rock crevices
Cladonia pleurota		2	fruticose	rotting wood or duff
Cladonia pocillum		3	fruticose	thin soil or duff
Cladonia pyxidata	CLD PYS	2	fruticose	soil
Cladonia singularis	CLD SIN	3	fruticose	thin soil, vegetation (moss)
Cladonia squamosa	CLD SQU	2	fruticose	soil, duff, vegetation
Cladonia spp.	CLD SPP	1--3	fruticose	soil, vegetation
Coccocarpia		3	squamulose	soil
Cornicularia normoerica	COR NOR	5	fruticose	rock
Dermatocarpon luridum		4	foliose	rock
Dermatocarpon reticulatum	DER RET	4	foliose	rock
Dermatocarpon rivulorum		4	fruticose	rock
Dimelaena sp.	DIMELA	2	crustose	rock
Diploschistes muscorum	DIPLOS	2	crustose	moss, soil, rock

Lichen Species	**Code**	**Colour**	**Growth Form**	**Substrate**
Flavocetraria cucullata	FLA CUC	1	fruticose	vegetation
Flavocetraria nivalis	FLA NIV	1	fruticose	vegetation
Hypogymnia austerodes		3	foliose	rock
Hypogymnia imshaugii		3	foliose	tree, krummholz
Hypogymnia occidentalis		2	foliose	tree, krummholz
Hypogymnia rugosa		2--3	foliose	tree branch, epiphytic
Lecanora bicincta		1	crustose	rock
Lecanora cavicola		4	crustose	rock
Lecanora dispersa		1--2	crustose	rock
Lecanora epibryon	LEC EPI	1	crustose	moss, vegetation
Lecanora hagenii		1--2	crustose	rock
Lecanora intricata	LEC INT	1	crustose	rock
Lecanora cf. leucothallina		2	crustose	rock
Lecanora malaena		4	crustose	rock
Lecanora polytropa	LEC POL	1	crustose	rock
Lecanora rupicola		1	crustose	rock
Lecanora spp.	LEC SPP		crustose	rock
Lecidea atrobrunnea	LCI ATR	4	crustose	rock
Lecidea atromarginata		1--2	crustose	rock
Lecidea cascadensis		4	crustose	rock
Lecidea lapicida		1--2	crustose	rock, red thallus
Lecidea praenubila		3	crustose	rock
Lecidea tessellata	LCI TES	1	crustose	rock, sandstone
Lecideine lichens	LCI LIC		crustose	rock
Lecidella wulfenii		1	crustose	rock
Lecidoma demissum	LEC DEM	4	crustose	soil
Lepraria cacuminum	LEP CAC	1	leprose	soil
Lepraria incana	LEP INC	1	leprose	soil
Lepraria neglecta		1	leprose	rock
Leprocaulon subalbicans	LEP SUB	1	fruticose	soil
Leprocaulon microscopium		1	leprose	soil
Leptogium sp.		4	fruticose	soil
Letharia columbiana		2	fruticose	epiphytic, high elevations, subalpine,
Letharia vulpina	LET VUL	2	fruticose	vegetation
Massalongia carnosa		3	foliose	moss over rock
Megaspora verrucosa		2	crustose	soil
Melanelia commixta	MEL COM	5	foliose	rock, sandstone

Lichen Species	**Code**	**Colour**	**Growth Form**	**Substrate**
Melanelia disjuncta		4--5	foliose	rock
Melanelia exasperatula		4	foliose	rock
Melanelia hepaitzon		5	foliose	rock
Melanelia infumata		4--5	foliose	rock
Melanelia panniformis		4--5	foliose	rock
Melanelia sorediata	MEL SOR	5	foliose	rock
Melanelia stygia	MEL STY	5	foliose	rock, sandstone
Mycobilimbia sabuletorum		3--5	crustose	rock
Mycoblastus affinis		2	crustose	rock
Mycoblastus sanguinarius		2	crustose	tree
Neofuscelia sp.		4	foliose	rock
Nodoryoria abbreviata	NOD ABB	5	fruticose	epiphytic, krummholz, subalpine trees
Ochrolechia upsaliensis	OCH UPS	1	crustose	soil
Ophioparma lapponica		1--2	crustose	rock
Pannaria peziziodes	PAN PEZ	4	foliose	soil
Parmelia saxatilis	PAR SAX	2--3	foliose	rock
Parmelia spp.	PAR SPP	3	foliose	rock, soil
Parmelia squarrosa	PAR SQU	3--4	foliose	rock
Parmeliopsis ambigua	PRP AMB	1	foliose	epiphytic, krummholz
Parmeliopsis hyperopta	PRP HYP	1	foliose	epiphytic, krummholz
Peltigera aphthosa	PEL APH	3	foliose	soil, humus, rocks
Peltigera britannica		3	foliose	soil, mossy rocks
Peltigera canina	PEL CAN	3	foliose	soil, rocks
Peltigera didactyla		3	foliose	soil, moss
Peltigera kristinssonii		3	foliose	soil
Peltigera lepidophora		3	foliose	soil, moss
Peltigera malacea	PEL MAL	3	foliose	soil, moss, vegetation
Peltigera ponojensis	PEL PON	3	foliose	soil
Peltigera praetextata	PEL PRA	3	foliose	soil
Peltigera rufescens	PEL RUF	3	foliose	soil, begetation
Peltigera scabrosa	PEL SCA	3	foliose	soil, moss
Phaeophyscia sciastra		3	foliose	rock, moss over rock
Phaeorrhiza nimbosa		2--3	squamulose	soil, moss, detritus
Phylliscum demangeonii		5	foliose	siliceous rock
Physcia caesia		1--3	foliose	rock
Physcia callosa		1--3	foliose	rock, moss over rock
Physcia dubia		1--3	foliose	rock, moss over rock

Lichen Species	**Code**	**Colour**	**Growth Form**	**Substrate**
Physcia phaea		1--3	foliose	rock, moss over rock
Physcia spp.	PHY SPP	2	foliose	rock
Physconia muscigena	PHC MUS	3	foliose	soil
Placynthiella uliginosa		4--5	crustose	soil
Platismatia glauca		2--3	foliose	trees
Polychidium muscicola	POL MUS	5	fruticose	moss
Porpidia contraponenda		1	crustose	rock
Porpidia thomsonii		1--2	crustose	rock
Protoparmelia badia		4	crustose	rock
Pseudephebe minuscula	PSE MIN	5	fruticose	rock
Pseudephebe pubescens	PSE PUB	5	fruticose	rock
Psora globifera		4	squamulose	soil
Psoroma hypnorum	PSO HYP	4	foliose	soil
Rhizocarpon bolanderi		4	crustose	rock
Rhizocarpon disporum		4	crustose	rock
Rhizocarpon distinctum		1--3	crustose	rock
Rhizocarpon eupetraeum		3	crustose	rock
Rhizocarpon geminatum (grande)?	RHI GEM	4	crustose	rock
Rhizocarpon geographicum	RHI GEO	1--2	crustose	rock
Rhizocarpon lecanorinum		1--2	crustose	rock
Rhizocarpon macrosporum		3	crustose	rock
Rhizocarpon obscuratum		2--3	crustose	rock
Rhizocarpon polycarpum		3	crustose	rock
Rhizoplaca chrysoleuca	RHP CHR	2	crustose	rock
Rhizoplaca melanopthalma	RHP MEL	2	foliose	rock
Rimularia insularis		4	crustose	parasitic
Rinodina sp.		3	crustose	rock
Rock crusts	ROCKCR		crustose	rock
Soil crusts	SOILCR		crustose	soil
Solorina crocea	SOL CRO	3	foliose	soil
Sporastatia polyspora		4	crustose	rock
Sporastatia testudinea		4	crustose	rock
Staurothele drummondii		3--4	crustose	rock
Staurothele fissa		3--4	crustose	rock
Stereocaulon alpinum		1	fruticose	soil, vegetation
Stereocaulon glareosum		1	fruticose	soil, vegetation
Stereocaulon rivulorum		1	fruticose	soil, vegetation

Lichen Species	**Code**	**Colour**	**Growth Form**	**Substrate**
Stereocaulon tomentosum		1	fruticose	soil, vegetation
Stereocaulon - white and gray	STE SPP	1	fruticose	soil, vegetation
Tephromela armeniaca		4	crustose	rock
Thamnolia spp.	THA SPP	1	fruticose	vegetation, soil
Thamnolia subuliformis	THA SUB	1	fruticose	vegetation, soil
Thamnolia vermicularis	THA VER	1	fruticose	vegetation, soil
Trapeliopsis granulosa	TRA GRA	3	crustose	soil
Tremolecia atrata	TRE ATR	2	crustose	rock
Tuckermannopsis chlorophylla		3--4	foloise	epiphyte
Tuckermannopsis merrillii		4--5	foliose	epiphyte
Tuckermannopsis subalpina	TUC SUB	4	fruticose	ericaceous epiphyte
Umbilicaria arctica	UMB ARC	5	umbilicate	rock
Umbilicaria cylindrica	UMB CYL	3	umbilicate	rock
Umbilicaria decussatus	UMB DEC	5	umbilicate	rock
Umbilicaria deusta		4--5	umbilicate	rock
Umbilicaria havaasii	UMB HAV	4	umbilicate	rock
Umbilicaria hyperborea	UMB HYP	5	umbilicate	rock
Umbilicaria krascheninnikovii	UMB KRA	5	umbilicate	rock
Umbilicaria proboscidea	UMB PRO	3	umbilicate	rock, sandstone
Umbilicaria rigida	UMB RIG	5	umbilicate	rock
Umbilicaria torrefacta	UMB TOR	5	umbilicate	rock
Umbilicaria vellea	UMB VEL	4	umbilicate	rock
Umbilicaria virginis	UMB VIR	3	umbilicate	rock
Umbilicaria spp.	UMB SPP	5	umbilicate	rock
Vulpicida tilesii	VUL TIL	1	foliose	soil
Xanthoparmelia coloradoensis	XNP COL	2	foliose	rock, gravel
Xanthoria elegans	XAN ELE	2	foliose	rock
Xanthoria fallax		2	foliose	rock
color - 1 pale------> 5 dark				

