Alpine Vascular Plant Biodiversity at Spray Park, Mount Rainier National Park, WA, U.S.A.

by

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Abstract

While alpine plants are adapted to withstand harsh, high elevation environments, they are still susceptible to human impact. At Mount Rainer National Park more quantitative studies on the flora are needed for park ecologists to make informed decisions on conservation efforts. A study on Burroughs Mountain in the summer of 2001, which created a thorough list of vascular plant and macrolichen species served as a model for this study. In this study a comprehensive catalogue of the flora of Spray Park was made. Fifty-one species of vascular plants were identified. In addition to creating a list of all the species of vascular plants in Spray Park, this study investigated the association between environmental factors, plants and lichens. Along sixteen 50m parallel pairs of transects, the following were measured: plant and macrolichen species' percent cover, slope, soil pH, aspect, substrate type, substrate stability, and soil moisture. Data from these transects were analyzed statistically with ordinations using the computer programs CANOCO and PC-ORD. Ordinations graphically illustrate quadrat relationships between species and environmental variables. Among these transects there were three major habitat types: lichen dominated areas, plant dominated areas and lichen/plant-dominated areas. Plant dominated areas consisted of mesic alpine meadows; whereas lichen dominated and lichen/plant dominated areas consisted of xeric, exposed ridgelines and talus slopes. There was a negative correlation between percent cover of lichen and plants, however, positive relationships between specific lichen species and plant species of particular structural forms existed.

Introduction

High altitudes, short growing seasons and exposed areas above tree line characterize temperate alpine zones (Körner 1999). Out of the entire global vascular flora, only 4% of vascular plants exist in alpine and arctic environments (Gardes and Dahlberg 1996). These alpine species are adapted to survive in the harsh alpine habitat. For instance, in many alpine areas the nutrient productivity is low. Many alpine plants maintain high tissue nutrient levels despite the low nutrient load of their environs through impeded growth. Consequentially, the growth forms of alpine plants tend to be small and close to the ground (Körner 1999).

Although such plants are able to withstand the extreme conditions of the alpine, they are still susceptible to anthropogenic impacts, such as trampling by hikers and air pollution. Given its close proximity to the Seattle/Tacoma area and the Centralia Power Plant, Washington's leading producer of sulfur emissions, air pollution is of concern at Mount Rainier (Mount Rainier Natural and Cultural Resources Division 2002). Air quality research performed by the National Park Service showed that Mount Rainier National Park has one of the highest levels of visibility impairment of all the national parks in the western United States.

Recreational impact from hikers is also a problem at Mount Rainier. In 2001 park ecologists performed a study on the impact of off trail hiking on individual plants in Paradise meadows, one of the most frequented areas within Mount Rainier National Park. The park ecologists placed plywood outlines of men's, women's and children's sized shoes on randomly selected sites within the meadows and recorded the number of individual plants impacted. A women's shoe of size eight averaged ten impacted plants. The average number of trampled plants was higher for men and lower for children (Mount Rainier National Park 2001). With increasing numbers of outdoor enthusiasts visiting the Park each year, park ecologists must consider what conservation efforts must be made in the future.

Currently plant ecologists at Mount Rainier have little quantitative information on plant diversity and abundance throughout the Park. While the geology of the varied alpine habitats of Mt. Rainier has been studied extensively, quantitative studies on the flora of Mt. Rainier are limited since many of these plants occur in areas that are hard to reach (Biek 2000, Franklin *et al.* 1988, St. John and Warren 1937). Park ecologists need more baseline data on the flora throughout the Park before they can make informed decisions on future conservation efforts.

Conservation of plants at Mount Rainier is of fundamental importance due to the considerable amount of biodiversity found in alpine areas. Alpine plant communities exhibit wide biodiversity due to the various latitudinal differences of high elevation regions (Körner 1999). Rare plants occur in alpine areas at latitudes where they generally would not exist due to climatic differences caused by increased elevations (Biek 2000). Monitoring of plants throughout the Park is not only important for future conservation efforts, but is also significant as a reflection of the environmental health of the surrounding Puget Sound region. High visibility impairment, like that recorded by researchers at Mount Rainier, is oftentimes associated with increasing amounts of toxic tropospheric ozone. While ozone in the stratosphere is necessary for human life, man-made ozone below the stratosphere within the troposphere is a primary component of air pollution (Peterson and Jacobs 1999). In 1987 and 1988 researchers measured high tropospheric ozone levels of 80 parts per billion at the Longmire ranger station in the Park. These increased levels of tropospheric ozone are alarming given that plants show visible damage at levels of 60 parts per billion (Mount Rainier Natural and Cultural Resources Division 2002). Monitoring of the plants at Mount Rainier may signal any future alarming declines in the environmental health of its surrounding environs.

One of the primary goals of this study was to contribute to the collection of baseline data on flora needed by park ecologists for proper monitoring of plants at Spray Park on the northwestern side of Mount Rainier (Figure 1). Spray Park is a highly frequented area in the summer because it is transected by the popular Wonderland Trail.

The collection of baseline data at Spray Park consisted of identifying all plants, defining the communities formed by these plants, and determining how environmental factors affect the plant populations of Spray Park.

To account for a biotic factor that could potentially affect plant populations at Spray Park, we also collected baseline data on the percent cover of lichens and the percent cover of vegetation. Previous studies in alpine and arctic areas show how lichens influence vascular plant distributions. In the alpine tundra of the Olympic Mountains, Washington, leaf nitrogen concentration was lower in regions with cryptobiotic crusts partially composed of lichens than in non-crusted areas (Gold *et al.* 2001). In arctic areas lichens create microhabitats in otherwise exposed areas where vascular plant seedlings are more easily established (Addison and Bell 1976). Since the distribution of plants can be positively affected by the occurrence of lichens, a loss of lichen biodiversity could result in a loss of plant biodiversity.

Conversely, alpine vascular plants exhibit notable roles on lichen distributions. A comparative study by Glew between Tatie Peak in the eastern Cascades and Deer Park in the Olympic Mountains of Washington state showed that vascular plants influence distributions and species richness of lichens. There was a negative correlation between percent cover of lichens and vegetation at the mesic, snow bank sites of Tatie Peak. At the drier, tundra sites of Deer Park there was a positive correlation between percent cover of lichens and plants. In both areas plants with tufted, mat-forming structures were positively correlated with lichen establishment. Vascular plants can modify lichen communities through competition or by changing soil substrate stability (Glew 1997).

In addition to collecting baseline data at Spray Park to inform conservation decisions for vascular plants at Mount Rainier, this study investigates the association between plants and lichens. In conjunction with the baseline data gathered for vascular plants in this study, John Berry collected similar baseline data on the macrolichens of Spray Park. Similar to plants, lichens are also highly responsive to air pollution and can be used to monitor air quality (Gold *et al.* 2001, Berglund and Eversman 1988, Sigal and Nash 1983). Park ecologists will also find the baseline data collected by Berry useful in their efforts to conserve lichen populations that serve as biological indicators of environmental quality.

A previous study by Lindsey Koepke and Corrine Miller in the summer of 2001 at Burroughs Mountain on the northeastern side of Mount Rainier served as a model for this study (Figure 1). In their study, Koepke and Miller surveyed the vascular plants at Burroughs Mountain and investigated the association between vascular plants and lichens, as well as the abiotic factors affecting their distributions (Koepke 2002, Miller 2002). The final objective of this study is to compare the results of Koepke and Miller's study at Burroughs Mountain to the results of the study at Spray Park. This comparative study at Mount Rainier in the western Cascades will also complement the comparative study by Glew in the eastern Cascades and Olympics of Washington.

In summary, there are three primary goals of this study. The first objective of this study is to identify all vascular plant species in Spray Park, to define any plant communities formed within Spray Park, and to investigate how abiotic factors influence individual species or communities. The second purpose of this study is to explore the association between plants and lichens. The final goal of this study is to compare the results of the Spray Park to those of Burroughs Mountain.

Site Description

Mount Rainier National Park is located in central Washington on the western side of the Cascade Mountains. The Park includes 378 square miles of rough terrain. The most prominent feature of the Park is a glacier-covered, active volcano – Mount Rainier (Fiske *et al.* 1963). With a height of 14,411 feet, Mount Rainier exhibits a number of alpine habitats with different climates for vascular plants. The robust height of the mountain creates its own rain shadow. Westerlies from the Pacific Ocean bring an abundance of precipitation to the southern and western sides of the mountain, but fail to bring much precipitation to the northeastern slopes (Biek, 2000). Koepke and Miller's study site at Burroughs Mountain was on the arid, eastern side of the mountain (Koepke 2002). Spray Park lies on the maritime, western side of Mount Rainier.

