ECOLOGICAL EVALUATION OF A RESTORED SUBALPINE GRASSLAND SUNRISE, MOUNT RAINIER

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DEDICATION

To Henry Harrison Kinskey

CHAPTER I INTRODUCTION

1.0 SUBALPINE PLANT COMMUNITIES

Subalpine plant communities are transition zones between closed montane forest and the treeless alpine zone. Also referred to as timberline or parkland, this ecotype consists of a mosaic of montane tree islands, open meadow communities, snow patches and rocky outcrops (Korner 1999). Like alpine plant communities, the subalpine zone is subject to stressful environmental conditions that include high winds, intense UV radiation, extended snow cover and short growing seasons. These environmental variables affect the size and type of vegetation found in subalpine areas. The distribution of montane tree islands and meadow communities are determined by environmental gradients such as snow depth in winter, time of snow melt, fire, and variations in geologic substrate (Armand 1992; Franklin and Dyrness 1988; Rochefort *et al.* 1994).

As the second highest peak in the continental United States, Mount Rainier has extensive subalpine meadow communities. The subalpine meadow communities of Mount Rainier in western Washington's Cascade Mountains were described by Henderson (1974). Dominant tree species found include *Tsuga mertensiana, Abies lasiocarpa,* and *Pinus albicaulis*. Meadow species include heath shrub communities dominated by ericaceous plants; perennial forb/low herbaceous communities dominated by *Valeriana sitchensis* and *Carex spectabilis* and dryer grasslands dominated by *Festuca viridula* and *Lupinus latifolius* or *Aster ledophyllus*. The Festuca grassland communities are conspicuous on the northeast slopes of Mount Rainier which have warmer, drier climates due to the rain shadow effect cast by Mount Rainier. The Fescue grasslands are the focus of this investigation.

The subalpine meadows of Mount Rainier provide habitat and summer forage to mountain goats (*Oreamnos americanus*), elk (*Cervus elaphus*), and marmots (*Marmota caligata*). Black bear (*Ursus americanus*) and cougars (*Puma concolor*) have also been

sited. One of the most conspicuous inhabitants of the subalpine meadows at Mount Rainier is the Hoary marmot (*Marmota caligata*) (Figure 1). Marmots graze on herbaceous perennials during the growing season, put on fat that nearly doubles their body weight and hibernate for about half the year. They create underground burrows into soils in both wet and dry meadows (Mathews 1999). The entrances to the burrows are characterized by large mounds which often have slightly different vegetation composition and density than the surrounding meadow. By creating disturbances and consuming "palatable" species, Marmots affect plant community dynamics in subalpine meadows (del Moral 1984).

Figure 1: Hoary Marmot (*Marmota caligata*)

Burrows were found throughout the subalpine grasslands at Sunrise including within restoration sites along the Sunrise Campground Trail.

Anthropogenic activities such as hiking and construction of roads, campsites and buildings pose a great threat to subalpine plant communities. Environmental stress

coupled with anthropogenic activities make recovery from disturbance a slow and difficult process. Road building and removal activities as well as trampling from foot traffic and camping cause soil loss and compaction, loss of soil aggregation and destroys diaspore resources and vegetative cover (Belnap 1998; de Gouvenain 1996; Fattorini 2001; Zabinski and Wojtowicz 2000).

Natural colonization and development of vegetative cover could take centuries even when degraded sites are close to undisturbed reference communities (Curtin 1995). For example, plant colonization was slowed and both diversity and cover of vascular plants were greatly reduced 31 years after construction in road cuts found in high sub-alpine areas compared to lower sub-alpine areas of Obstruction Point in the Olympic Mountains of Washington (Bell and Bliss 1973). Likewise, natural revegetation of an abandoned road was limited to road cut edges of the Sunrise Road in Mount Rainier National Park twenty years after vehicle access ceased (Rochefort 1997).

1.1 REVEGETATION OF SUBALPINE MEADOWS

Direct seeding and use of greenhouse grown plants and transplants are two strategies used to speed the recovery of subalpine grasslands damaged by anthropogenic disturbance. By using transplants, the vulnerable life stages of germination and recruitment are bypassed allowing establishment and reproduction to occur more quickly (Fattorini 2001; Urbanska 1997).