APPENDIX E: PLANT SPECIES FOUND BY SITE

Appendix E: Plant Species Found by Site

Plant Species found by Site

Plant	CODE	FORM	BC	DP	EM	SD	TP	SP
Abies lasiocarpa (Hook.) Nutt.	ABI LAS	krumholz				X	X	X
Achillea millefolium L.	ACH MIL	herb	X	X	X	X		X
Agoseris glauca (Pursh) Raf.	AGR GLA	herb	X	X	X			X
Allium cernuum Roth.	ALL CER	herb		X				
Allium crenulatum Wieg.	ALL CRE	herb		X				
Anemone	ANE DEL	herb-tuft						
Anemone drummundii Wats.	ANE DRU	herb-matt	X	X	X			X
Anemone/ Delphinium	ANEMON	herb						X
Antennaria alpina (L.) Gaertn.	ANT ALP	herb-rosette	X	X	X	X		X
Antennaria lanata (Hook.) Greene	ANT LAN	herb	X		X		X	X
Antennaria micropylla Rydb.	ANT MIC	herb-rosette	X	X	X		X	X
Arenaria capillaris Poir.	ARE CAP	herb-tuft	X	X	X		X	X
Arenaria obtusiloba (Rydb.) Fern *(Minuartia)*	ARE OBT	cushion	X	X	X		X	X
Arenaria rubella (Wahlenb.) J.F. Smith *(Minuartia)*	ARE RUB	cushion	X	X	X			X
Artemisia trifurcata Steph.	ART TRI	herb-tuft	X	X				
Aster alpigenus (T. & G.) Gray	AST ALP	herb						X
Campanula rotundifolia L.	CAM ROT	herb-rosette	X	X	X	X		
Carex spp.	CAR SPP	graminoid	X	X	X	X	X	X
Cassiope mertensiana (Bong.) G. Don	CAS MER	E-woody matt		?		X	X	X
Cassiope stelleriana (Pall.) DC.	CAS STE	E-ground cover					X	
Castilleja miniata Dougl. *(C. rhexifolia* Rydb, *C. elmeri* Fern*)*	CAS MIN	herb		X			X	
Castilleja parviflora Bong. *var. albida* (Pennell) Ownbey	CAS PAR	herb				X		
Castilleja sp. (red)	CAS SPP	herb				X		

Plant	CODE	FORM	BC	DP	EM	SD	TP	SP
Cerastium arvense L.	CER ARV	herb-matt		X				
Chamaecyparis nootkatensis (D. Don) Spach	CHA NOO	krumholz		X				
Douglasia laevigata Gray	DOU LAE	cushion	X	X	X			
Dryas octopetala L.	DRY OCT	herb-matt						X
Empetrum nigrum L.	EMP NIG	woody ground cover				X		
Erigeron aureus (y) Greene	ERI AUR	herb				X	X	X
Erigeron compositus (w) Pursh	ERI COM	herb	X	X	X			?
Erigeron peregrinus (p) (Pursh) Greene	ERI PER	herb	X	X	X	X		X
Erigeron sp.	ERI SPP	herb		X				
Eriogonum ovalifolium (y) Nutt.	ERG OVA	herb-matt	X	X	X			X
Eriogonum pyrolifolium (p) Hook.	ERG PYR	herb-matt	X	X	X			X
Eriophyllum lanatum (Pursh) Forbes	ERI LAN	herb-tuft		X				
Festuca ovina L. var. brevifolia (R. Br.) Wats.	FES OVI	graminoid		X	X			X
Gentiana calycosa Griseb.	GEN CAL	herb			X			
Geum triflorum Pursh	GEU TRI	herb-tuft		X	X			
Grass	GRASS	graminoid	X	X	X	X	X	X
Haplopappus lyallii Gray	HAP LYA	herb-shrub			X			
Hedysarum occidentale Greene	HED OCC	herb-shrub		X	X			
Juncus parryi Engelm.	JUN PAR	graminoid	X	X	X	X	X	
Juniperus communis L.	JUN COM	woody ground cover	X	X	X			X
Kalmia microphylla (Hook.) Heller	KAL.MIC	E-woody shrb						X
Larix lyallii Parl.	LAR LYA	krumholz					X	
Leptarrhena (Saxafraga) pyrolifolia (D. Don) R. Br.	LEP PYR	herb-rosette						X
Ligusticum garyi ?	CAR ROT	herb		X				
Luetkea pectinata (Pursh) Kuntze.	LUE PEC	woody ground cover			X	X	X	X
Lupinus latifolius Agardh	LUP LAT	herb				X		X
Lupinus lepidus (lyalii) Dougl.	LUP LEP	herb-matt	X	X	X	X		
Luzula spicata (L.) DC.	LUZ SPI	graminoid	X	X		X		
Lycopodium sitchensis Rupr.	LYC SIT	cryptogam				X		
Moss	MOSS	cryptogam	X	X	X	X	X	X
Oxytropus campestris (L.) DC.	OXY CAM	herb-tuft	X	X	X			
Penstemon davidsonii Greene	PEN DAV	woody gc	X					X

Plant	CODE	FORM	BC	DP	EM	SD	TP	SP
Phacelia sericea (Grah.) Gray	PHA SER	herb-matt	X	X	X			
Phlox diffusa Benth.	PHL DIF	cushion	X	X	X	X		X
Phlox hendersonii (E. Nels.) Cronq.	PHL HEN	cushion	X		X			
Phyllodoce empetriformis (Sw.) D. Don	PHY EMP	E-woody matt				X	X	X
Phyllodoce glanduliflora (Hook.) Cov.	PHY GLA	E-woody mat				X	X	X
Picea engelmannii Parry	PIC ENG	krumholz					X	
Pinus albicaulis Engelm.	PIN ALB	krumholz						X
Polemonium elegans Greene	PO LELE	herb	X		X			X
Polemonium pulcherrimum Hook.	POL PUL	herb		X				
Polygonum bistortoides Pursh	PLY BIS	herb				X		
Potentilla diversifolia Lehm.	POT DIV	herb-tuft	X	X	X	X		X
Potentilla drummondii Lehm.	POT DRU	herb-matt				X		
Potentilla flabellifolia (Lehm.) Nutt.	POT FLA	herb-rosette						X
Potentilla fruiticosa L.	POT FRU	woody shrb	X	X	X			
Ranunculus eschscholtzii Schlecht.	RAN ESC	herb				X		X
Salix cascadensis Cockerell	SAL.CAS	woody shrub					X	
Salix nivalis Hook.	SAL.NIV	woody ground cover	X		X	X		X
Saxifraga bronchialis L.	SAX BRO	cushion	X		X	X		X
Saxifraga caespitosa L.	SAX CAE	cushion	X	X	X			X
Saxifraga ferruginea Grah.	SAX FER	herb-rosette						
Saxifraga tolmiei T. & G.	SAX TOL	cushion	X					
Sedum divergens Wats.	SED DIV	perennial.ground cover						X
Sedum lanceolatum Torr.	SED LAN	perennial.ground cover		X	X			X
Selaginella wallacei Hieron.	SEL AGI	cryptogam	X	X	X	X	X	X
Sibbaldia procumbens L.	SIB PRO	herb-matt	X		X	X	X	X
Silene acaulis L.	SIL ACA	cushion	X			X		X
Silene douglasii Hook.	SIL DOU	herb						
Silene parryi (Wats.) Hitchc. & Mag.	SIL PAR	herb						X
Silene scouleri Hook.	SIL SCO	herb	X		X	X		
Smelowskia calycina (Steph.) C. A. Mey.	SME CYC	herb-matt	X	X	X			
Solidago multiradiata Ait.	SOL MUL	herb	X	X	X	X		X
Synthris pinnatifida Wats.	SYN PIN	herb-matt	X	X	X			

Plant	**CODE**	**FORM**	**BC**	**DP**	**EM**	**SD**	**TP**	**SP**
Vaccinium deliciosum Piper	VAC DEL	E-woody shrb		X	X	X	X	X
Vaccinium scoparium Leiberg	VAC SCO	E-woody shrb						X
Valeriana sitchensis Bong.	VAL.SIT	herb				X		X
Veronica cusickii Gray	VER CUS	herb			X		X	X
Viola sp.	VIOLA	herb		X				
Graminoids	**CODE**	**FORM**	**BC**	**DP**	**EM**	**SD**	**TP**	**SP**
Agrostis scabra Willd. - grass	AGR SCA	graminoid				X		
Calamagrostis purpurascens R. Br. - grass	CAL.PUR	graminoid			X			
Danthonia intermedia Vasey - grass	DAN INT	graminoid		X				
Deschampsia atropurpurea (Wahl.) Scheele - grass	DES ATR	graminoid				X	X	X
Festuca idahoensis Elmer - grass	FES IDA	graminoid		X				
Festuca idahoensis var. oregana (Hack.) Hitchc. - grass	FES IDA OR	graminoid			X			X
Festuca ovina var. brevifolia (R.Br.) Wats. - grass	FES OVI	graminoid			X	X	X	X
Festuca viridula Vasey - grass	FES VIR	graminoid						X
Phleum alpinum L. - grass	PHL ALP	graminoid						X
Poa alpina L. - grass	POA ALP	graminoid						X
Poa cusickii var. *epilis* (Scribn.) Hitchc. - grass	POA CUS	graminoid					X	X
Poa cusickii var. *purpurensis* (Vasey) L.C. Hitchc.- grass	POA CUS PU	graminoid	X	X				
Poa incurva Scribn. & Will. - grass	POA INC	graminoid						X
Poa sandbergii Vasey *(P. secunda)* - grass	POA SAN	graminoid			X			
Poa stenantha Trin. - grass	POA STE	graminoid		X				
Sitanion hystrix (Nutt.) Smith var. *hystrix* - grass	SIT HYS	graminoid		X				X
Luzula campestris var. *multiflora* (Ehrh.) Celak. - woodrush	LUZ CAM	graminoid				X		
Luzula piperi (Cov.) Jones - woodrush	LUZ PIP	graminoid				X	X	X
Luzula spicata (L.) DC. - woodrush	LUZ SPI	graminoid	X	X	X			
Carex nigricans Retz. - sedge	CAR NIG	graminoid				X		
Carex obtusata Lilj. - sedge	CAR OBT	graminoid		X				
Carex phaeocephala Piper - sedge	CAR PHA	graminoid	X	X	X			X

Carex pyrenaica Wahl. - sedge	CAR PYR	graminoid					X	
Carex spectabilis Dewey - sedge	CAR SPE	graminoid	X		X	X		X
Juncus drummondii E. Meyer - rush	JUN DRU	graminoid					X	
Juncus parryi Engelm. - rush	JUN PAR	graminoid	X		X		X	X
SITE CODES								
Buckhorn Cirque	BC							
Deer Park	DP							
Elk Mountain	EM							
Skyline Divide	SD							
Tatie Peak area	TP							
Slate Peak	SP							

APPENDIX F: PLANT PERCENT COVER AND FREQUENCY FOR EACH SITE

APPENDIX F: Plant percent cover and frequency for each site. Standard deviation is listed ± after each percent cover value. Frequency is listed in parentheses under percent cover. Frequency is the number of quadrats in which the species occurred, out of 160 quadrats per site (180 quadrats for Buckhorn Cirque (BC) and Skyline Divide (SD)).

* For Buckhorn Cirque, Elk Mountain, and Slate Peak, values are in % **frequency** rather than % cover.