The Spray Park trailhead is accessible at the end of the Mowich Lake Road on the southeast side of the Mowich Lake campground (3.5 miles to Upper Spray Park). Spray Park lies between Observation Rock, Echo Rock and Ptarmigan Ridge at an elevation ranging from approximately 1768m to 2134m (Figure 2). Echo Rock and Observation Rock, on the northeast corner of Spray Park, are remains of two smaller volcanoes that erupted during the last major glaciation long after the eruption of Mount Rainier. The subsequent lava flows following the eruptions of Echo and Observation Rocks followed by erosion from glaciers created Spray Park. Spray Park is composed primarily of olivine andesite from these eruptions (Fiske *et al.* 1963).

The majority of the research was based in upper Spray Park and the ridge below Echo Rock between 46°55'-54'N and 121°49'-48'W (Figure 2). This area consisted of three principal habitats: a lower-alpine meadow, the ridgeline between Spray Park and Echo Rock and an upper alpine talus slope just below Echo Rock. Low stature or prostrate woody shrubs dominated the lower-alpine meadows in upper Spray Park at an elevation of 1885m. These meadows contained patches of andesite boulder fields and krumholz forms of *Pinus albicaulis*. Small ponds and streams of water from late snowmelt drainage transected the low-alpine meadows. The ridgeline between Spray Park and Echo Rock was further up at a height of 1895m to 2109m. Both plants and lichens dominated this habitat. Andesite boulder and pumice patches were more frequent and krumholz tree formations were absent along the ridgeline. These areas were drier than the low alpine meadows because the snow there melted earlier in the summer. The upper alpine talus slopes just below Echo Rock were at an elevation of 2134m. Lichens were more abundant than vascular plants in these areas. Most of the plants present at this site were cushion plants or herbaceous perennials, which often formed rosettes. These areas consisted of andesite talus slopes interspersed with andesite boulder fields.

Materials and Methods

The fieldwork consisted of two parts, which were performed during late July through early August of 2002. The first portion of the fieldwork was the collection of samples of all plant and lichen species present at Spray Park to create a catalogue of species diversity for future conservation efforts. For each vascular plant species, we collected a minimum of three samples to provide voucher specimens to verify their occurrence. We collected the most frequently occurring bryophyte species and identified them later in the lab. The herbaria of Mount Rainier, the University of Puget Sound's Slater Natural History Museum and the University of Washington (WTU) house these voucher specimens.

We identified vascular plants in the field using dichotomous keys unless they required microscopic observation in the laboratory and only collected plants in populations of greater than twenty individuals to avoid the collection of rare species (Biek 2000, Hitchcock 1955). Current scientific names were verified using Hanson (2000). Pictures were taken of rare species to document their occurrence. Despite these precautions, we collected samples of *Pedicularis rainierensis*, a plant listed as 'sensitive' by the Washington Natural Heritage Program that is very abundant in Spray Park (Washington Natural Heritage Program 2002). Since this study focused on vascular plants and lichens, only a couple of the most abundant mosses in Spray Park were identified. Moss identifications were performed using a dichotomous key in the lab because they required microscopic observation (Lawton 1971). John Berry collected and identified lichen species. Katherine Glew verified vascular plant and lichen identifications. David Giblin verified graminoid species. Judy Harpel, moss specialist for the Gifford Pinchot National Forest Service, verified bryophyte identifications.

The second portion of the fieldwork consisted of recording environmental information and the percent cover of each plant and lichen species found in quadrats along transects (Figure 3). Data collected from transects was used to analyze the influence of abiotic factors on plant communities and the association between plants and lichens. Eight pairs of 50m parallel transects were positioned throughout upper Spray Park and along the ridge below Echo Rock (Figure 2). The second transect laid down in each parallel pair was placed 5m to the left of the first transect. The approximate latitudinal and longitudinal locations and elevations of each transect pair was determined using GPS coordination. The transect length of 50m was long enough to account for variations in microclimate among sites, such as patches of boulders (Koepke 2002). Every 5m along the right side of the transect tape 20cm by 50cm quadrats were placed. The reduced size of the quadrats used corresponded to the typically smaller size of alpine plants and lichens (Koepke 2002). Data were collected from a total of 155 quadrats.

Within quadrats each species and its percent cover was recorded. Subdivision of quadrats into 10cm by 10cm sections helped to determine the percent cover of each species more accurately. The percent covers of some plants were listed under only the genus name if the plants could not be identified to the species level. For instance, some of the *Minuartia* was recorded as "*Minuartia* spp." because it had not yet bloomed and was, thus, difficult to identify to the species level. Some of the *Phyllodoce* on exposed ridges bloomed early in the summer before the site could be accessed due to lingering snowfields in the lower elevation meadows. It was difficult to determine such *Phyllodoce* beyond the genus level because the petals had fallen off, so it was recorded as "*Phyllodoce* spp." Since this study focused on vascular plants and lichens the percent cover of mosses was recorded, but mosses were not characterized beyond the general term 'Bryophyte species.'

Information on the following environmental factors was also recorded: slope, aspect, substrate type, substrate stability, soil moisture, and soil pH (Table 1). Slope was ascertained using a clinometer. Aspect was determined in degrees using a compass then the direction was converted to a numerical system for later statistical analysis (Glew

1998). Substrate was based on observations of the ratio of soil to rock and rated on a scale of 1 (soil) to 5 (rock). Stability was also established from observations of the percentage of soil to rock then rated on a scale of 1 (loose) to 5 (stable). The soil moisture of a quadrat was difficult to classify because sites were very dry during the summer. Soil moisture was ranked on the percent cover of vegetation, presence or absence of run-off from snowfields, exposure, and the presence or absence of indicator plants and cryptogams characteristic of particular moisture levels. Soil moisture was recorded on a scale of 1 (dry) to 5 (wet). To assess soil pH, soil samples were taken at five and forty-five meters along each 50m transect. Soil was transported from the study sites to the lab in aluminum canisters. In the lab a 1:1 (soil weight : distilled water weight) mixture was made and sat overnight. Sample mixtures were stirred just before measuring the mixture with a pH meter. pH values ranged from 4.8-7.5.

Information on plant species' percent covers and environmental factors recorded from quadrats was analyzed with ordinations using the computer programs CANOCO and PC-ORD. Ordinations are statistical tools for summarizing communities. The program CANOCO created a canonical correspondence analysis (CCA) and a detrended corresponded analysis (DCA) of the data. The program PC-ORD provided a data summary and a cluster analysis used to graph a cluster dendrogram.

Five out of the 155 quadrats were excluded from the ordinational analyses using CANOCO and PC-ORD because they did not contain any vegetation. Five outlier species were also left out of the DCA and CCA analyses created by the program CANOCO and the cluster dendrogram created by PC-ORD. Each of these outlier species occurred on only one quadrat with covers of less than 5%. These outlier species were

Penstemon davidsonii, Artemisia furcata, and *Pedicularis contorta. Penstemon davidsonii, Artemisia furcata,* and *Pedicularis contorta* were not abundant throughout Spray Park. While *Phyllodoce intermedii* and *Phyllodoce glanduliflora* occurred frequently in many of the quadrats, the ambiguous title of '*Phyllodoce* species' was only used once during data collection. In the particular quadrat where this title was applied, identification to species level of a small cover of *Phyllodoce* could not be made because the flowers had bloomed too early. Similarly, the classification of '*Pedicularis* spp.' was only used once when the bracts were too withered to identify the plant beyond genus level. *Abies lasiocarpa* was another potential outlier in the ordinational analyses because although it occurred in more than one quadrat with percent covers of up to 37%, it was only present on one out of sixteen transects. *Abies lasiocarpa* was included in the CCA and DCA ordinations generated using CANOCO because it did not skew the relationships between community groupings. In the species cluster dendrogram, *Abies lasiocarpa* was excluded because it skewed the relationships between community groupings and caused excessive chaining.

Results

We identified a total of 51 vascular plant species and 45 species of lichens in Spray Park (Table 2). Two rare plant species, *Polemonium viscosum* and *Pedicularis rainierensis,* were found. The Washington Natural Heritage Program (2002) lists both these species as 'sensitive'. No previous documentation exists for populations of these two rare species in Spray Park (Mount Rainier National Park 2001).

Analysis by ordinations using the program CANOCO created both a detrended correspondence analysis (DCA) and a canonical correspondence analysis (CCA) on the data collected from transects. Ordination analyses determine relationships among samples to environmental gradients and species composition (Oklahoma State University Ecology Department 2002). Ordination analyses also recapitulate the variation between sites and along transects (Glew 1997). DCA groups species into communities without accounting for abiotic factors. CCA is a multiple regression analysis that illustrates the relationships between species and numerous environmental variables simultaneously (Jongmann *et al.* 1987). In considering the combined effects of environmental variables on plants, ordinations can provide more realistic interpretations of the correlations between plants and their surroundings. However, the multiplicity of regressions in ordinational analysis can potentially decrease the statistical confidence of the tests.