During the first growing season, transplants have little aboveground growth and use most of their energy for belowground investments. In the subalpine, the majority of shoot growth occurs only after the second and third growing seasons (Urbanska 1997). Because root development is the key to survival in alpine and subalpine environments, investing resources early in root development allows alpine plants to access water and

nutrients for vegetative and reproductive shoot growth in the following growing seasons (Korner 1999).

Greenhouse grown plants facilitate the formation of a self-sustaining plant community and speed the recovery process of degraded grasslands. These plants serve as population founders by acting as nurse plants and seed sources. In plant communities where “abiotic stress is high” such as in high elevations, plants enhance the “performance of neighboring species” by providing shade, protection from herbivores and nutrient sinks (Callaway 2002). Greenhouse plugs and transplants also provide such advantages as microclimates for new seedlings to emerge and decrease seedling mortality due to physical stress (Rochefort and Gibbons 1992; Urbanska 1997).

The effect of vegetation present on a site rather than abiotic factors such as soil composition and microclimate, guides the subsequent species composition of a disturbed site (Curtin 1995). In his research on the structure and function of restored tall grass prairies, Baer (2002) found that by establishing native grasses, disturbed plant communities were put on a trajectory toward recovery and over time mirrored the original system.

1.2 SOIL FUNCTIONS AND RESTORATION

Soils are complex systems comprised of minerals, organic compounds and living organisms. The soil system has specific biological, chemical and physical properties that define its ecological functioning and affect the entire ecosystem. Soils sustain plants and animals by providing the appropriate environment for the exchange and regulation of water, air, nutrients and energy. Plant development functions without limitation when the demands of plant growth do not exceed the soils capacity to provide adequate moisture,

aeration, nutrients, strength, appropriate temperatures and soil organisms (de Gouvenain 1995).

Alpine and subalpine soils are young, poorly developed soils that are exposed to intense climatic and cryogenic processes that affect soil formation and stability (Korner 1999). These soils are also exposed to human impacts that negatively affect plant cover, soil organic matter, soil compaction, soil chemistry and microbial activity (de Gouvenain 1996). Soil microorganisms and mycorrhizal fungi play a pivotal role in nutrient cycling, organic matter decomposition and soil structural development (Bradshaw 1997; Haselwandter 1997). Microbial and fungal communities in extreme or chronically disturbed ecosystems are generally destroyed due to plant loss and soil structure degradation (Zabinski and Gannon 1997).

In degraded alpine grasslands, bare soils subject to high solar radiation, needle ice heaving and topsoil desiccation permit only few seedlings to survive and creates barriers to recovery from disturbance (Korner 1999). Degraded soils can be restored; however, the trajectory of succession and restoration success are largely determined by the type of disturbance, the treatments used and the vegetation established on the site (Chambers 1997; van Ommeren 2001).

1.3 ECOLOGICAL RESTORATION: QUANTIFYING RECOVERY

The objective of restoration is to reflect in the restored community the ecological processes present in the reference community. Therefore, comparisons between undisturbed and restored sites can be used to evaluate restoration progress and success (Chambers 1997). Although monitoring is included in most restoration plans, studies that evaluate the structure and ecological functioning of above- and belowground components are few (Baer *et al*. 2002).

Curtin (1995), in his study evaluating natural recovery patterns in disturbed subalpine communities of Colorado, states that recovery can not always be defined as a return to pre-disturbance conditions. This is due to stochastic events that preclude recovery from occurring such as ongoing disturbance and climate change. In her efforts to quantify recreational impacts in subalpine areas of Arches National park, Belnap (1998) discusses the importance of choosing indicators for evaluation that have ecological relevance for a particular habitat as well as understanding their response to disturbance. This includes evaluating plant community and soil types in undisturbed areas as well as the level and kind of disturbance present.

Assessing growth and productivity of plant communities as well as characterizing soil development and microbial activity has important diagnostic value for determining the status of ecological functions and the long-term sustainability of restoration in the subalpine. Ideally, both short- and long-term evaluation should be implemented to characterize the fitness of vegetation and soil components, particularly in subalpine and alpine ecosystems where recovery from disturbance is extremely slow.