Plant species	**BC***	**DP**	**EM***	**SD**	**SP***	**TP**
Abies lasiocarpa				.63 ± 5.68 (2)	.03 ± .58 (4)	1.18 ± 9.04 (7)
Achillea millefolium	.40 ± .49 (72)	1.55 ± 2.57 (94)	.47 ± .51 (70)	.02 ± .14 (3)	.01 ± .08 (1)	
Agoseris glauca	.14 ± .35 (25)	.18 ± 1.35 (7)	.25 ± .43 (38)		.01 ± .11 (2)	
Allium cernuum		.28 ± .78 (25)				
Allium crenulatum		.26 ± .71 (25)				
Anemone drummundii	.01 ± .08 (1)	.15 ± .56 (12)	.05 ± .21 (7)		.02 ± .14 (3)	
Anemone/ Delphinium					.03 ± .18 (5)	
Antennaria alpina	.13 ± .34 (24)	.13 ± .92 (6)	.04 ± .20 (6)	.36 ± .94 (29)	.03 ± .18 (5)	

Plant species	BC*	DP	EM*	SD	SP*	TP
Antennaria lanata	.08 ± .27 (14)		.08 ± .27 (12)		.06 ± .24 (10)	2.53 ± 4.54 (96)
Antennaria rosea	.26 ± .44 (46)	.07 ± .32 (8)	.05 ± .22 (8)		.20 ± .40 (32)	.01 ± .08 (1)
Arenaria capillaris	.06 ± .24 (11)	1.70 ± 3.70 (41)	.32 ± .47 (48)		.09 ± .29 (15)	.09 ± .51 (6)
Arenaria obtusiloba	.60 ± .69 (102)	.26 ± 1.30 (10)	.34 ± .47 (51		.16 ± .37 (26)	.01 ± .16 (1)
Arenaria rubella	.51 ± .50 (91)	.15 ± .55 (15)	.27 ± .45 (41)		.06 ± .24 (10)	
Artemesia trifurcata	.10 ± .30 (18)	.16 ± .87 (9)				
Aster alpigenus					.01 ± .08 (1)	
Campanula rotundifolia	.29 ± .46 (52)	.37 ± .85 (37)	.09 ± .29 (14)	.13 ± .55 (12)		
Carex spp., *Luzula* spp.	.72 ± .45 (130)	1.47 ± 2.98 (70)	.61 ± .49 (93)	6.49 ± 8.05 (125)	.46 ± .50 (73)	12.18 ± 20.95 (133)
Cassiope mertensiana				13.42 ± 25.57 (52)	.29 ± .45 (46)	32.12 ± 28.25 (120)
Cassiope stelleriana						.81 ± 4.45 (7)
Castilleja miniata (C. rhexifolia, C. elmeri)						.01 ± .08 (1)
Castilleja parviflora var. albida				.59 ± 6.34 (8)		

Plant species	BC*	DP	EM*	SD	SP*	TP
Castilleja sp.				.02 ± .14 (3)		
Cerastium arvense		.54 ± 1.39 (38)				
Chamaecyparis nootkatensis		.57 ± 7.14 (1)				
Douglasia laevigata	.18 ± .38 (32)	.05 ± .50 (2)	.01 ± .08 (1)			.01 ± .08 (1)
Dryas octopetala					.21 ± .41 (33)	
Empetrum nigrum				9.19 ± 20.27 (36)		
Erigeron aureus				1.57 ± 3.85 (67)	.08 ± .27 (13)	1.33 ± 2.97 (77)
Erigeron compositus	.02 ± .13 (3)	.31 ± 1.09 (20)	.07 ± .25 (10)			
Erigeron peregrinus	.02 ± .15 (4)	.25 ± 2.41 (6)	.10 ± .30 (15)	.19 ± 1.35 (9)	.01 ± .08 (1)	
Erigeron sp.		.06 ± .26 (8)				
Eriogonum pyrolifolium	.08 ± .27 (14)	.01 ± .08 (1)	.13 ± .11 (2)		.01 ± .08 (1)	
Eriogonum ovalifolium	.01 ± .08 (1)	.10 ± .58 (6)	.04 ± .20 (6)		.05 ± .22 (8)	
Eriophyllum lanatum		.308 ± 1.15 (19)				

Plant species	BC*	DP	EM*	SD	SP*	TP
Gentiana calycosa			.01 ± .08 (1)		.01 ± .11 (2)	
Geum triflorum		1.57 ± 4.30 (48)	.03 ± 16 (4)			
Grass	.44 ± .60 (81)	3.55 ± 5.45 (109)	.29 ± 46 (44)	.11 ± .53 (8)	.11 ± .32 (10)	.14 ± 1.28 (6)
Haplopappus lyallii			.02 ± .14 (3)			
Hedysarum occidentale		.11 ± .68 (6)	.03 ± .16 (4)			
Juncus parryi			.13 ± .34 (20)	.58 ± 1.67 (25)		.51 ± 1.41 (32)
Juniperus communis.	.01 ± .08 (1)	1.96 ± 10.16 (11)	.18 ± .40 (28)		.04 ± .19 (6)	
Kalmia microphylla					.19 ± .40 (31)	
Larix lyallii						.86 ± 4.13 (9)
Leptarrhena pyrolifolia					.01 ± .08 (1)	
Ligusticum garyi		.16 ± .51 (15)				
Luetkea pectinata			.02 ± .14 (3)	6.82 ± 10.51 (77)	.29 ± .45 (46)	8.34 ± 13.97 (109)
Lupinus latifolius				.96 ± 4.48 (13)	.02 ± .14 (3)	

Plant species	BC*	DP	EM*	SD	SP*	TP
Lupinus lepidus (lyalii)	.44 ± .50 (80)	.23 ± .77 (19)	.59 ± .49 (90)	.01 ± .08 (1)		
Luzula spicata	.18 ± .39 (33)	.01 ± .08 (1)		.01 ± .11 (2)		
Lycopodium sitchensis				1.98 ± 6.29 (33)		
Moss	.74 ± .44 (134)	2.43 ± 5.80 (94)	.28 ± .45 (42)	19.08 ± 15.20 (138)	.41 ± .49 (65)	15.72 ± 17.34 (131)
Oxytropus campestris	.19 ± .39 (34)	1.26 ± 2.85 (49)	.01 ± .11 (2)			
Penstemon davidsonii	.01 ± .08 (1)	.03 ± .33 (2)			.13 ± .33 (25)	
Phacelia sericea	.01 ± .08 (1)	.10 ± .98 (3)	.04 ± .20 (6)			
Phlox diffusa	.17 ± .38 (31)	14.99 ± 16.27 (132)	.67 ± .47 (102)	3.53 ± 8.06 (41)	.16 ± .37 (26)	
Phlox hendersonii	.58 ± .50 (104)		.03 ± .18 (5)			
Phyllodoce empetriformis				5.52 ± 16.04 (24)	.13 ± .34 (21)	7.31 ± 14.60 (56)
Phyllodoce glanduliflora				3.61 ± 9.57 (30)	.01 ± .08 (1)	2.84 ± 8.68 (24)
Picea engelmannii						.67 ± 7.85 (2)
Pinus albicaulis					.02 ± .14 (3)	

Plant species	BC*	DP	EM*	SD	SP*	TP
Polemonium elegans	.18 ± .32 (21)		.01 ± .11 (2)		.02 ± .14 (3)	
Polemonium pulcherrimum		.05 ± .37 (4)				
Polygonum bistortoides			.02 ± .14 (3)	1.24 ± 4.01 (30)		
Potentilla diversifolia	.34 ± .48 (61)	.01 ± .33 (2)	.04 ± .20 (6)	.13 ± .61 (10)	.11 ± .31 (17)	
Potentilla drummondii				.06 ± .64 (3)		
Potentilla flabellifolia			.01 ± .08 (1)		.03 ± .16 (4)	
Potentilla fruiticosa	.15 ± .36 (27)	1.23 ± 6.73 (9)	.10 ± .30 (15)			
Ranunculus eschscholtzii				.13 ± 1.14 (3)	.02 ± .14 (3)	
Salix cascadensis						.30 ± 1.69 (10)
Salix nivalis	.20 ± .40 (36)		.03 ± .18 (5)	0.49 ± 3.37 (9)	.01 ± .08 (1)	
Saxifraga bronchialis	.02 ± .13 (3)		.07 ± .26 (11)	.01 ± .16 (1)	.21 ± .41 (34)	
Saxifraga caespitosa	.04 ± .21 (8)	.01 ± .08 (1)	.03 ± .18 (5)		.04 ± .21 (7)	
Saxifraga ferruginea						

Plant species	BC*	DP	EM*	SD	SP*	TP
Saxifraga tolmiei	.01 ± .08 (1)					
Sedum divergens					.01 ± .08 (1)	
Sedum lanceolatum		.04 ± .19 (6)	.13 ± .34 (20)		.20 ± .40 (32)	
Selaginella wallacei	.33 ± .47 (59)	9.40 ± 14.54 (82)	.15 ± .36 (23)	.11 ± .55 (7)	.12 ± .33 (19)	.01 ± .16 (1)
Sibbaldia procumbens	.01 ± .11 (2)		.01 ± .08 (1)	1.05 ± 3.35 (35)	.01 ± .11 (2)	.01 ± .08 (1)
Silene acaulis	.11 ± .32 (20)			.24 ± 2.19 (3)	.01 ± .11 (2)	
Silene douglasii		.13 ± 1.05 (4)				
Silene parryi	.01 ± .11 (2)		.02 ± .14 (3)	.10 ± .57 (6)	.01 ± .11 (1)	
Smelowskia calycina	.50 ± .50 (90)	.01 ± .16 (1)	.19 ± .39 (29)			
Solidago multiradiata	.70 ± .46 (126)	.19 ± 2.01 (3)	.40 ± .49 (60)	2.21 ± 4.39 (51)	.13 ± .33 (20)	
Synthris pinnatifida	.25 ± .43 (45)	.59 ± 2.95 (13)	.07 ± .26 (11)			
Vaccinium deliciosum		.03 ± .32 (1)	.03 ± .18 (5)	13.13 ± 20.00 (60)	.07 ± .25 (11)	3.68 ± 9.07 (36)
Vaccinium scoparium					.13 ± .33 (20)	1.12 ± 4.55 (17)

Plant species	BC*	DP	EM*	SD	SP*	TP
Valeriana sitchensis				1.57 ± 9.20 (7)	.05 ± .22 (8)	.01 ± .08 (1)
Veronica cusickii			.01 ± .11 (2)		.21 ± .41 (33)	.87 ± 1.66 (70)