Eigenvalues are a measure of the integrity of ordinational analyses, which indicate the accuracy with which environmental axes in a DCA or CCA affect the distributions of species. Eigenvalues are on a scale of 0 to 1. An eigenvalue close to one implies that the axes for abiotic factors confidently explain the species distributions. An eigenvalue close to zero indicates that the species are randomly distributed about the environmental axes (Jongmann *et al.* 1987).

For the DCA of the transect data the eigenvalue for the horizontal axis was 0.914 (Figure 4). The six-letter reference for each species refers to the first three letters of the genus and species names (Table 3). 'Spp.' refers to plants that could not be identified to the species level in the field. In the DCA the plants separate out into two clusters – a mesic grouping and a xeric grouping. Plants of the mesic grouping were present in the moist, upper alpine meadows where snowfields melted late in the season. Plants of the xeric grouping grew in the more arid areas on the ridge between Spray Park and Echo

Rock and on the upper talus slope just below Echo Rock. Snow on these more exposed, wind-swept areas melted out early in the summer although they were at higher elevations than the upper alpine meadows. While the xeric group was more diverse than the mesic group and had a higher percentage of lichen cover, total vegetation cover (abundance) was greater in the upper alpine meadow habitats of the mesic grouping.

Along the ridgeline *Empetrum nigrum* and *Arctostaphylos uva-ursi* were most abundant with combined percent covers taking up over 60% of many quadrats. The other plants in xeric group tended to occur along the ridgeline in patches where *Empetrum nigrum* and *Arctostaphylos uva-ursi* were absent. On the upper talus slopes vegetation cover was much smaller and lichen cover was much greater than in the meadow or along the ridgeline. Loose talus and large boulder patches characterized this area. No particular species dominated the upper talus slopes as *Empetrum nigrum* and *Arctostaphylos uva-ursi* did along the ridgeline.

Bryophyte species and *Aster alpigenus* fall between the xeric and mesic groupings and are included in both groups. Mosses and *Aster alpigenus* were found in both mesic and xeric sites at all elevations. In the upper alpine meadow habitats, the percent covers of mosses ranged from 16-40% and the percent covers of *Aster alpigenus* ranged from 2-16%. Along the ridgeline and on the upper talus slope, mosses and *Aster alpigenus* were less abundant with percent covers of 0.5-3%. Bryophytes and *Aster alpigenus* are generalists capable of occurring throughout upper Spray Park.

Abies lasiocarpa is an outlier lying above both groupings in the DCA. *Abies lasiocarpa* occurred on only one of the sixteen transects from which percent cover information was collected. This transect was located in a low alpine, plant dominated, mesic, meadow area at an elevation of 1968m. Populations of *Abies lasiocarpa* were infrequent in upper Spray Park, but were common in the lower elevation, subalpine region of Spray Park. The transect in which *Abies lasiocarpa* occurred represented a transition area at the treeline where the subalpine zone ended and the alpine zone began. The *Abies lasiocarpa* population on this transect was characteristically in its krummholz form.

While DCA groups species without considering abiotic factors, CCA emphasizes how species are influenced by environmental variables. In canonical correspondence analysis, eigenvectors representing environmental variables are included along with information on species distributions. The maximum value of the abiotic factor points away from the origin of the horizontal and vertical axes. Eigenvectors closest to one of the main axes are more likely to represent a particular environmental variable. Longer vectors represent those abiotic factors that most influence species distributions. Species are nearer the environmental factors with which they are more strongly correlated (Jongmann 1987). The CCA for the transect data shows that the environmental variables of soil pH, soil moisture, substrate stability and substrate type have the greatest influence on plant communities in upper Spray Park (Figure 5). A correlation matrix created by CANOCO shows a positive correlation between soil moisture and soil pH (Table 4). The following pairs of abiotic factors exhibit negative correlations: substrate type and slope, substrate type and moisture, and elevation and aspect.

The eigenvalue for the CCA is 0.819, which is close to the maximum of one. The plants separate into the same two groups in the CCA as they did in the DCA. Mesic group plants from the DCA lie in the first and fourth quadrants of the CCA. Xeric group plants from the DCA lie in the second and third quadrants of the CCA. In the CCA *Phyllodoce glanduliflora* is closer to plants of the xeric grouping from the DCA rather than plants of the mesic grouping. The plants of mesic group from the DCA that occurred in the upper alpine meadows are strongly correlated with high soil pH, high soil moisture and soil substrate type. Measurements of pH from transects ranged between 4.8 and 7.5. Relative to this pH range, a 'high' value for pH is ~6.5-7.5.

While the plants of the mesic group are all primarily influenced by soil pH, soil moisture and substrate type, the effects of environmental factors on the plants of the xeric group are more varied. The following xeric group plants are also strongly correlated with lower soil pH, lower soil moisture and rock substrate type: *Empetrum nigrum, Smelowskia calycina, Castilleja rupicola,* and *Dasiphora floribunda. Arctostaphylos uva-ursi* is more affected by substrate stability than by soil pH, soil moisture or substrate type. Other plants are more highly correlated with elevation such as *Minuartia obtusiloba* and *Phyllodoce glanduliflora.* A large number of plants making up the xeric group do not show any striking correlations with any one environmental variable. *Anemone drummondii, Juniperus communis, Silene acaulis, Phlox diffusa, Vaccinium scoparium, Minuartia rubella, Erigeron aureus* and *Lupinus lepidus* are all not highly correlated with any eigenvector in particular. These plants may be influenced by a biotic factor, such as competition, or a specific combination of abiotic factors that this study did not address.

Analysis by ordinations using the program PC-ORD generated a cluster analysis used to make a species cluster dendrogram. A cluster analysis creates a hierarchical classification of species in which similar species are linked close together and dissimilar species are placed far apart. There are various methods for linking or sorting species and for measuring the similarity or dissimilarity between species. The cluster analysis generated in this study employed Ward's linkage method and the Sorenson (Bray-Curtis) distance measure. The Ward method is advantageous because it reduces the amount of chaining within the cluster. When chaining occurs single species are added to existing groups, and the dendrogram created from the cluster analysis fails to separate the data into a smaller number of groups. The Sorenson (Bray-Curtis) distance measure is the most effective method for use with ecological data. The only disadvantage to using Ward's Method with the Sorenson (Bray-Curtis) distance measure is that the two are incompatible. Nonetheless, according to McCune and Mefford (2000), who created the software for PC-ORD, the combination of Ward's Method and the Sorenson (Bray-Curtis) distance measure yields acceptable results despite their incompatibility.

In the species cluster dendrogram created by the PC-ORD cluster analysis there was a low degree of chaining of 6.01% (Figure 6). The results of the cluster analysis support the community groupings of the CCA and DCA. Mesic group species of the moist, meadow plant community are in the lower cluster of the dendrogram, whereas xeric group species of the arid, ridgeline community are in the upper cluster of the dendrogram. In the dendrogram, *Aster alpigenus* falls between the lower cluster of the species of the xeric, ridgeline community and the upper cluster of the species of the mesic, meadow community. The occurrence of *Aster alpigenus* between the two community clusters of the dendrogram supports the DCA and CCA evidence, which suggests that it is a generalist between the two plant communities. In contrast while *Bryophyte* spp. appeared as generalists between the two communities in the DCA and

CCA, in the dendrogram they occur among the cluster of plants from the mesic, meadow community rather than between the two communities. Although generalists capable of existing in either plant community, *Bryophyte* spp. may prefer moister habitats like those of the mesic, meadow plant community.

Phyllodoce glanduliflora appears closer to species of the mesic group in the DCA, but occurs among species of xeric group in the CCA and in the dendrogram. Like *Aster alpigenus* and *Bryophyte* spp., *Phyllodoce glanduliflora* was a generalist capable of growing among either plant community. *Phyllodoce glanduliflora* was more common in the mesic, meadow community than it was in the xeric, ridgeline community. Within the xeric, ridgeline community *Phyllodoce glanduliflora* tended to only grow in areas of unusually high moisture, such as drainages or pockets between boulders were water could collect.

The program PC-ORD also summarized data about the number of species per quadrat, the percent cover of species per quadrat, evenness, species richness, and diversity. Spray Park had an average of 1.4 species present per quadrat, and an average percentage cover per quadrat of 50%. Average evenness was 0.701 (Table 5). Evenness measures how equally distributed species are among quadrats. Evenness is rated on a scale of 0 to 1. An evenness value of one means that on average the same number of species is found per quadrat. The average species richness in Spray Park was 3.4. The highest species richness measured in a quadrat was nine (Table 5). Diversity indices consider both evenness and the number of species, also known as species richness (Townsend *et al.* 2000). The Shannon Diversity Index typically ranges from 0 to 3.5. A larger value for the Shannon Diversity Index corresponds with greater diversity. The

Shannon Diversity Index for Spray Park was 0.60. The most abundant plants at Spray Park listed from most to least common with their maximum percent cover in parentheses were: *Empetrum nigrum* (99%), *Arctostaphylos uva-ursi* (95%), *Bryophyte* spp. (90%), *Phyllodoce intermedii* (70%), and *Phyllodoce glanduliflora* (62%).