1.4 RESEARCH FOCUS

This study examines plant community and soil characteristics in the Sunrise Restoration Area of Mount Rainier and adjacent undisturbed subalpine meadows. Qualitative and quantitative monitoring is an integral component of the restoration program at Mount Rainier National Park. However, only qualitative assessments of the Sunrise restoration have been conducted based on seeding success, seedling survival and mulch condition. The objective of this study is to evaluate the progress of the Sunrise Restoration through a quantitative ecological approach by:

1. Comparing soil chemical, physical and biological properties among restoration sites of different ages.
2. Comparing vegetative cover and species composition in the restoration sites and adjacent undisturbed grasslands.
3. Evaluating the productivity of greenhouse grown *Festuca-viridula* plugs in the restoration sites.

CHAPTER II METHODS

2.0 STUDY SITE

Sunrise campground and the connecting roadway were constructed in a subalpine meadow in Mount Rainier National Park in the early 1930's. The auto-camp was constructed in a valley adjacent to Yakima Park and Burroughs Mountain providing visitors with easy access to subalpine parkland and alpine tundra. Sunrise is located in the northeastern side of the park (latitude 46° 55′ N, longitude 121° 39′ W) at 1950 m elevation (See Figures 2 and 3 for study location). The study site includes the 2698 m of road leading to Sunrise campground from the trailhead junction.

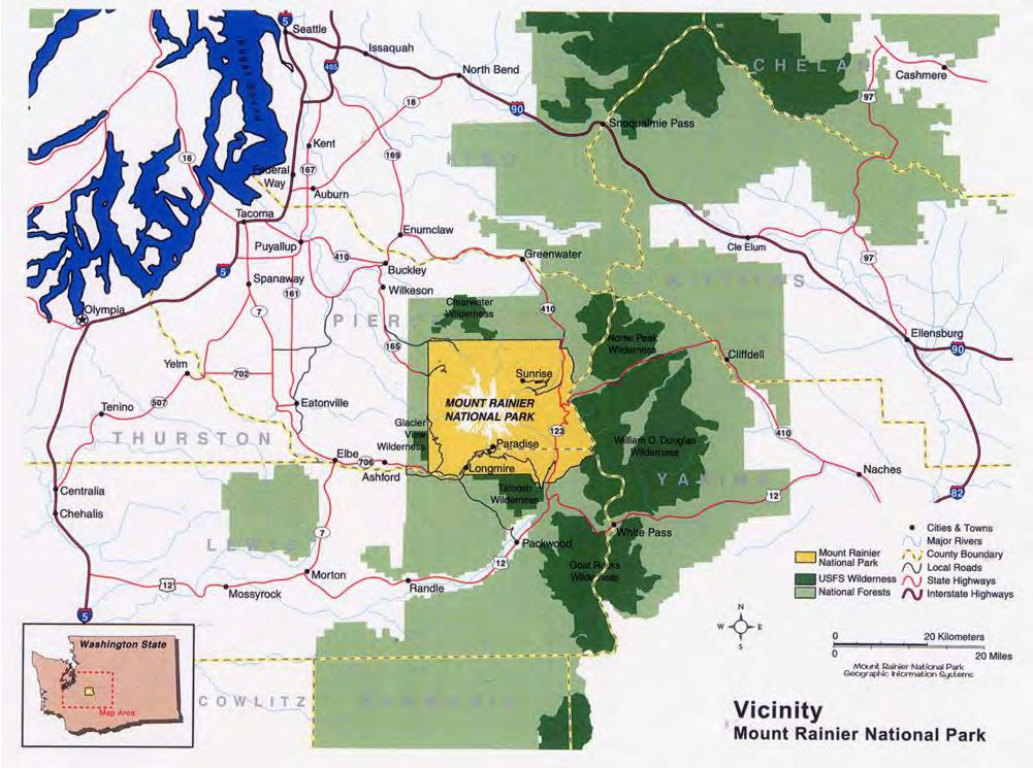

Figure 2: Map of southwestern Washington.

Mount Rainier, highlighted in yellow, is the most conspicuous peak in the Cascade Mountains of Washington. Mount Rainier National Park is located about 60 miles south of the Seattle-Tacoma metropolitan area.