APPENDIX G: COLLECTION NUMBERS OF LICHEN SPECIES FOUND AT EACH SITE

SPECIES	**SITES AND COLLECTION NUMBERS**
Acarospora fuscata	**DP:** 960715-14 **EM:** 940915-8 **SD:** 910910-15 **TP:** 910723-32
Acarospora sp.	**EM:** 900729-12, 910902-33
Adelolecia pilati	**EM:** 910712-15
Ahtiana sphaerosporella	**BC:** 940730-19 (Marmot Pass), **SP:** 960809-4 **TP:** 900726-51, 900726-55, 910723-17, 910723-23, 910723-27, 970809-1
Alectoria nigricans	**BC:** 930814-3, 940721-3, 940721-10 **DP:** 950706-6 **EM:** 940826-3 **SD:** 910911-19, 950827-19 **TP:** 950811-14
Alectoria ochroleuca	**DP:** 950711-27, 950711-32 **SD:** 950822-1, 950826-16, 950826-32, 950827-9
Alectoria sarmentosa	**DP:** 910731-2 **SD:** 910910-1
Alectoria sp.	**DP:** 910731-72,
Allantoparmelia alpicola	**EM:** 910712-29, 970723-3 **SD:** 950826-17
Arthrorhaphis citrinella	**SD:** 950822-15, 960821-8
Aspicilia caesiocinerea	**DP:** 910731-40 **EM:** 900729-29, 940915-5 **TP:** 910723-11
Aspicilia candida	**TP:** 910723-28
Aspicila cf. contorta	**EM:** 910712-4

Aspicilia sp.	**DP:** 950708-42 **EM:** 900729-36, 910902-29, 910817-8, 930918-7, 940707-6, 940707-16, 940708-1, 940825-3, 940915-1, 940915-17 **SD:** 910911-14 **SP:** 910723-42, 940713-16 **TP:** 940811-57
Bellemerea alpina	**SD:** 910910-14, 910910-30 **SP:** 970808-8 **TP:** 950810-8, 970810-4
Bellemerea cinereorufescens	**BC:** 920731-7, 960715-13 **DP:** 960715-13, **EM:** 910817-15 **SD:** 910910-25, 910910-31, 950822-21 **SP:** 940713-26 **TP:** 910723-13, 950809-3, 950810-21
Bellemerea subsorediza	**SD:** 960820-3, 960820-7 **SP:** 940713-27 **TP:** 910916-37, 950810-22
Bellemerea sp.	**TP:** 910916-38
Brodoa oroarctica	**BC:** 940720-14, 960712-6 **DP:** 910731-28, 910731-35, 950711-10, 950711-20, 950711-23, 950711-30 **SD:** 910911-9 **TP:** 940811-30, 940811-35
Bryoria capillaris	**SP:** 900720-66
Bryoria chalybeiformis	**BC:** 920828-2 **DP:** 950707-33, 950708-1, 950708-10, 950708-31, 950710-1, 950711-4, 950711-18 **EM:** 940708-9 **SD:** 950826-2, 950826-15, 960821-4
Bryoria fremontii	**SP:** 900720-51a **TP:** 900726-59
Bryoria fuscescens	**BC:** 930711-1, 940730-21 (Marmot Pass), **DP:** 910731-46
Bryoria glabra	**BC:** 940730-18 (Marmot Pass)
Bryoria pseudofuscescens	**SP:** 900720-51b
Bryoria sp.	**DP:** 950710-27

Bryoria trichodes	**DP:** 910730-14
Buellia geophila	**BC:** 920610-10, 940720-9
Buellia sp.	**BC:** 960712-2 **SD:** 950826-10
Caloplaca ammiospila	**BC:** 930825-5, 930825-6, 940721-15, 940730-4
Caloplaca epithallina	**EM:** 900729-22
Caloplaca lamprocheila	**DP:** 950708-6
Caloplaca jungermanniae	**SP:** 940809-9
Caloplaca saxicola	**DP:** 910731-34
Caloplaca tiroliensis	**BC:** 920731-3, 930814-4, 930825-17, 930825-19, 940721-20, 940730-6 **DP:** 950706-8, 950708-4 **EM:** 940915-2
Caloplaca sp.	**BC:** 960712-10, **DP:** 950707-18, 950708-2, 950710-16 **EM:** 940707-8, 940825-7 **SD:** 950823-9 **SP:** 910916-17
Candelariella aurella	**DP:** 910731-36, 910731-43
Candelariella terrigena	**BC:** 920731-3, 940721-7
Candelariella vitellina	**BC:** 940721-4 **DP:** 950708-7, 950710-7, 960715-12 **EM:** 900729-28 **SD:** 910911-16 **SP:** 940715-5
Candelariella spp.	**BC:** 930825-18 **DP:** 910731-26, 950708-3, 950708-37, 950711-6 **EM:** 910902-31, 920726-1 **SD:** 910911-32 **TP:** 940811-25, 940811-46
Catapyrenium spp.	**TP:** 910723-8
Cetraria aculeatum	**EM:** 910712-13 **SP:** 910916-4

Cetraria ericetorum	**BC:** 920610-9, 940720-2 **DP:** 910731-18, 950707-19, 950708-26, 950709-12 **EM:** 900729-10, 920625-9, 920625-17 **SD:** 910910-12, 950822-14, 950826-6, 950826-46, 950826-50 **SP:** 900720-55, 900720-62, 900726-18, 920701-2, 940712-3, 940809-8 **TP:** 940811-10
Cetraria islandica	**BC:** 940720-11 **DP:** 910731-70, 910731-32, 950707-1, 950707-8, 950709-1 **EM:** 900729-9, 910712-2, 910712-10, 910902-15, 910817-5, 920625-8, 920625-16, 940915-3 **SD:** 910910-16, 910910-12b, 910911-5, 950822-9, 950823-12, 950827-3, 950827-4, 960820-1, 960820-2 **SP:** 940712-2, 960809-6, 960809-7 **TP:** 910723-10, 940811-2, 940811-6, 940811-9, 950808-3, 950811-16b, 950811-20
Cetraria muricatum	**BC:** 940720-3 **DP:** 910731-66, 910731-71, 950706-3, 950706-9, 950707-9, 950707-23, 950708-16, 950708-27, 950708-36, 950709-8 **EM:** 910902-17, 920625-15 **SD:** 910910-12c, 910911-18, 950826-8 **SP:** 900720-63, 940715-4, 940809-13
Cladina arbuscula	**BC:** 940721-6
Cladina mitis	**BC:** 940730-14 **DP:** 910731-17, 950708-5, 960715-3 **EM:** 910902-14, 920625-5, 920625-7, 930707-4, 940915-12 **SD:** 910910-6, 950817-1, 950822-20, 950823-1, 950823-15 **SP:** 900720-60, 900726-12, 910916-1, 940811-1 **TP:** 950809-5
Cladonia bellidiflora	**SD:** 910910-4
Cladonia cariosa	**BC:** 940721-16,
Cladonia carneola	**DP:** 950708-15, 950708-2 **EM:** 940915-10 **SD:** 950817-6, 950821-4, 950822-7, 950822-8, 950822-19 **SP:** 910916-30, 910916-31, 940809-1, 960811-4 **TP:** 940811-14, 950810-2, 970810-5

Cladonia chlorophaea	**DP:** 950706-1 **SP:** 940809-5
Cladonia crispata ?	**DP:** 950707-22
Cladonia ecmocyna	**BC:** 920731-9, 930710-6, 940722-1, 940730-11 **DP:** 950710-2 **EM:** 940708-7, 940915-9, 940915-11, 940915-14 **SD:** 910910-7, 950817-7, 950817-8, 950822-3, 950822-12, 950822-16, 950823-2, 950823-3, 950823-4, 950823-6, 950823-11 **SP:** 900720-59, 900726-4, 900726-14, 910916-28, 940713-19, 940713-20, 940714-2, 940810-1 **TP:** 940811-3, 940811-7, 950808-1, 950808-6, 950808-7, 950808-8, 950811-2, 950811-8, 950811-9, 950811-19
Cladonia fimbriata	**SP:** 900726-5
Cladonia macroceras	**SP:** 900720-52
Cladonia macrophyllodes	**BC:** 920610-8, 960712-5, **DP:** 910731-7, 950608-1 **EM:** 910902-23 **SD:** 950821-3 **TP:** 950810-5
Cladonia pleurota	**SD:** 910910-10
Cladonia pocillum	**DP:** 910731-9, 950706-11, 950708-12 **EM:** 910712-14, 940707-13 **SP:** 940713-14
Cladonia pyxidata	**DP:** 950708-33
Cladonia singularis	**SD:** 950822-10, 950823-13
Cladonia squamosa	**SD:** 950821-6, 950822-5, 950823-5
Cladonia sp.	**DP:** 950709-3, 950709-4, 950711-1, 960715-5 **EM:** 900729-3, 900729-17, 920912-2, 940825-13 **SD:** 950826-26, 950827-1, 960821-7 **TP:** 950809-6
Coccocarpia sp.	**BC:** 930825-3
Cornicularia normoerica	**DP:** 910731-1, 910731-54, **EM:** 910712-20, 910902-30, 920716-4, 940707-5, 940708-3 **SD:** 950827-5

Dermatocarpon luridum	**SP:** 960811-5a **TP:** 830808-1, 940811-16
Dermatocarpon reticulatum	**BC:** 960702-4 **SP:** 960811-10 **TP:** 900726-58
Dermatocarpon rivulorum	**SP:** 960811-5b
Diploschistes muscorum	**SD:** 950826-18
Flavocetraria cucullata	**BC:** 940720-1 **DP:** 910731-71, 910731-31, 950707-7, 950707-20, **EM:** 900729-15, 910712-5, 910712-11, 910902-16, 920625-14, 940915-13 **SP:** 940713-13b, 940715-16
Flavocetraria nivalis	**BC:** 940720-16 **DP:** 910731-30, 950707-12, 950709-5 **EM:** 930630-2 **SD:** 910911-3, 950826-13 **SP:** 900720-57, 910916-13, 940713-13a,
Hypogymnia austerodes	**EM:** 930918-6
Hypogymnia imshaugii	**SP:** 960809-13
Hypogymnia occidentalis	
Hypogymnia rugosa	**DP:** 910730-15, 910731-3
Hypogymnia sp.	**DP:** 950710-30
Lecanora bicincta	**BC:** 930825-1, 940720-6, 960712-4 **DP:** 910730-18, 950710-9, 950710-14, 960715-8 **EM:** 900729-32, 910902-1, 910902-6, 910902-7, 910902-32, 930630-3, 960716-5 **SP:** 910723-36, 960809-8 **TP:** 940811-17, 940811-36, 940811-44, 940811-59
Lecanora dispersa	**DP:** 910731-42, 960715-10 **SD:** 910911-27, 910911-34
Lecanora epibryon	**BC:** 920828-3, 930814-8, 940720-5, 940720-8
Lecanora hagenii	**DP:** 950706-7 **SD:** 910911-31