In addition to describing the plant communities at Spray Park and determining how various abiotic factors influence these plant communities, the association between plants and lichens was investigated. While the plants in Spray Park existed in two communities (the xeric, ridgeline and mesic, meadow communities), the lichens in Spray Park consisted of three distinct communities (Berry 2003). Overall there was a negative correlation between the percent cover of plants and the percent cover of lichens per quadrat (Figure 7). Despite this general trend, a few outlying quadrats exhibited both high percent covers of lichens and plants. These quadrats contained particular plant and lichen species that frequently occurred together. While there may be a general negative correlation between the percent cover of lichens and plants, there may be a positive association between lichens and plants on a species to species level.

Discussion

There is slightly greater vascular plant diversity at Burroughs Mountain than at Spray Park. Koepke identified 43 species of vascular plants at Burroughs Mountain that had an average Shannon Diversity Index of 0.89 (Koepke 2003). There were 51 species of vascular plants at Spray Park, which had a smaller Shannon Diversity Index of 0.60. Although Spray Park had more diversity than Burroughs Mountain, the average evenness for both sites was similar (Table 5).

Plants were far more abundant at Spray Park than they were at Burroughs Mountain. The average percent cover of vegetation per quadrat at Spray Park was 50%, whereas at Burroughs Mountain it was 15.4%. Plants may be more abundant at Spray Park due to climactic differences between the east and west sides of Mount Rainier. Spray Park receives more precipitation than Burroughs Mountain, which is in the rain shadow of Mount Rainier (Biek 2000). This difference in precipitation may be more pronounced when comparing this study to that of Koepe's due to the extremes between winter and spring precipitation in 2001 and 2002. Koepke performed the Burroughs Mountain study in the summer of 2001 after an unusually dry winter and spring when western Washington experienced a drought. On the other hand, the Spray Park study during the summer of 2002 followed an unusually wet winter and spring in which mid-summer snow levels throughout the Park were two times greater than most years.

The survey results of Burroughs Mountain and Spray Park show that the two sites have twenty-six species in common (Table 2). Burroughs Mountain had 15 exclusive species, and Spray Park had 27 exclusive species. The Sorenson's Index of Similarity between Burroughs Mountain and Spray Park is 0.52. The values for the Sorenson's Index of Similarity range from 0 to 1. A value of one indicates that the two sites are identical in species composition, whereas a value of two indicates that there was no similarity between the two sites.

The most abundant species of Spray Park differ from the most abundant species at Burroughs Mountain. At Spray Park the most abundant plants listed from most to least common in occurrence with their maximum percent cover in parentheses were: *Empetrum nigrum* (99%), *Arctostaphylos uva-ursi* (95%), *Bryophyte* spp. (90%), *Phyllodoce intermedii* (70%), and *Phyllodoce glanduliflora* (62%). The most commonly occurring plants at Spray Park all have structural forms that are ericaceous dense mats (i.e. *Phyllodoce glanduliflora* and *Phyllodoce intermedii*), woody ground covers (i.e. *Empetrum nigrum* and *Arctostaphylos uva-ursi*), or cryptograms (*Bryophyte* spp.). Given the high abundance of *Bryophyte* species at Spray Park, future studies on the flora in the area should ideally identify mosses to genus and species levels. At Burroughs Mountain the most abundant plants listed from most to least common with their maximum percent cover in parentheses were: *Lupinus sellulus* (95%), *Carex spectabilis* (53%), *Potentilla diversiloba* (48%), *Erigeron aureus* (47%), *Carex nardina* (44%), and *Phlox diffusa* (34%). The most abundant vascular plants at Burroughs Mountain exhibit the following structural forms: simple herbs (i.e. *Erigeron aureus* and *Solidago multiradiata*), cushions (i.e. *Phlox diffusa*), herbaceous mats (i.e. *Lupinus sellulus*), graminoids (i.e. *Carex spectabilis* and *Carex nardina*), and low-medium woody shrubs (i.e. *Potentilla diversiloba*).

Koepke's (2002) report on Burroughs Mountain includes none of the most common species and genera found in Spray Park. At Spray Park three of the most abundant species at Burroughs Mountain were present, but they occurred with less frequency. These three species were *Carex spectabilis, Erigeron aureus,* and *Phlox diffusa.* Although *Lupinus sellulus, Potentilla diversiloba,* and *Carex nardina* were not found at Spray Park, other members of these plants genera did occur at Spray Park. Although Spray Park and Burroughs Mountain are both located on Mount Rainier they have strikingly different species compositions of plant populations.

While this study identified two plant communities within Spray Park, the Burroughs Mountain study defined three plant communities. Burroughs Mountain is a formation composed of three small mountains. A different plant community existed on each of the three mountains of Burroughs Mountain (Koepke 2002). At Spray Park the primary environmental factor determining overall community composition was soil moisture. According to Koepke, at Burroughs Mountain the most influential abiotic factors in determining overall community composition were substrate type and substrate stability. In comparing the relative abundances of the plant communities at Spray Park to those at Burroughs Mountain, moisture appears to be the environmental factor that is most significant in determining the relative plant communities between the two sites. Prior to this study, moisture would not be apparent as a major determinant of plant community structure at Burroughs Mountain simply because the area is so devoid of moisture. Once again, the difference in the climates of Spray Park and Burroughs Mountain is due to the rain shadow created by immense height of Mount Rainier (Biek 2000).

Given the low percent covers of both plants and lichens at Burroughs Mountain, Koepke and Miller did not compare the percent cover of lichens to the percent cover of plants. In this study the greater abundance of plants and lichens enabled a comparison of the percent cover of lichens to the percent cover of plants in order to further investigate the association between plants and lichens studied by Glew (1997). In Glew's study, there was a negative correlation between percent cover of lichens to other plants in the mesic, snow bank communities of Tatie Peak. Conversely, there was a positive correlation between percent cover of lichens and vascular plants and other cryptograms at the xeric, tundra site of Deer Park. In this study a negative correlation existed between percent cover of lichens and plants. In more mesic plant-dominated habitats, plant may outcompete lichens because of their ability to grow and reproduce more rapidly. Lichens tend to dominate in more arid habitats where soil moisture is low because unlike plants lichens are capable of obtaining moisture from the air.

Although Glew (1997) noted an overall negative correlation between the percent covers of lichens and plants at the snow bank communities of Tatie Peak, particular species of plants exhibited a positive relationship with particular species of lichens. Moreover, lichen communities were not dependent on particular plant species, but were dependent on specific plant structural forms. For instance, plants with woody, shrub structural forms that tended to form mats (i.e. *Phyllodoce empetriformis, P. glanduliflora, Cassiope mertensiana,* and *Vaccinium deliciosum*) frequently had the following lichen species growing among them: *Tuckermannopsis subalpina, Solorina crocea, Cladina mitis, Trapeliopsis granulosa,* and *Cladonia* spp.

At Spray Park positive species to species relationships between plants and lichens were noted, but have not yet been quantified. For instance, *Cladonia* spp. were observed among plants with structures that formed ericaceous dense mats, such as *Phyllodoce intermedii, P. glanduliflora, P. empetriformis,* and *Cassiope mertensiana.* As an epiphyte, *Cladonia* oftentimes appeared to be using the matted structures of *Phyllodoce* and *Cassiope* as a trellis on which it could spread out to optimize its exposure to the atmosphere. The lichen *Peltigera ponogensis* oftentimes occurred at the base of or entangled in the tussocks of graminoid species, such as *Carex spectabilis* and *Festuva ovina.*

Since lichens tend to associate with plants of particular structural forms rather than with specific plant species, lichen communities can stretch across different plant communities as long as the different plant communities exhibit the same structural forms (Glew 1997). At Spray Park Berry noted three distinct lichen communities although there were only two plant communities (Berry 2003). Lichens and plants existing in the same habitat do not necessarily have the same community structures. In monitoring populations of plants and lichens it is important to realize that the two are different, but highly related components of their environment.