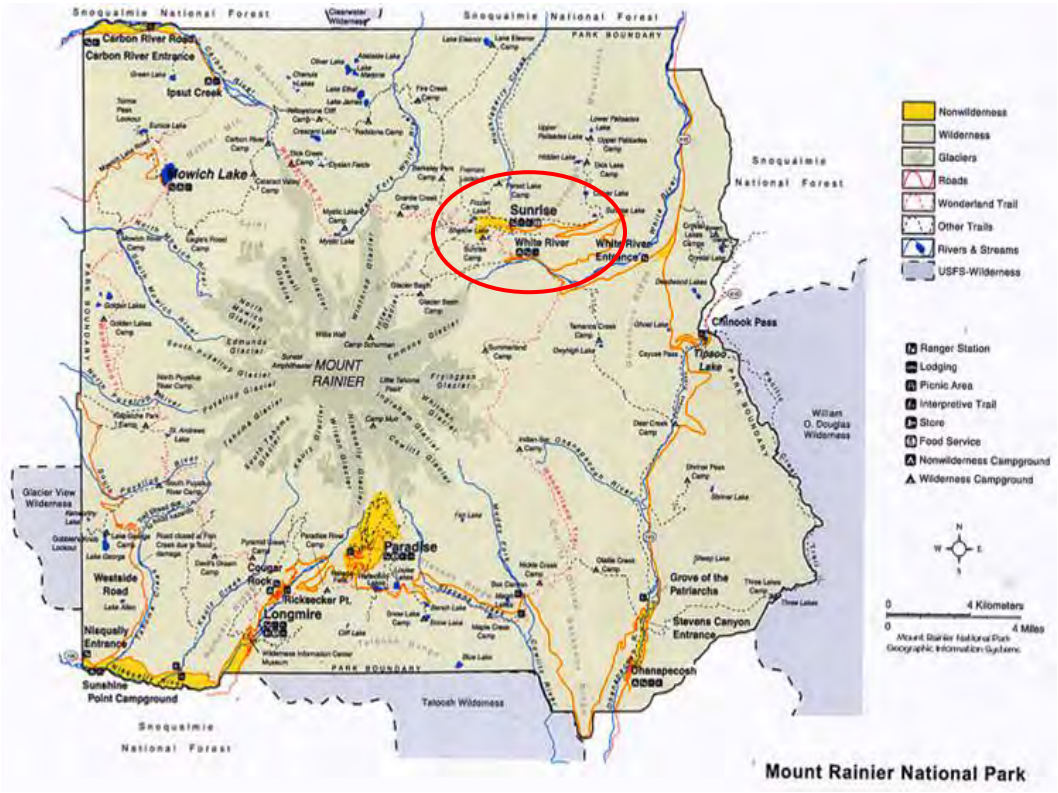

Figure 3: Map of Mount Rainier National Park
Sunrise, circled in red, is located in the northeast corner of Mount Rainier National Park at an elevation of 1950 m.

The climate of Sunrise is characterized by dry, moderately hot summers and long cold winters with extensive snow fall. The snow-free growing season typically extends for 8-12 weeks during the summer months beginning in mid to late July and ending in early October.

Vegetation of the area is characterized as subalpine parkland consisting of herbaceous meadows with a mosaic of tree islands. Tree islands are dominated by *Abies lasiocarpa*, *Picea engelmannii*, and *Pinus albicaulis*. The Sunrise meadows are dominated by *Festuca viridula* and also include *Lupinus latifolius, Castilleja species, Aster alpigenus*

and *Aster ledophyllus*. Meadow species grow in clumps surrounded by areas of bare ground.

Vegetation in these areas is sensitive to human impact due to the short growing season and low resilience of plants to human trampling. The popularity of Sunrise campground and adjacent trails caused severe damage to the meadow as vehicles and hikers began wandering off the constructed roads and trails. Soil erosion and destruction of meadow plant communities occurred throughout this area. In 1973 the camp was closed to cars and reduced to a small walk-in camp. In the late 1970's the oiled gravel road surface was partially removed from the roadbeds, but restoration funding was not available at that time for a large-scale rehabilitation (Rochefort, NPS report, unpublished).

In 1996, a restoration plan was initiated that included field surveys to quantify impacts to the meadow. Approximately 10 acres (4.5 hectares) of disturbed land was documented including the 2698 m of roadway leading to the campground. Although some natural revegetation occurred over the last twenty-five years, it was restricted to fill slopes along road edges. Based on the observed rate of plant succession on this site and other disturbed areas in the park's subalpine zone, park ecologists did not expect this area to naturally recover within the next two hundred years. In order to assist in the recovery of this site, it was necessary to restore the original geomorphic contours and hydrologic patterns of the roadway and actively revegetate the disturbed areas with greenhouse grown native plants and native seed.