Lecanora intricata ?	**BC:** 940720-7, **EM:** 940826-1 **SD:** 910911-24, 950827-14 **SP:** 910916-41, 910916-51, **TP:** 900726-60, 910723-14, 910723-30, 910916-52, 910916-57, 950811-5, 950811-11
Lecanora malaena	**EM:** 900729-13
Lecanora polytropa	**BC:** 930710-7, 940730-10 **DP:** 950708-8, 950710-6, 960715-10, 960715-10 **EM:** 900729-14, 900729-24, 900729-27, 900729-35, 910902-2, 910817-7 **SD:** 950822-17 **SP:** 900720-81, 910916-6, 910916-15, 910916-49 **TP:** 940811-28, 940811-37
Lecanora sp.	**SD:** 910910-23 **SP:** 940715-18, 960809-15 **TP:** 910916-53
Lecidea atrobrunnea	**BC:** 920731-8, 930710-10, 940722-2, **DP:** 910730-13, 950708-28, 950708-38, 950710-8, 960715-5, 910817-16 **EM:** 900729-23, 900729-26, 910902-25, 910817-2, 930928-2, 940709-6, 940709-7, 940826-6 **SD:** 910910-28, 950826-28 **SP:** 900726-25, 910916-21, 910916-61, 940713-7, 940810-3, 960809-17 **TP:** 910723-12, 910723-31, 940810-10, 940811-22, 950810-16, 950810-23, 950811-10
Lecidea atromarginata	**TP:** 910916-34, 910916-34
Lecidea cascadensis	**EM:** 910902-3 **SP:** 910916-5, 910916-23
Lecidea cf. cascadensis	**TP:** 910916-39
Lecidea lapicida	**BC:** 950724-1 **SD:** 910910-20
Lecidea cf. leucothallina	**EM:** 910817012
Lecidea praenubila	
Lecidea cf. tessellata	**DP:** 950708-11 **EM:** 940915-16, 970723-2 **SP:** 970808-9 **TP:** 940811-23, 940811-51, 950811-12

Lecidea sp.	**BC:** 920731-10, 940721-9, 960712-13 **EM:** 910712-16, 910712-26, 940709-4 **SD:** 910911-10, 910911-25, 910911-26 **SP:** 900726-27, 960809-5 **TP:** 900726-63, 910723-6, 940811-38, 950810-24
Lecidella wulfenii	**BC:** 960712-9, 960712-14
Lecidella sp.	**BC:** 930814-6 **EM:** 910902-8, 910902-1, 910916-33
Lecidoma demissum	**BC:** 930710-4 **EM:** 920716-3, 940708-6 **SD:** 950817-3, 950821-5, 950826-12 **TP:** 950810-1, 950811-13, 950811-17
Lepraria cacuminum	**BC:** 940721-14 **EM:** 900729-4, 940708-5 **SD:** 950817-2, 950821-1, 950821-8 **SP:** 940713-2, 940714-1 **TP:** 950811-18
Lepraria neglecta	**EM:** 910712-28 **SP:** 910916-12
Lepraria sp.	**BC:** 960702-7 **EM:** 910902-21 **TP:** 950810-6
Leprocaulon microscopium	**TP:** 910723-3
Leprocaulon subalbicans	**EM:** 920912-3 **SD:** 910911-20 **TP:** 910723-5, 950810-3, 950810-4, 950810-9, 960810-1
Leptogium sp.	**DP:** 950707-21, 950708-30
Letharia columbiana	**BC:** 920610-5 **TP:** 900726-54, 910723-18, 910723-22, 910723-26
Letharia vulpina	**BC:** 940730-16 (Marmot Pass) **EM:** 920625-4, 920625-11 **SP:** 960809-3 **TP:** 830807-1, 900726-53
Lobaria linita	**SD:** 910910-11
Massalongia carnosa	**TP:** 910723-33
Megaspora verrucosa	**BC:** 960712-3 **EM:** 910902-20, 910827-3, 940825-4, 940915-4

Melanelia commixta	**BC:** 920827-2, 960702-3 **EM:** 920912-3, 940707-11, 940707-14, 940709-5, 940825-14, 940826-9 **SD:** 910910-24, 910911-17, 950826-20, 960821-1 **SP:** 940715-1, 940715-2, 940715-3, 940715-9
Melanelia disjuncta	**BC:** 930825-7
Melanelia exasperatula	**EM:** 920625-3, 920625-23 **SD:** 910911-13
Melanelia hepatizon	**BC:** 920827-5
Melanelia infumata	**EM:** 910902-4 **SD:** 910911-23
Melanelia panniformis	**EM:** 910712-27
Melanelia sorediata	**BC:** 940720-12 **EM:** 940707-2, 940707-9, 940707-12 **SD:** 950826-11
Melanelia stygia	**DP:** 910730-5, 910731-52, 910731-59, **SD:** 950826-1
Melanelia sp.	**DP:** 910730-9, 910731-60, 910731-49, 950708-14, 950711-9
Mycobilimbia sabuletorum	**BC:** 940730-3
Mycoblastus sanguinarius	**DP:** 910731-5 **SD:** 910910-18
Mycoblastus sp.	**DP:** 910731-47
Neofuscelia sp.	**EM:** 910902-11
Nodobryoria abbreviata	**BC:** 940730-20 (Marmot Pass) **SP:** 960809-1 **TP:** 900726-56, 910723-20, 910723-24
Ochrolechia upsaliensis	**BC:** 920731-5, 930825-9, 940720-4, 960712-10 **DP:** 910731-12, 950707-11, 950707-16 **EM:** 910712-6, 910712-12, 910902-22 **SD:** 910911-12, 950826-9
Ochrolechia sp.	**BC:** 960712-12, 960712-15 **DP:** 950710-28

Ophioparma lapponica	**DP:** 910731-14 **EM:** 960716-4
Pannaria pezizoides	**BC:** 940730-2, 940730-13
Parmelia saxatilis	**EM:** 930618-5 **SD:** 950827-6
Parmelia sp.	**BC:** 920827-3
Parmeliopsis ambigua	**SP:** 900720-61, 900726-17a
Parmeliopsis hyperopta	**DP:** 910731-6 **SP:** 900726-17b, 940715-13
Peltigera aphthosa	**DP:** 910731-29
Peltigera didactyla	**EM:** 960716-7
Peltigera kristinssonii.	**EM:** 900729-5
Peltigera lepidophora	**DP:** 950710-19 **EM:** 940825-9 **TP:** 940811-11
Peltigera malacea	**BC:** 930826-3, 950906-1 **EM:** 920912-1 **SD:** 910910-8, 950822-6, 950827-2 **TP:** 950809-9
Peltigera ponojensis	**DP:** 910731-13 **EM:** 910902-13 **SP:** 940809-7
Peltigera praetextata	**SP:** 900726-8
Peltigera rufescens	**BC:** 920610-12, 920731-2, 960702-8 **DP:** 910731-8, 910731-22, 950706-2, 950707-10, 950710-18 **EM:** 900729-16, 910712-1, 910817-6, 940708-4 **SD:** 950827-7 **SP:** 900720-54, 910916-25, 940712-1 **TP:** 900726-52
Peltigera sp.	**BC:** 940720-18 **DP:** 950707-29, 950710-2, 950710-15 **SP:** 910916-10, 910916-27, 940713-15 **TP:** 950811-15
Pertusaria sp. ?	**SD:** 960821-5

Phaeophyscia sciastra	**EM:** 910712-18
Phaeophyscia sp.	**DP:** 910731-27
Phaeorrhiza nimbosa	**BC:** 960712-1, 960712-7, 960712-8
Phylliscum demangeonii	**SD:** 950826-35
Physcia caesia	**DP:** 910731-37 **SD:** 910911-28
Physcia callosa	**SD:** 910911-29
Physcia phaea	**EM:** 940825-10
Physcia sp.	**DP:** 910731-38, 950706-4, 950708-39, 950711-8, 950711-16 **EM:** 970723-4 **SD:** 910911-33 **TP:** 940811-24
Physconia muscigena	**BC:** 920828-4, 930814-5, 930825-4, 930825-8, 940720-10 **DP:** 950707-2, 950707-3, 950707-13, 950708-13 **EM:** 930918-4, 940825-12, 940826-2 **SD:** 910911-8, 910911-15
Placynthiella uliginosa	**BC:** 930825-20 **EM:** 920625-10 **SD:** 910910-17 **SP:** 910916-32
Platismatia glauca	**DP:** 910730-16, 910731-4,
Polychidium muscicola	**BC:** 920710-9 **DP:** 950708-17, 950710-3
Porpidia contraponenda	**SD:** 950821-7
Porpidia thomsonii	**SD:** 950823-8
Porpidia sp.	
Protoparmelia badia	**SP:** 900720-78, 910916-62, 960809-14 **TP:** 940811-39

Pseudephebe minuscula	**BC:** 940720-13 **DP:** 910731-58, **EM:** 910902-9, 910902-24, 920818-1, 920913-2, 930918-3 **SD:** 950822-22 **SP:** 910723-40, 910916-9, 910816-14, 910916-42, 910916-54, 940713-12, 940715-11 **TP:** 940811-18, 940811-33, 940811-48
Pseudephebe pubescens	**BC:** 920827-4 **DP:** 910730-2, 910730-4, 910730-8, 910731-57, 950710-24, 950711-29 **EM:** 900729-6, 910712-21, 910712-24, 910712-30, 910712-33, 910902-12, 910902-27 **SD:** 910911-21 **SP:** 900720-79, 900726-13, 910723-34 **TP:** 940811-31
Psora globifera	**SD:** 910911-11
Psoroma hypnorum	**SP:** 900726-2, 940809-4
Rhizocarpon bolanderi	**DP:** 950710-41 **EM:** 940915-7
Rhizocarpon disporum	**EM:** 940707-1
Rhizocarpon distinctum	**SP:** 900720-77
Rhizocarpon eupetraeum	**SP:** 910916-58
Rhizocarpon geographicum	**BC:** 940721-13 **SD:** 910910-26, 910911-6 **SP:** 900720-53, 900720-76, 910916-59 **TP:** 940811-26
Rhizocarpon lecanorinum	**EM:** 940707-15, 940915-6
Rhizocarpon macrosporum	**EM:** 910817-14
Rhizocarpon obscuratum	**SD:** 960820-5
Rhizocarpon polycarpum	**SD:** 910910-27

Rhizocarpon sp.	**BC:** 930710-11, 930814-1, 930825-12 **DP:** 950707-4, 950708-40, 950708-41, 950710-5, 950711-24, 950711-31, 950715-11, 960715-11 **EM:** 900729-30, 910712-17, 910902-28, 910817-4 **SD:** 910910-5, 910910-22, 950826-27 **SP:** 900726-24, 910723-35, 910723-41, 910916-16, 910916-18, 910916-19, 910916-20, 910916-40, 910916-45, 910916-47, 910916-48, 910916-55, 910916-56, 960809-16 **TP:** 830807-3, 910723-1, 910916-50, 940810-9, 940811-19, 940811-20, 940811-34, 940811-43, 940811-50, 940811-56, 950808-10
Rhizoplaca chrysoleuca	**DP:** 950711-3
Rhizoplaca melanopthalma	**BC:** 920828-6, 940730-15, 950711-7 **DP:** 910731-63, 950731-36 **EM:** 900729-21, 910902-5, 920625-2, 920625-21 **TP:** 940811-58
Rimularia insularis	**EM:** 900729-33 **SP:** 910723-44 **TP:** 940811-40
Rimularia sp.	**BC:** 930825-14
Rinodina sp.	**BC:** 940721-18 **SD:** 910911-30
Solorina crocea	**SD:** 910910-2, 950822-11 **SP:** 900720-3, 910916-26 **TP:** 830807-2, 910723-4, 910723-7, 910916-35, 940811-12, 950808-9, 950811-3
Sporastatia polyspora	**SD:** 950826-29
Sporastatia testudinea	**BC:** 930825-11 **EM:** 900729-34 **SD:** 950826-24, 960820-4 **SP:** 970808-7 **TP:** 940811-21, 940811-53, 940811-54, 970810-3
Staurothele drummondii	**DP:** 910731-44 **EM:** 910817-13 **SP:** 940809-3 **TP:** 900726-65, 910916-36
Staurothele fissa	**SP:** 960811-6