Conclusion

Spray Park was inaccessible due to snow until mid-July by which time some plants on the exposed ridges may have already bloomed. Although the survey of plants was thorough, some of these plants may have been overlooked. The plants in Spray Park should be surveyed in subsequent years to contribute to the catalogue of plants documented by this study. The plants of Spray Park should also be surveyed to monitor the two 'sensitive' plants, *Pedicularis rainierensis* and *Polemonium viscosum,* in the area. The Mount Rainier National Park General Management Plan (GMP) lists both of these plants as species whose occurrences should be documented (Mount Rainier National Park 2001). Although infrequent in the state of Washington, *Pedicularis rainierensis* was extremely abundant in Spray Park. Conversely, there were only 24 individuals of *Polemonium viscosum* in the area.

Information collected from transects may contribute to a better understanding of the distributions of these rare plants. It is important to understand where imperiled plant species occur in the natural environment to increase the success of revegetation efforts.

For instance, when ecologists attempt to alleviate populations of endangered plants they must be aware of where the newly reintroduced populations will be most successful (Center for Plant Conservation 2002). *Pedicularis rainierensis* occurred in the mesic, lower and upper alpine meadows of Spray Park. *Polemonium viscosum* only occurred in the xeric, upper talus slope area below Echo Rock. The CCA shows that the upper alpine meadow habitat of *Pedicularis rainierensis* is most influenced by pH, moisture and substrate. On the other hand, the influence of environmental factors in drier areas such as the ridgeline and talus slope is more varied. More plants in the xeric ridge and talus regions did not show high correlations to one particular environmental variable. These plants may be more affected by biotic factors not considered in the CCA, such as associations with lichens. Although *Polemonium viscosum* was not present on any of the transects in this study, an understanding of the distribution of plants included in its community may aid to understanding its conservation in the future.

Further analysis should be performed to explore the association between plants and lichens across Mount Rainier. While a comparison of the percent macrolichen to plant cover was not possible due to the low percent covers of both plants and lichens at Burroughs Mountain, it may be possible to compare the percent of microlichen cover to plant cover. In dry, tundra sites like that of Burroughs Mountain, there tend to be more saxicolous or rock crust lichens. In addition to performing a more intensive study of the microlichens at Burroughs Mountain, it would be necessary to classify the plants from the Burroughs Mountain and Spray Park studies into structural form groupings. Ideally, after combining the information on the association between plants and lichens at Burroughs

Mountain and Spray Park, a comparison could be made between the Mount Rainier findings and Glew's study in the Olympic and North Cascade Mountains.

Table 1. Description of collection of data on abiotic factors from transects and quadrats.

Factor	Tools	Scale
Location	GPS coordination	Latitude and Longitude
Elevation	GPS coordination, topographic map	Meters
Slope	Clinometer	Degrees
Aspect	Compass	Degrees converted to numeric scale • 1 = N, NE, NNE • 2 = ENE, NNW • 3 = E, NW • 4 = E, SE, WNW • 5 = SE, W • 6 = S, SW, SSW
Substrate	Ratio of soil to rocks	Scale of 1 (soil) to 5 (rock) with: • 1 = 100% soil • 5 = 100% rock
Stability	Ratio of soil to rocks	Scale of 1 (loose) to 5 (stable) with: • 1 = >60% soil • 5 = >60% 10cm^3 or larger rocks or boulders
Soil Moisture	Percent of vegetation cover, presence/absence of snowfield runoff and presence/absence of indicator plants or cryptogams	Scale of 1 (dry) to 5 (wet) with: • 1 = vegetation cover of 0-30%, no runoff, indicator plants or cryptogams absent • 2 = vegetation cover of 50-100%, runoff, indicator plants or cryptogams present
Soil pH	pH meter	pH

Table 2. List of all vascular plants and some of the mosses found in Spray Park and Burroughs Mountain. Thirty-five of the fifty-one species of plants found in Spray Park were present on transects from which percent cover and environmental data were collected. Twenty-four of the species present in Spray Park were also present on Burroughs Mountain. Mosses were not identified when collecting percent cover information from transects, but given their high abundance in Spray Park, the moss species listed probably occurred on transects.

Species Name	Common Name	Spray Park	Burroughs Mountain	Spray Park Transect	Burroughs Mountain Transect
Vascular Plants					
Abies lasiocarpa (Hook.) Nutt.	Subalpine Fir	X		X	
Achillea millefolium var. alpicola (Rydb.) Garrett	Common Yarrow		X		
Agoseris glauca var. dasycephala (Torr. & Gray) Jepson	Pale Agoseris		X		X
Anemone drummondii S. Wats.	Drummond's Anemone	X	X	X	X
Antennaria lanata (Hook.) Greene	Woolly Pussytoes	X	X		X
Antennaria media Greene	Rocky Mountain Pussytoes		X		X
Arctostaphylos uva-ursi (L.) Spreng.	Kinnikinnick	X		X	
Arenaria capillaries Poir.	Slender Mountain Sandwort		X		X
Artemisia furcata var. *furcata* Bieb.	Forked Wormwood	X	X	X	X
Caltha leptosepala DC.	White Marsh Marigold	X			
Carex spectabilis Dewey	Showy Sedge	X	X	X	X
Cassiope mertensiana (Bong.) D. Don	Western Moss Heather	X	X	X	
Castilleja parviflora Bong.	Mountain Indian Paintbrush	X	X		
Castilleja rupicola Piper ex Fern.	Cliff Indian Paintbrush	X	X	X	
Cistanthe umbellata var. caudicifera	Mount Hood Pussytoes		X		X
Dasiphora floribunda (Pursh) Kartesz, comb. nov. ined.	Shrubby Cinquefoil	X	X	X	
Dodecatheon jeffreyi Van Houtte	Sierra Shootingstar	X			
Empetrum nigrum L.	Black Crowberry	X		X	
Erigeron aureus Greene	Alpine Yellow Fleabane	X	X	X	X
Eriogonum pyrofolium var. coryphaeum Torr. & Gray	Shasta Buckwheat		X		X
Erythronium montanum S. Wats.	White Avalanche-lily	X			
Festuva ovina L.	Sheep Fescue		X		X

Gentiana calycosa Griseb.	Rainier Pleated Gentian	X			
Juniperus communis L.	Common Juniper	X		X	
Kalmia microphylla (Hook.) Heller	Alpine Laurel	X		X	
Ligusticum grayi Coult. & Rose	Gray's Licorice Root	X			
Luetkea pectinata (Pursh) Kuntze	Partridgefoot	X	X	X	
Lupinus arcticus S. Wats.	Alpine Lupine	X			
Lupinus lepidus Dougl. ex Lindl.	Pacific Lupine	X		X	
Lupinus sellulus ssp. *sellulus* var. lobbii (Gray ex S. Wats.) Cox	Donner Lake Lupine		X		X
Minuartia obtusiloba (Rydb.) House	Twinflower Sandwort	X	X	X	X
Minuartia rubella (Wahlenb.) Hiem.	Beautiful Sandwort	X		X	
Oreostemma alpigenum (Torr. & Gray) Greene	Tundra Aster	X	X	X	X
Oxyria digyna (L.) Hill	Alpine Mountainsorrel		X		
Pedicularis contorta Benth.	Coiled Lousewort	X	X	X	X
Pedicularis ornithorhynca Benth.	Ducksbill Lousewort	X		X	
Pedicularis rainierensis Pennell & Warren	Mt. Rainier Lousewort	X		X	
Penstemon davidsonii Greene	Davidson's Penstemon	X	X	X	X
Penstemon procerus Dougl. ex Graham	Littleflower Penstemon	X	X		X
Phlox diffusa Benth.	Spreading Phlox	X	X	X	X
Phyllodoce empetriformis Sm. D. Don	Pink Mountainheath	X	X		
Phyllodoce glanduliflora (Hook.) Coville	Yellow Mountainheath	X	X	X	X
Phyllodoce intermedii (Hook.) Rydb. (pro sp.)		X	X	X	
Picea engelmannii Parry ex. Engelm.	Engelmann Spruce	X	X		
Pinus albicaulis Engelm.	Whitebark Pine	X	X	X	
Polemonium elegans Greene	Elegant Jacob's Ladder	X	X		
Polemonium viscosum Nutt.	Sticky Jacob's Ladder	X			
Polygonum bistortoides Pursh	American Bistort	X			
Polygonum davisiae Brewer ex Gray	Davis' Knotweed		X		
Potentilla diversifolia var. diversifolia	Varileaf Cinquefoil		X		X
Potentilla flabellifolia Hook. ex Torr. & Gray	High Mountain Cinquefoil	X			
Sagina saginoides L.	Arctic Pearlwort	X			

Karst.					
Saxifraga caespitosa ssp. *Caespitosa* L.	Tufted Alpine Saxifrage		X		X
Saxifraga tolmiei Torr. & Gray	Tolmie's Saxifrage	X	X		
Sedum rupicola G.N. Jones	Curvedleaf Stonecrop		X		X
Selaginella wallacei Hieron.	Wallace's Spikemoss	X			
Silene acaulis L. Jacq.	Moss Campion	X	X	X	X
Smelowskia calycina (Steph. ex Willd.) C.A. Mey	Alpine Smelowskie	X	X	X	X
Solidago multiradiata Ait.	Rocky Mountain Goldenrod		X		X
Solidago simplex Kunth.	Mt. Albert Goldenrod	X		X	
Tauschia stricklandii (Coult. & Rose) Mathias & Constance	Strickland's Umbrellawort	X		X	
Trisetum spicatum (L.) Richter	Spike Trisetum		X		X
Vaccinium deliciosum Piper	Cascade Bilberry	X		X	
Vaccinium scoparium Leib. ex Coville	Grouse Whortleberry	X		X	
Veronica cusickii Gray	Cusick's Speedwell	X	X		X
Xerophyllum tenax (Pursh) Nutt.	Common Beargrass	X			
Mosses					
Dryptodon patens		X			
Rhacomitrium heterostichum		X			

Table 3. List of plants in the ordination graphs (with their six-letter codes).