Geomorphic restoration took place in the summer of 1997 and revegetation of meadow plant species began that fall. Each year from 1997 through 2001, measurable sections of restored roadbed were planted. Plant stock was grown from seed collected at reference sites within the area by the horticulturist at Mount Rainier National Park.

2.1 EXPERIMENTAL DESIGN AND HYPOTHESES

Measurable sections of roadway were revegetated each year between 1997 and 2001 resulting in six delineated sections. The restored roadbed was revegetated using greenhouse plugs grown from seed collected in the undisturbed grasslands. For purposes of this study, each restored section was given a site code based on the number of years since planting (Table 1). For example, the site planted in 1997 was 6-years-old at the time of sampling and is referred to as 6 YR. The "unplanted" section refers to the site that was recontoured but never planted and "reference" refers to adjacent natural meadows not subject to restoration. The area of each site was approximated using a 100-m fiberglass tape.

Table 1: Site codes, descriptions and area of restoration and reference sites.
Proportional allocation of sampling points was based on the area of the study site. Larger sites were sampled more heavily than smaller sites based on their percentage of the total study area in m^2.

Site Code	Description	Area (m^2)
Unplanted	Regraded in 1997; never planted	789
2 YR	Planted 2001	586
3 YR	Planted 2000	1093
4 YR	Planted 1999	1307
5 YR	Planted 1998	681
6 YR	Planted 1997	234
Reference	Natural Grassland; Five sections adjacent to restoration sites	2073

One of the challenges in designing an analysis of this restoration project was the lack of replication of each age class. There is only one site or "restoration section" per age-class in the Sunrise restoration which is statistically considered pseudoreplication (Hurlbert 1984). In light of this, a chronosequence based on the years since planting or "site age" was used to analyze change in plant and soil properties over time. This same approach was used by Fyles *et al.* (1985) in their study of vegetation and soil development on coal mine spoil in the Canadian Rockies. In a chronosequence, sites of different ages are assumed to represent points in time in the development of an individual site. Since a longitudinal study was not possible, the chronosequence allows a space for time substitution.

The following hypotheses were tested:

H_1: The percent vegetative cover in the Sunrise Restoration will increase with the maturity of the planting site with greatest cover found in the Reference meadows.

H_2: As greenhouse plants installed in restoration sites increase in cover over time, this creates suitable "safe sites" for the germination and survival of other meadow plants immigrating onto the site. Therefore, the species composition of restoration sites will become more diverse as the restoration sites mature.

H_3: Assuming that with successive growing seasons and continued soil development the conditions for plant growth continue to improve, (a) total percent cover and (b) above-ground biomass of *Festuca viridula* per area will be higher in mature planting sites than younger planting sites.

With an increase in plant cover, litter fall and carbon inputs into the soil system, soil ecological processes, including decomposition and nutrient cycling, improve. Therefore, it is hypothesized that:

H_4: (a) Total percent carbon and (b) C:N will increase with the maturity of the planting site.

H_5: Total and available nitrogen will increase with the maturity of the plant site.

H_6: With an increase in vegetation cover that shades the soil and reduces water losses from runoff and evaporation, soil moisture will increase with the maturity of the planting site.

H_7: Soil pH will differ among restoration sites in response to changes in other soil factors.

H_8: (a) Microbial activity and (b) biomass will increase with the maturity of the planting site.

2.2 VEGETATION SAMPLING

In mid July after snow-melt, the study sites were delineated and labeled with flagging on wire posts. The sites were labeled by the year of out-planting 1997 through 2001.

2.2.1 Percent Cover

A total of one hundred sampling points were established in the restoration site and thirty sampling points in the reference area using the simple random sampling method. Since the sites varied in size, the number of sampling points per site was weighted based on the area of the site. Total percent cover and cover of individual species were collected using a

variation of the cover class systems outlined by Elzinga *et al*. (1998). Quadrats used to estimate cover were 1.0 x 0.5 meter.