Stereocaulon alpinum	**BC:** 940721-1, 940721-2, 940721-11, 940721-12, 940722-5 **DP:** 950708-23 **SP:** 900726-15 **TP:** 910723-1
Stereocaulon glareosum	**BC:** 940722-4 **SD:** 950817-6 **SP:** 900720-58
Stereocaulon rivulorum	**BC:** 930814-2
Stereocaulon tomentosum	**SP:** 910916-7
Stereocaulon spp.	**BC:** 930710-2, 940730-1 **EM:** 940707-3, 940707-7, 940707-10, 940708-2, 940709-8, 940825-5 **SD:** 910910-3, 910911-2, 950822-2, 950823-10, 950823-14, 950826-5,950826-25, 950827-8, 950827-11, 950827-12, 950827-13, 960821-2, 960821-3, 960821-6, 960821-9 **SP:** 940713-3, 940713-11, 940715-12, 940715-14, 940809-12, 940810-2, 940810-5 **TP:** 940810-8, 940811-8
Tephromela armeniaca	**TP:** 940811-27, 940811-32
Thamnolia subuliformis	**BC:** 920610-6, 920610-7, 930825-2b, 930826-1b, 960702-2, 960702-6, 910731-33 **DP:** 910731-65, 910731-68, 910731-24, 950707-5, 950707-6, 950707-15, 950707-17, 950707-24, 950707-25, 950707-26, 950707-31, 950707-32, 950708-25, 950708-35, 950709-7, 950709-11, 950710-21, 950711-22, 950711-26, 950711-31, 960715-2, 960715-9, 960715-9 **EM:** 900729-2, 910712-7, 910712-9, 910902-19, 910817-1, 920625-12, 920625-19, 930630-1b, 960716-2 **SD:** 910910-9, 950826-31, 950826-36, 050826-42, 950826-43, 950826-45, 950826-48 **SP:** 900720-56, 920701-1

Thamnolia vermicularis	**BC:** 930825-2a, 930826-1a, 940702-5 **DP:** 910731-64, 910731-67, 910731-10, 910731-11, 910731-48, 950707-30, 950708-24, 950708-29, 950708-34, 950709-6, 950709-9, 950709-10, 950710-20, 950711-21, 950711-25, 950711-33, 960715-1, 960715-1, 960715-4 **EM:** 900729-1, 910712-3, 910712-8, 910902-18, 920625-13, 920625-20, 930630-1a, 960716-1, 960716-6 **SD:** 910911-4, 950826-34, 950826-41, 950826-44, 950826-49 **SP:** 900720-65, 910916-2, 940715-15 **TP:** 940811-4
Trapeliopsis granulosa	**BC:** 920828-1 **SD:** 950822-4 **SP:** 900726-6, 910916-29, 940809-6, 960811-3 **TP:** 950808-2, 950808-4, 950810-7, 970810-2
Tremolecia atrata	**SD:** 950826-21, 950826-47, 960820-6
Tuckermannopsis chlorophylla	**DP:** 910730-17
Tuckermannopsis merrillii	**BC:** 940730-17 (Marmot Pass) **SP:** 960809-1 **TP:** 900726-57, 910723-19, 910723-21, 910723-25
Tuckermannopsis subalpina	**BC:** 930710-8 (Marmot Pass) **SD:** 950817-4, 950821-2, 950822-13, 950823-7 **SP:** 900726-1, 910916-24 **TP:** 940811-13, 950809- 10, 950809-12, 950811-7, 950811-16a
Umbilicaria arctica	**SD:** 950826-30, 950826-37 **SP:** 900726-10, 940715-19
Umbilicaria cylindrica	**SP:** 900720-64, 940713-6, 940713-8, 940713-9, 940715-20, 940809-10, 940810-6, 960809-10 **TP:** 950809-1
Umbilicaria decussata	**EM:** 920625-22, 920912-4, 970723-1 **SD:** 950826-38 **SP:** 940715-10, 960808-12 **TP:** 940811-49
Umbilicaria deusta	**SD:** 910910-13
Umbilicaria havaasii	**EM:** 920818-3, 940709-2, 940709-3, **SD:** 910911-1 **SP:** 940715-6

Umbilicaria hyperborea	**BC:** 920827-1, 940730-7, **DP:** 910730-10, 970731-61, 950708-20, 950711-11 **EM:** 900729-7, 900729-18, 900729-19, 910712-19, 910712-22, 910712-23, 910712-32, 910902-10, 920818-5, 930918-1, 940825-6, 940826-10 **SD:** 910910-19, 910910-20, 910910-29, 910911-22, 950822-18, 950826-33 **SP:** 900720-80, 900726-11, 900726-16, 910723-39, 910916-8, 910916-11, 910916-22, 910916-60, 940713-10, 940715-7, 960811-9 **TP:** 950809-2
Umbilicaria kraschenninnikovii	**BC:** 940730-2 **DP:** 950708-21, 950710-11, 950711-14 **EM:** 920912-5 **SP:** 960811-2, 970808-11 **TP:** 940811-47
Umbilicaria proboscidea	**DP:** 910731-17, 950710-10, 950710-25, 950711-28 **SD:** 950826-14, 950826-19 **SP:** 940715-17, 960811-7, 970808-7 **TP:** 940811-42
Umbilicaria rigida	**BC:** 930825-10, 940721-8, 960702-1, **DP:** 910731-62, 910731-51, 950710-26, 950711-12, 950711-13, 950711-35 **EM:** 900729-8, 910902-26, 920625-1, 920818-2, 940826-7, 960716-3 **SP:** 970808-1, 970808-4
Umbilicaria torrefacta	**BC:** 940720-17 **EM:** 910712-25, 940825-1, 940825-2, 940826-4, 940826-5, 940826-8 **SD:** 950826-4, 950826-7
Umbilicaria vellea	**SD:** 950826-3
Umbilicaria virginis	**BC:** 920828-5 **SD:** 950826-23 **SP:** 940809-11, 960811-1, 960811-8, 970808-5
Umbilicaria sp.	**BC:** 940730-8 **DP:** 910731-50, 910731-56, 950710-22 **EM:** 900729-20, 970723-6, 970723-7 **SD:** 950826-39, 950826-40 **SP:** 910916-44, 940810-4, 960809-11, 970808-2, 970808-3

Vulpicida tilesii	**BC:** 920610-11, 930826-2
Xanthoparmelia coloradoënsis	**BC:** **DP:** 910731-19, 910731-23, 950706-10, 950711-5 **EM:** 920625-18, 940825-19
Xanthoparmelia wyomingica	**BC:** 940721-5 **DP:** 950711-37 **EM:** 920625-6
Xanthoria falax	**DP:** 910731-15
Xanthoria elegans	**BC:** 940721-17, 940730-9 **DP:** 910730-3, 910731-21, 910731-25, 950711-19, 960715-7 **SD:** 910911-7 **SP:** **TP:** 910723-29, 910916-51, 940811-45, 940811-55

APPENDIX H: REGRESSIONS OF LICHEN AND VEGETATION PERCENT COVER FROM EACH SITE

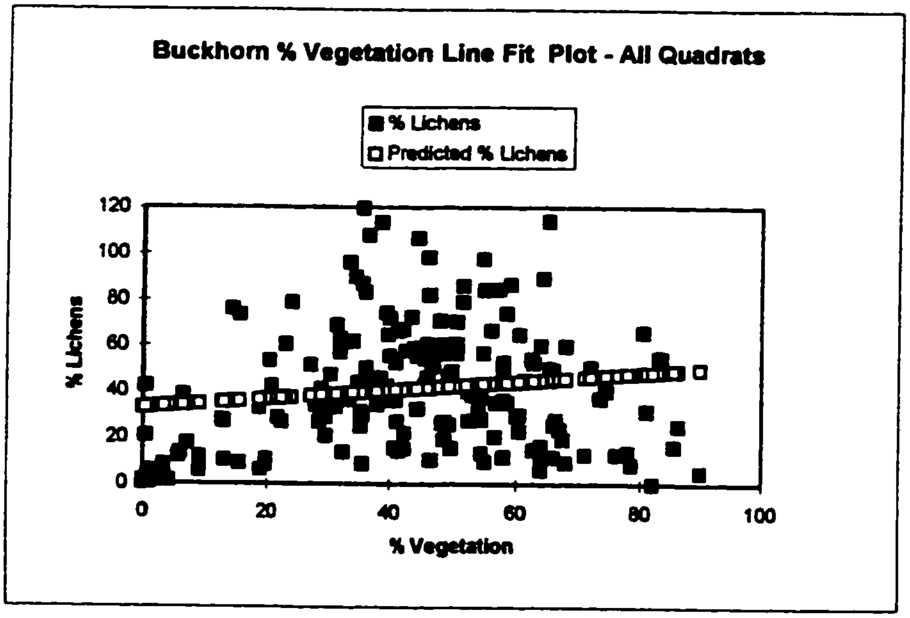

Figure 39. Buckhorn Cirque, all quadrats. Regression comparing lichen and vegetation percent cover.