ABI LAS = *Abies lasiocarpa,* ANE DRU = *Anemone drummondii,* ARC UVA = *Arctostaphylos uva-ursi,* ART FUR = *Artemisia furcata,* AST ALP = *Aster alpigenus,* BRY SPP = Bryophyte species, CAR SPP = *Carex* species, CAS MER = *Cassiope mertensiana,* CAS RUP = *Castilleja rupicola,* DAS FLO = *Dasiphora floribunda,* EMP NIG = *Empetrum nigrum,* ERI AUR = *Erigeron aureus,* GEN CAL = *Gentiana calcyosa,* GRA SPP = Graminoid species, KAL MIC = *Kalmia microphylla,* JUN COM = *Juniperus communis,* LUE PEC = *Luetkea pectinata,* LUP LEP = *Lupinus lepidus,* MIN OBT = *Minuartia obtusiloba,* MIN RUB = *Minuartia rubella,* MIN SPP = *Minuartia* species, PED CON = *Pedicularis contorta,* PED ORN = *Pedicularis ornithorhynca,* PED RAI = *Pedicularis rainierensis,* PED SPP = *Pedicularis* species, PHL DIF = *Phlox diffusa,* PHY GLA = *Phyllodoce glanduliflora,* PHY INT = *Phyllodoce intermedii,* SIL ACA = *Silene acaulis,* SME CAL = *Smelowskia calycina,* SOL SIM = *Solidago simplex,* TAU STR = *Tauschia stricklandii,* VAC DEL = *Vaccinium deliciosum,* VAC SCO = *Vaccinium scoparium.*

Table 4. Correlation matrix of environmental variables in the CCA of upper Spray Park plants. Variables may be positively or negatively correlated with strongest correlations corresponding to +/-1. There is a strong positive correlation between moisture and pH.

Environmental Variable	Elevation	pH	Slope	Aspect	Substrate	Stability	Moisture
Elevation	1.0000	-	-	-	-	-	-
pH	-0.6425	1.0000	-	-	-	-	-
Slope	-0.0063	0.1946	1.0000	-	-	-	-
Aspect	-0.8602	0.6286	-0.181	1.0000	-	-	-
Substrate	0.4680	-0.6063	-0.0955	-0.3496	1.0000	-	-
Stability	-0.1458	-0.0644	0.0218	0.2080	-0.0370	1.0000	-
Moisture	-0.5274	0.8049	0.1298	0.4076	-0.7816	0.0201	1.0000

Table 5. A comparison of information from PC-ORD data summarizations for Spray Park and Burroughs Mountain.

Study Site	Average number of species per quadrat	Average percent cover per quadrat	Average Evenness	Average Species Richness	Average Shannon Diversity Index
Spray Park	1.4	50%	0.701	3.4 (up to 9)	0.60
Burroughs Mountain	5.5	15.4%	0.726	4.4 (up to 11)	0.89

Figure 1. Map of Mount Rainier National Park, Washington, U.S.A. The study site is located at Spray Park (46.916°N, 121.824°W) on the northwestern side of the mountain. Miller and Koepke's study in 2001 was performed at Burroughs Mountain (46.55° N, 121.41° W) on the northeastern side of the mountain. (National Geographic 2002, GORP 2002)

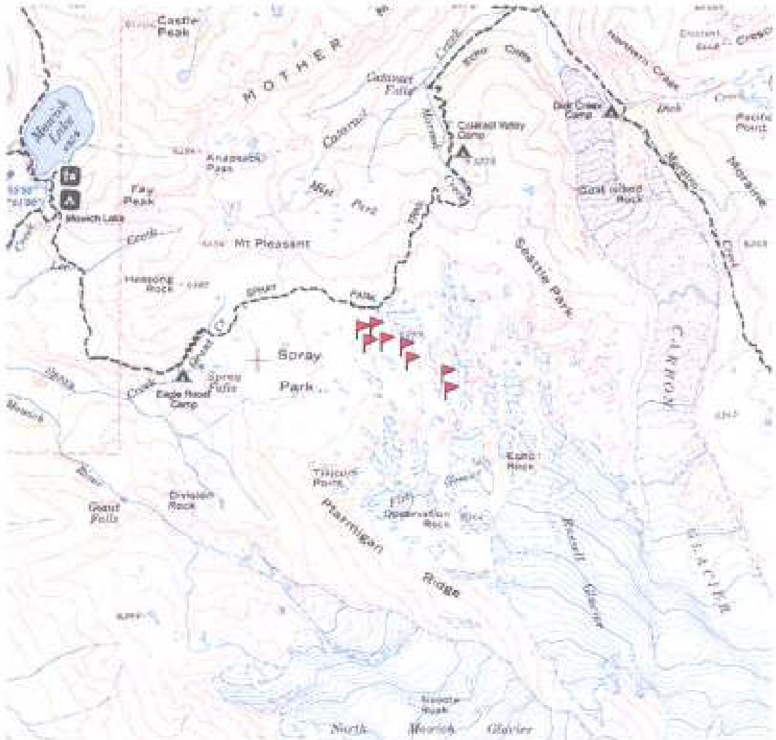

Figure 2. Topographic map of Spray Park, Mount Rainier. The ridge below Echo Rock lies between Spray Park and Seattle Park. The summit of Mount Rainier is to the southeast corner of the map. Locations of pairs of 50m parallel transects are indicated by flags. The dotted line marks the Wonderland Trail, which transects Spray Park. Elevations at labeled on the index contour lines are in feet.

Figure 3. Transect tape positioned along the ridge between Spray Park and Echo Rock where both lichens and plants are dominant. Echo Rock is to the left. The summit of Mount Rainier is to the right.