2.2.2 Aboveground biomass of *Festuca viridula*

Aboveground biomass is a less destructive yet still instructive measure of growth compared with total plant biomass which requires the harvesting of the entire plant. In order to reduce the number of plants harvested from the restoration sites, aboveground biomass of *Festuca viridula* was estimated using regression analysis. Twenty-five plants of varying size were collected within all restoration areas. The leaf and flower height and mat width of each plant was recorded before harvesting. Specimens were then oven dried and weighed to determine dry weight in grams. Then twenty-five plants each were measured in the 2- 4- and 6-year-old restoration sites. This data were used to estimate plant biomass per area using known values of vegetative height, flower height and mat width.

The model used to predict aboveground biomass for *Festuca viridula* was fairly strong (r^2=.664) (Table 2). The model was not able to predict convincing biomass measurements for extremely small plants. Therefore, negative predicted values were changed to .001 for the analysis.

Table 2: Regression model used to predict *Festuca viridula* biomass

F. viridula biomass (g) = -2.228 + .014*flower height (cm) + .528* vegetative height (cm) + .086*width of plant mat (cm)

Plant Biomass (r^2= 0.664)					
Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	45.406	3	15.135	21.084	.000
Residual	22.971	32	.718		
Total	68.377	35			

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-2.228	.613		-3.633	.001
	FLOWERHT	.014	.008	.212	1.664	.106
	WIDTH	.528	.116	.518	4.572	.000
	VEGHT	.086	.039	.287	2.188	.036

2.3 SOIL COLLECTION AND ANALYSIS

Two sets of soil samples were collected in August and September 2002. August 2002 samples were taken from sites 4YR, 6YR, unplanted restoration and reference sites. Analysis conducted on these samples included soil moisture, C:N, %C and %N. September 2002 samples were collected from 6 YR, Unplanted restoration and Reference sites. Analysis for microbial biomass and activity, pH and available Nitrogen were conducted on these samples.

Soil samples (50 g) were collected from sampling points established for vegetation analysis. Since plant roots in general did not penetrate deeper than 20 cm below the soil surface, all samples were collected from the top 15 cm of the soil surface using a trowel and bulb planter. Because vegetation cover usually affects underlying soil properties, samples were taken from the rooting zone of plant clumps as well as between clumps.

A t-test was conducted to compare samples collected from the plant rooting zone and between plant clumps. No significant differences (p=.226) were found beneath and between plant clumps for either C:N or soil moisture. Based on this information, all further analysis was done on samples collected from the rhizosphere of plant clumps. In cases where quadrats had no vegetation, soil was collected to the same depth (15 cm) as samples beneath plants and included in analysis.

All soil samples were stored in airtight plastic bags, transported in coolers and refrigerated until laboratory experiments could be conducted. Since laboratory experiments were all performed at the College of Forest Resources Analytical Lab at the University of Washington in Seattle, samples were stored for about 1-2 weeks.

2.3.1 C:N, %C and %N

Approximately 50 mg of soil were ground, sieved and then analyzed using the Perkin-Elmer 2400 CHNS/O Analyzer (D. Xue, personal communication). The total percent CHN content of the soil is provided and C:N are calculated by taking a ratio of the percent Carbon and Nitrogen in the soil (Nelson and Sommers 1996). Total Percent Nitrogen was also converted to mg/g and presented with available nitrogen results.

2.3.2 Soil Moisture

Percent gravimetric soil moisture was determined by weighing samples before and after being oven dried at 105° C for 24 hours. Soil moisture was tested in early August 2002 (about three weeks after snowmelt) on the unplanted restoration, 4- and 6-year old sites and reference sites. Soil moisture was also determined as part of the microbial activity experiments on the unplanted, 6-year old restoration sites and reference sites in early September 2002.

2.3.3 Available Nitrogen

Ammonium and nitrate, both forms of plant available nitrogen, were measured by incubation and extraction with KCl. Ten grams of field moist soils were placed in glass jars with deionized water and incubated for three weeks at 30° C. 2M KCl was added to each jar and processed on a table shaker for about 30 minutes. Samples were then filtered through Whatman filter paper, refrigerated and analyzed on a Lachat colorimetric automated ion analyzer (Mulvaney 1996; D. Xue personal communication). Results are expressed in milligrams of nitrogen per gram of soil.