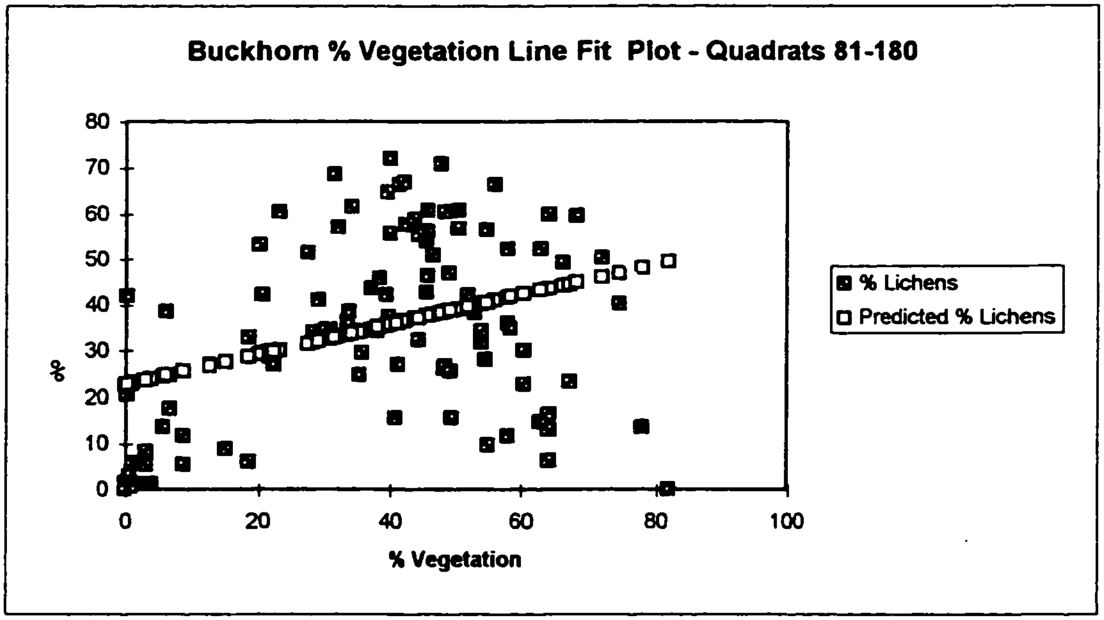

Figure 40. Buckhorn Cirque, quadrats 81-180. Regression comparing lichen and vegetation percent cover.

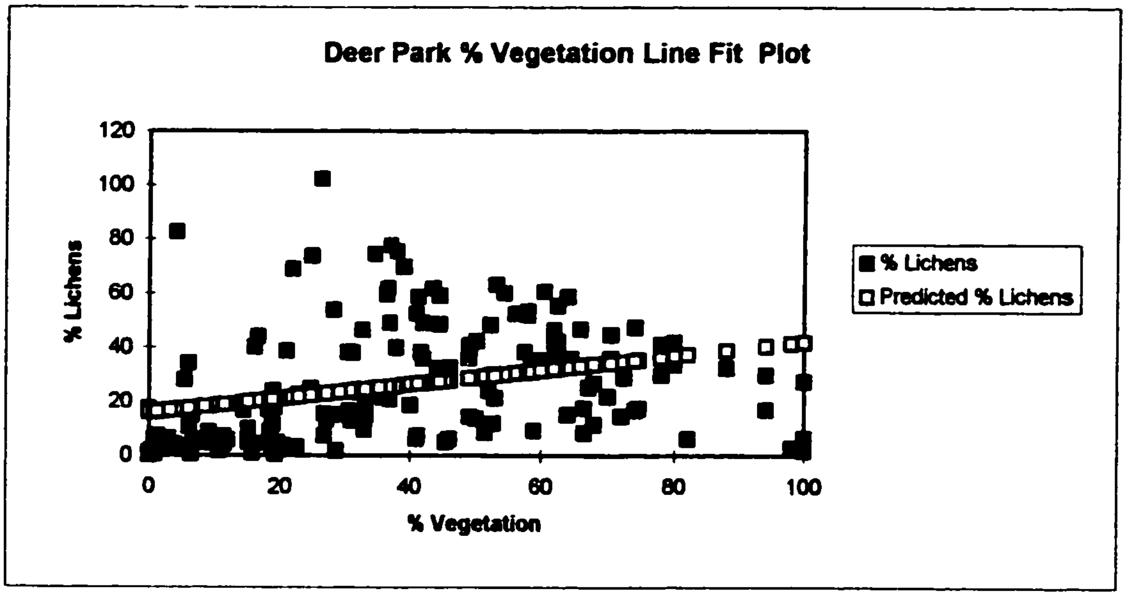

Figure 41. Deer Park, all quadrats. Regression comparing lichen and vegetation percent cover.

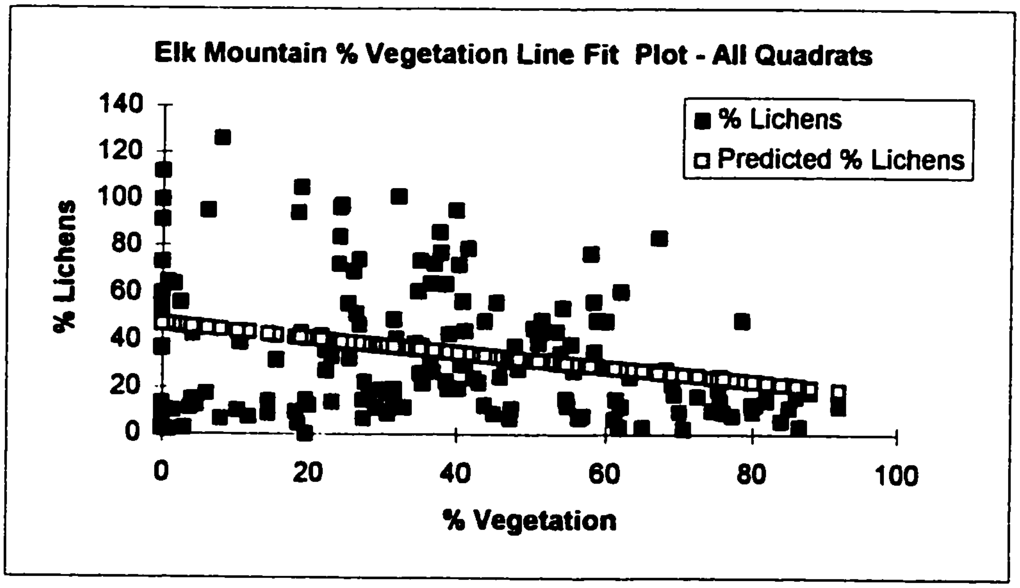

Figure 42. Elk Mountain, all quadrats. Regression comparing lichen and vegetation percent cover.

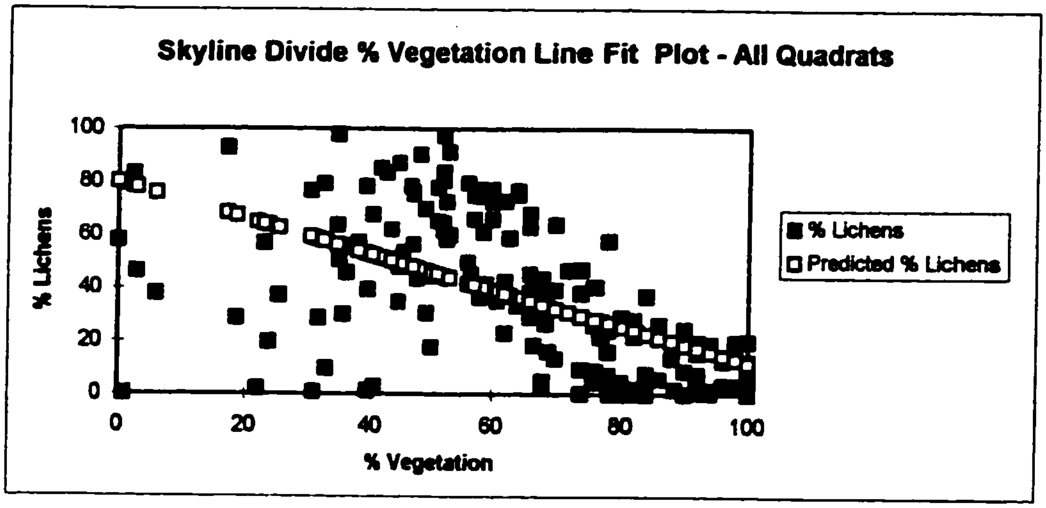

Figure 43. Skyline Divide, all quadrats. Regression comparing lichen and vegetation percent cover.

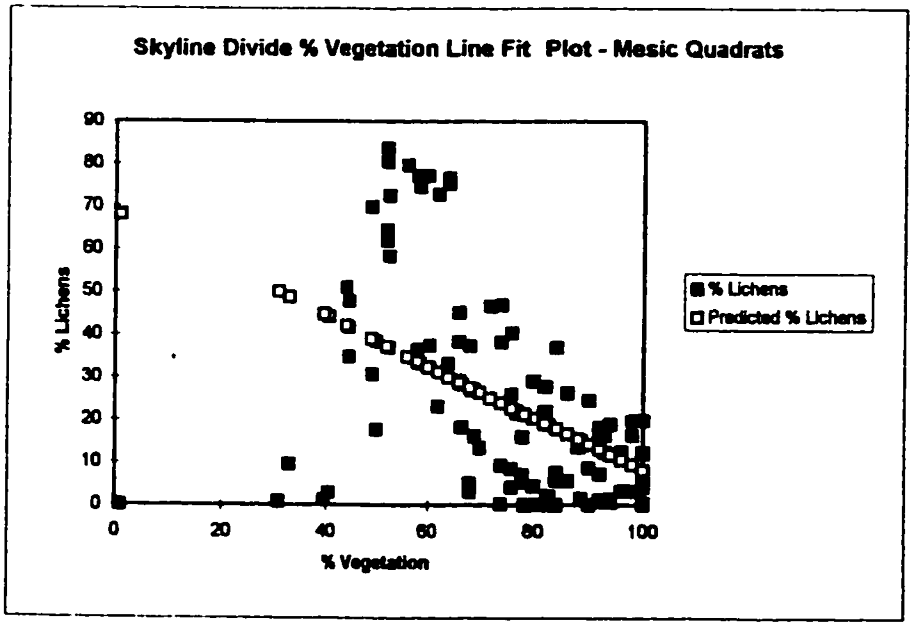

Figure 44. Skyline Divide, mesic quadrats. Regression comparing lichen and vegetation percent cover.

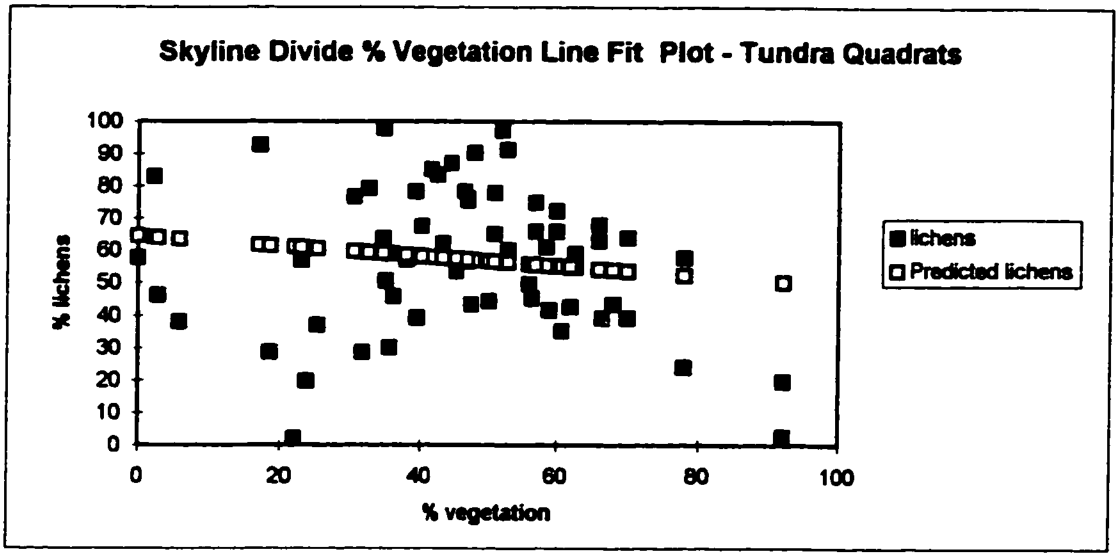

Figure 45. Skyline Divide, tundra quadrats. Regression comparing lichen and vegetation percent cover.