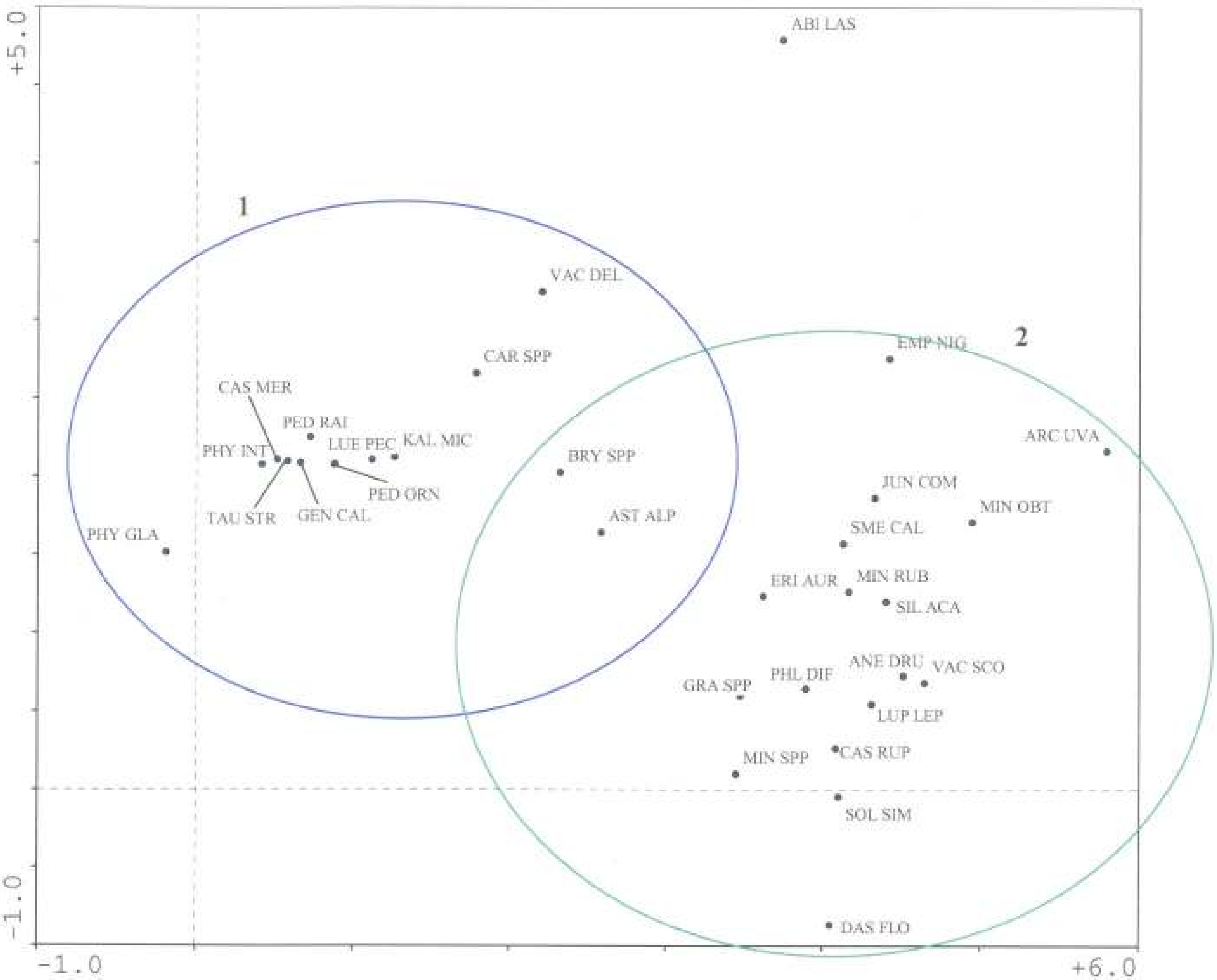

Figure 4. Detrended Correspondence Analysis (DCA) for species percent cover data collected on transects. For six-letter code of plant names see Table 3. The grouping labeled with the number one represents plants that occur in mesic, upper alpine meadow areas. The grouping labeled with the number two represents plants that occur in xeric areas along the ridgeline between Spray Park and Echo Rock and on the talus slope below Echo Rock. Bryophyte species and *Aster alpigenus* are generalists occurring throughout upper Spray Park in both the mesic and xerix communities.

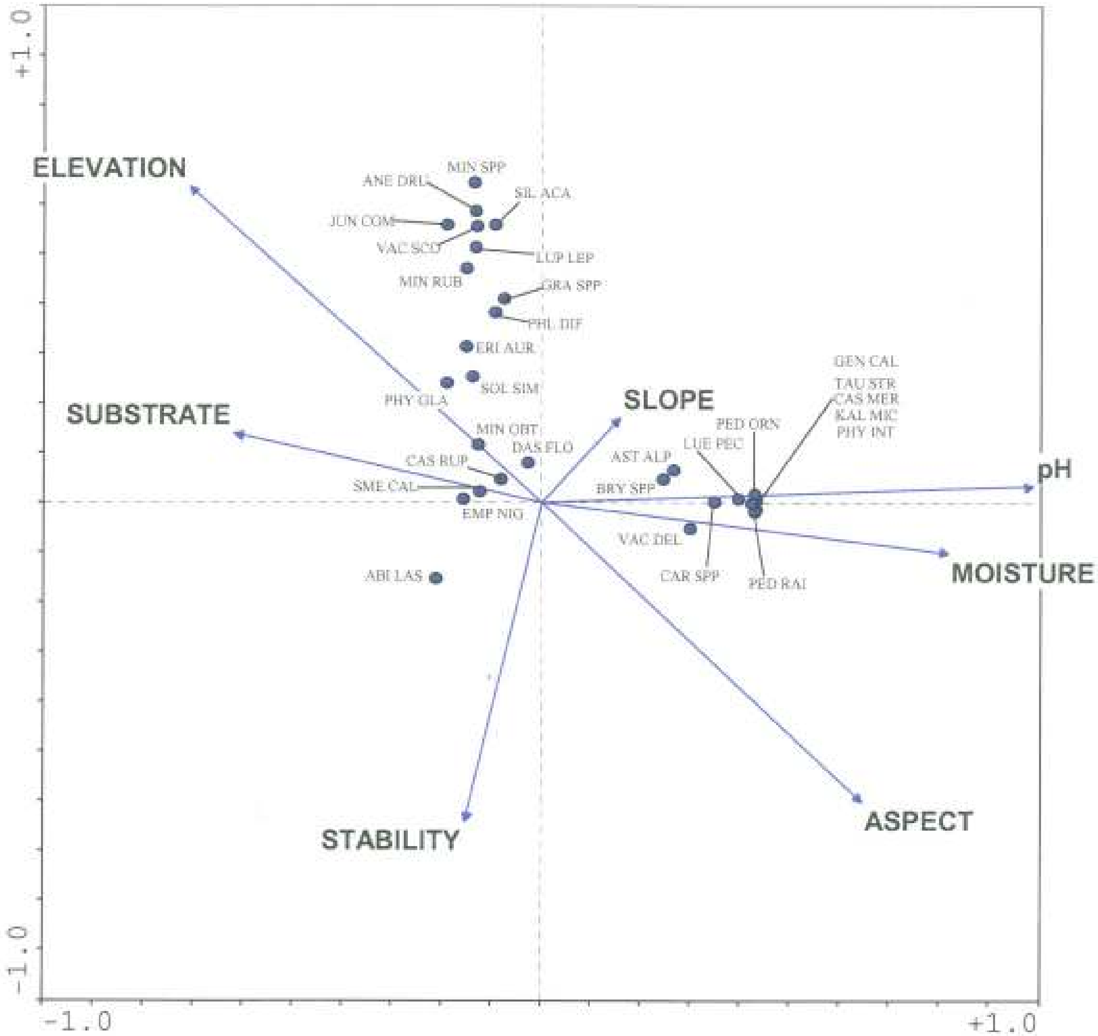

Figure 5. Canonical Correspondence Analysis (CCA) for species and environmental data collected on transects. For six-letter code of plant names see Table 3. Plants separate into two groups here as they did in the DCA in Figure 4 with the exception of *Phyllodoce glanduliflora.*