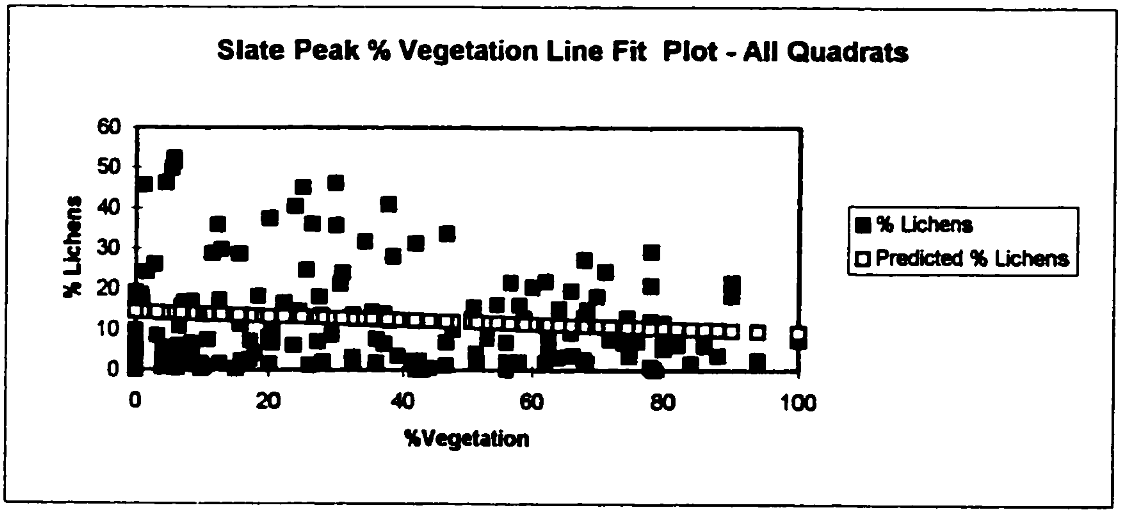

Figure 46. Slate Peak, all quadrats. Regression comparing lichen and vegetation percent cover.

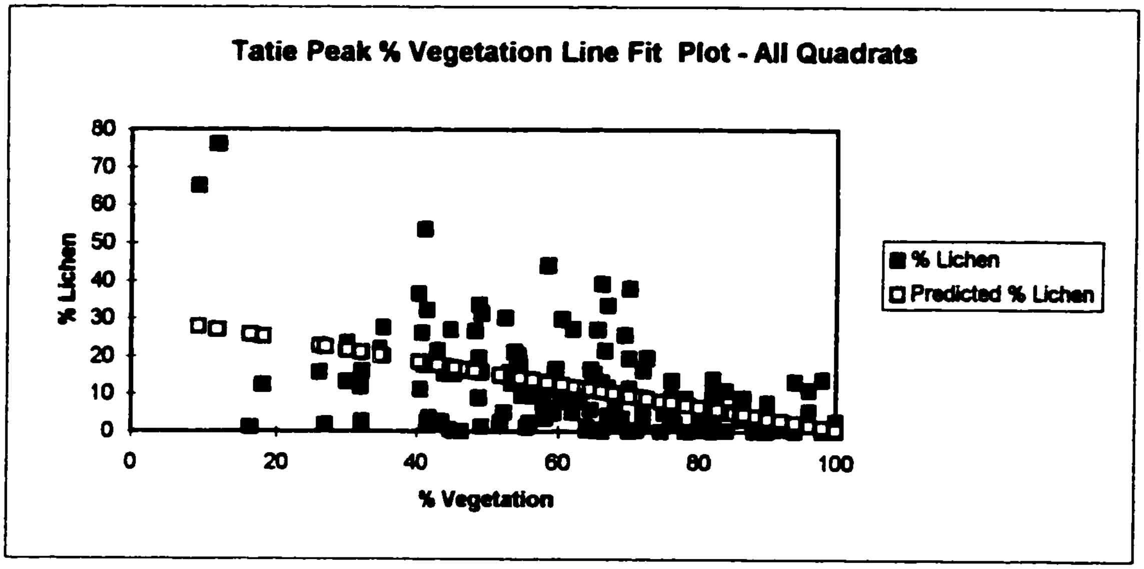

Figure 47. Tatie Peak, all quadrats. Regression comparing lichen and vegetation percent cover.

VITA

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University of Washington

1998

Education

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University of Washington, Seattle, WA. M. Sci. Ed. in Curriculum and Instruction. August, 1981.

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Grants, and Awards

American Bryological and Lichenological Society (ABLS) Executive Committee: Member-at-Large. 1997-1999.

American Bryological and Lichenological Society Travel Award. 1997.

Daniel E. Stuntz Memorial Foundation Travel Award. 1997.

Travel Award from the University of Washington Botany Department. 1992, 1995, 1996.

Daniel E. Stuntz Foundation. Grant: student field assistant Summer, 1995.

Elisabeth Carey Miller Scholarship Award in Horticulture from the Northwest Horticultural Society. 1995.

Research Grant from the Northwest Orchid Society. Spring, 1995.

Daniel E. Stuntz Foundation, scholarship. 1991-1992, 1994-1995.

Murdock Trust Grant with the Research Corporation. The "Partners in Science" Program. Research support. 1992-1994.

Washington's Outstanding Biology Teacher Award through NABT, 1990.

Publications

Glew, Katherine A. 1998. Alpine Lichens of Washington I. Lichens from the Northeast Olympics and North Cascades Mountains. *Mycotaxon: Lichenographa Thomsoniana, North American Lichenology in Honor of John W. Thomson.* pp. 261-280.

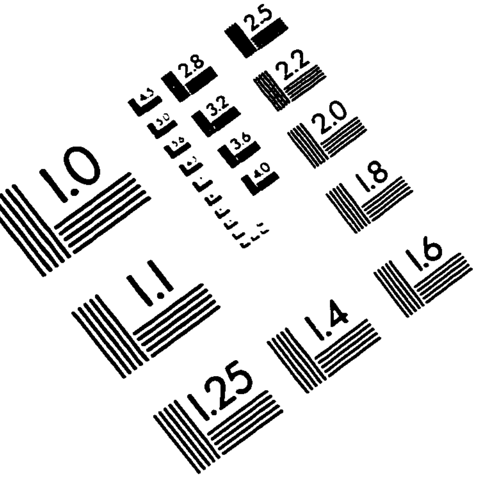
Glew, Katherine A. 1997. Lichens. Contributor in: *Endangered, Threatened and Sensitive Plants of Washington - with working lists of Rare Non-Vascular Species.* Washington Natural Heritage Program. Department of Natural Resources. pp. 50-57.

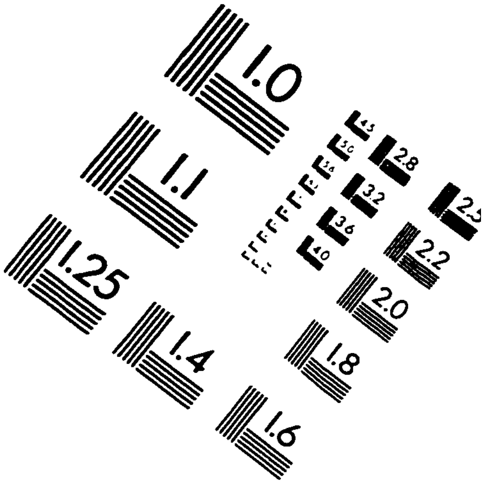
Glew, Katherine A. 1997. Do vascular plant communities provide structure for alpine lichen communities? *Bibliotheca Lichenologia* Band 68: 177-194.

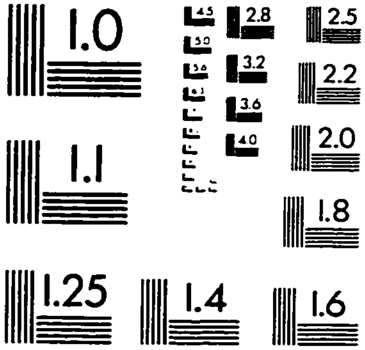
Glew, Katherine A. 1994. Lichen Communities in Alpine Regions of Washington State. *Partners in Science Conference Summary* Research Corporation, Tucson, Arizona. p.41-48.

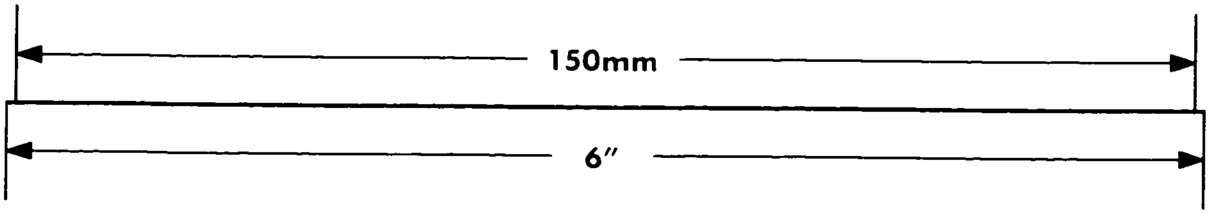
Glew, Katherine A. 1994. Range extension of the lichen *Vulpicida tilesii* into the Pacific Northwest of the United States. *The Bryologist* 97(1): 83-84.

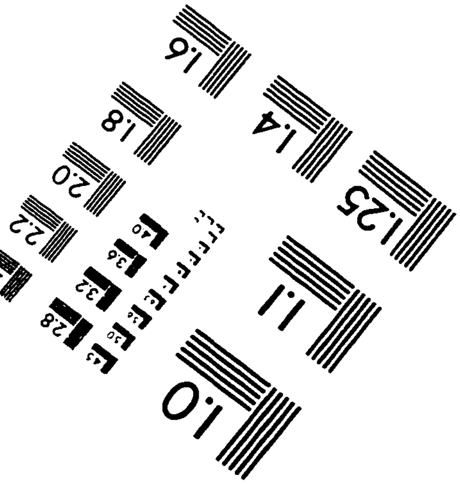
IMAGE EVALUATION
TEST TARGET (QA-3)











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