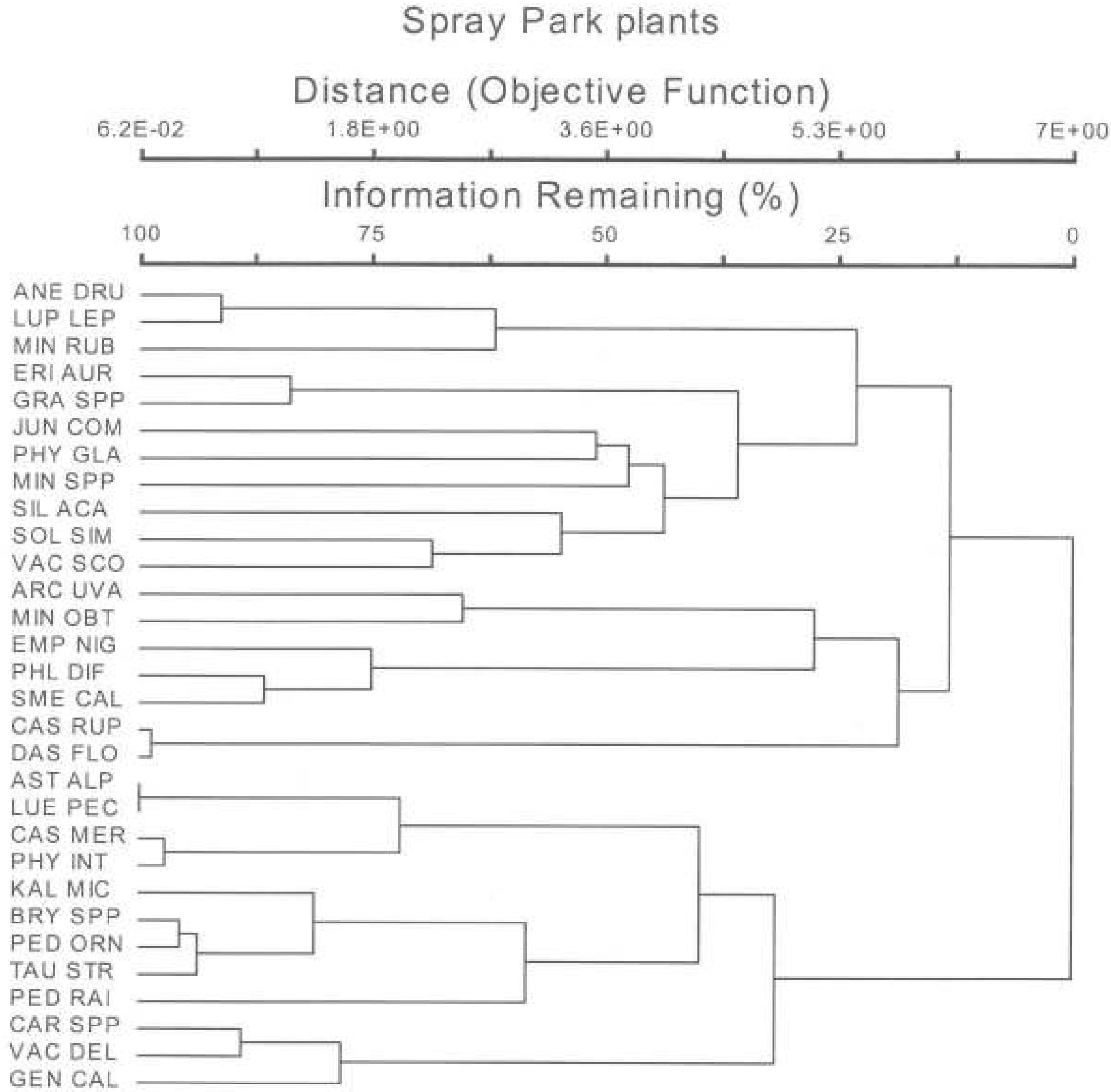

Figure 6. Dendrogram created by species cluster analysis generated by PC-ORD. The cluster analysis was performed using Ward's linkage method and the Sorenson (Bray-Curtis) distance measure. Plants separate into two groups here as they did in the DCA in Figure 4 and the CCA in Figure 5.

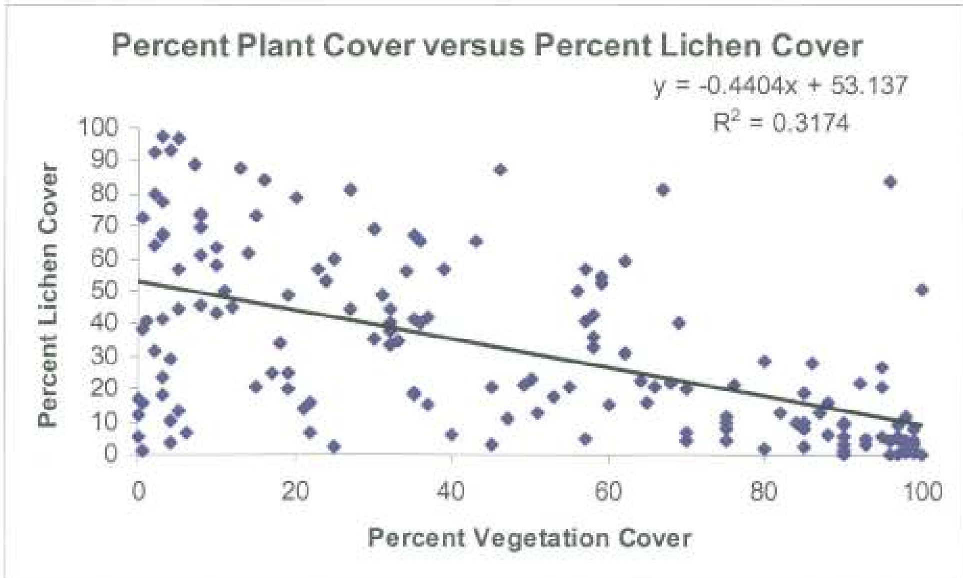

Figure 7. Plot of percent plant cover versus percent lichen cover per quadrat. Overall there was a negative correlation between percent plant cover and percent lichen cover. A positive correlation between plant and lichen percent cover was observed on a species to species level. Outliers on the graph below in which there is both high lichen and plant percent cover represent quadrats containing positively associated lichen and plant species.

References

Addison, P.A. and K.L. Bell. 1976. Plant growth in relation to surface disturbances, King Christian Island. Ed. L.C. Bliss. Department of Indian Affairs and Northern Development, Ottawa.

Berglund, L. and Eversman, S. 1988. Flow cytometric measurement of pollutant stresses on algal cells. *Cytometry* **9**: 150-155.

Berry, J. 2003. Alpine macrolichen diversity at Spray Park, Mount Rainier National Park, WA, USA. Senior Thesis at the University of Puget Sound. Tacoma, WA. Unpublished.

Biek, D. 2000. Flora of Mount Rainier National Park. Oregon State University Press, Corvallis.

Center for Plant Conservation. 2002. Recovering America's Vanishing Flora. http://www.centerforplantconservation.org. [Accessed online April 21, 2003].

Fiske, R. S., C.A. Hopson & A.C. Waters. 1963. Geology of Mount Rainier National Park. Geological Survey Professional Paper 444. United States Government Printing Office, Washington.

Franklin, J.F., W.H. Moir, M.A. Hemstrom, S.E. Greene & B.G. Smith. 1988. The Forest Communities of Mount Rainier National Park. U.S. Government Printing Office, Washington, D.C.

Gardes, M. and A. Dahlberg. 1996. Mycorrhizal diversity in arctic and alpine tundra: an open question. *New Phytologist* **133**(1): 147-157.

Glew, K.A. 1997. Do vascular plant communities influence the structure of alpine lichen communities? *Bibliotheca Lichenologica* **68**: 177-194.

Glew, K.A. 1998. Distribution and diversity of alpine lichens: Biotic and abiotic factors influencing alpine lichen communities in the northeast Olympic and North Cascade Mountains. Ph.D. dissertation. University of Washington. Seattle, Washington. 210pp.

Gold, W.G., K.A. Glew & L.G. Dickson. 2001. Functional influences of cryptobiotic surface crusts in an alpine tundra basin of the Olympic Mountains, Washington, U.S.A. *Northwest Science* **75**(3): 315-326.

GORP. 2002. Mount Rainier National Park Area Map. http://www.gorp.com/gifs/states/wa/m_mtrahk.gif. [Accessed online December 17, 2002].

Hanson, E. 2000. Plants database from: USDA/Natural Resources Conservation Service. U.S.

Forest Service, Portland.

Hithcock, C.L. 1955. Vascular Plants of the Pacific Northwest. University of Washington Press, Seattle.

Jongmann, R.H.G., C.J.F. ter Braak & O.F.R. van Tongeren. 1987. Data Analysis in Community and Landscape Ecology. Cambridge University Press, New Haven.

Lawton, E. 1971. Keys for the Identification of the Mosses of the Pacific Northwest. Hattori Botanical Laboratory, Nichinan, Japan.

Koepke, L. 2002. Description of alpine vascular plant communities on Burroughs Mountain, Mt. Rainier, WA, U.S.A. Senior Thesis at the University of Puget Sound. Tacoma, WA. Unpublished.

Körner, C. 1999. Alpine Plant Life. Springer, Berlin.

McCune, B. & Mefford, M.J. 2000. PC-ORD. Multivariate Analysis of Ecological Data, Version 2.0. mjm Software Design User's Guide. Glenenden Beach, Oregon.

Miller, C. 2002. Description of alpine macrolichens on Burroughs Mountain, Mt. Rainier, WA, U.S.A. Senior Thesis at the University of Puget Sound. Tacoma, WA. Unpublished.

Mount Rainier National Park. 2001. Ecological Plant Monitoring Report. Unpublished.

Mount Rainier Natural and Cultural Resources Division. 2002. Air resources management. http://www.nps.gov/mora/ncrd/airrm.htm. [Accessed online December 11, 2002].

National Geographic. 2002. Destinations: Mount Rainier National Park. *http://www.nationalgeographic.com/destinations/images/art/Mount-Rainier.gif*. [Accessed online December 17, 2002].

Oklahoma State University Ecologoy Department. Ordination methods for ecologists. *http://www.okstate.edu/artsci/botany/ordinate/*. [Accessed online September 11, 2002].

Peteron, D. and R. Jacobs. 1999. USGS study confirms an urban air-pollution problem at Mount Rainier National Park. U.S. Department of the Interior news release. *http://www.crcwater.org/issue8/19990530mtranier.html*. [Accessed online December 15, 2002].

Sigal, L.L. & T.H. Nash. 1983. Lichen communities in southern California mountains: an ecological survey relative to oxidant air pollution. *Ecology* **64**(6): 1343-1354.

St. John, H. & F.A. Warren. 1937. The plants of Mount Rainier National Park, Washington. *American Midland Naturalist* **18**(6): 952-985.

Townsend, C.R., J.L. Harper, and M. Begon. 2000. Essentials of Ecology. Blackwell Science, Oxford.

Washington Natural Heritage Program. 2002. Rare plant species with ranks. *http://www.wa.gov/dnr/htdocs/fr/nhp/refdesk/fsrefix.htm*. [Accessed online December 17, 2002].