2.3.4 pH

Soil pH was determined using a Hanna Instruments HI 8314 membrane pH meter. Soil samples were sieved and mixed with deionized water (1:1) in a beaker before being measured.

2.3.5 Microbial Activity and Biomass

Soil microbial activity was determined using field and laboratory experiments. Soil respiration was measured in the field through carbon dioxide detection by soda lime absorption (Bigham *et al.* 1994). Six-ounce canning jars were filled with 10 grams of oven-dried soda lime (12 mesh) and placed on a wire stand on the ground. A 1 gallon plastic paint bucket covered in aluminum foil was then placed over the canning jars and stabilized with rocks (Figure 4). The soda lime method measures CO_2 respired from a defined and isolated soil surface area over a 24 hour period. The difference in dry weight of the soda lime at the beginning and end of the 24 hour period reflects CO_2 absorption by the soda lime. The weight gain determined after oven drying was multiplied by a correction factor of 1.41 to adjust for the generation of water during CO_2 absorption by the soda lime. Although this method does not distinguish between CO_2 respired by soil microbes versus plant roots, it is used as an estimate of microbial activity in the soil.

Figure 4: Photograph of Carbon Dioxide Detection by Soda Lime Absorption

The Chloroform-Fumigation-Incubation (CFI) method was used to measure the mineralization of carbon in the laboratory. This method provides a measure of the soil's microbial biomass. Fifty grams of dry weight soil were fumigated in chloroform for 24 hours. Fumigated and control samples were incubated in airtight jars for 10 days at 25° C with a scintillation vial containing 2 mL of 2M NaOH (used as CO_2 trap). Since an aspirator or rotary vacuum pump was not available, samples were fumigated in a lab hood. Single End-point Titration was used to measure total CO_2 mineralized by back titrating excess NaOH with 0.5 M HCl after addition of $BaCl_2$ to precipitate carbonate ions. The following equation was used to calculate CO_2 mineralization following tritration: ([B-T] x M x 6 mg C) when M is the molarity of the HCl in mol/L). The blank

titre (B) minus the sample titre (T) equals the CO_2 in the sodium hydroxide trap (Paul *et al.* 1999).

2.4 DATA ANALYSIS

Linear regression was applied to the vegetation component of the chronosequence looking for change in vegetation over time. In using linear regression, the average of each site variable is compared versus time and the problem of comparing variances between and within replicated sites is avoided. Linear regression was not applied to the soils data since not all sites were surveyed leaving a very small sample size (J. Corbois, personal communication).

The distribution of data and means for all variables tested were compared using descriptive statistics calculated in SPSS 11.5. Since vegetative cover was collected using a cover class system, the midpoint percentage of the cover classes was used in order to compare average cover for each restoration section.

Patterns of species distribution and plant community composition were analyzed by Detrended Correspondence Analysis (DCA) using PC Ord for Windows version 4.10. DCA, also referred to as ordination, is a multivariate technique that arranges stands (sites) along axes on the basis of species composition. The more similar the vegetation, the closer the stands will appear on the diagram. The more dissimilar, the farther away the stands will appear. DCA also creates eigenvalues which are measures of the strength of an ordination axis. Axes with eigenvalues greater than .30 have good explanatory power.

In order to further interpret the relationships represented by the DCA diagram, a second data set or “matrix” can be overlayed on the original data. This second matrix is represented by an arrow, which represents the trend in the data across the diagram. To examine the relationship between the stand distribution and the age of the sites, an overlay of “site age” was used. Also, in order to examine C:N and soil moisture data on these sites directly, the original vegetation data was edited to include only those sites where soil data was collected. These included the unplanted, 4- and 6-year-old restoration sites as well as all reference sites.

CHAPTER III RESULTS

3.0 VEGETATION ANALYSIS

3.0.1 Percent Cover

Total vegetative cover in restoration sites increased each year by site age. The linear regression model that correlates total vegetative cover with the age of restoration site had moderately strong explanatory power (r^2=0.64) (Table 3). The six-year-old restoration site had the highest total cover and lowest percentage of bare ground and the youngest restoration sites (2-year-old and unplanted site) had the lowest total plant cover and the highest bare ground. The 3-year-old site, however, does break from this trend with percent cover values 4% higher than the 4-year-old site and 2% higher than the 5-year-old site. Bare ground distribution (r^2=0.88) reflects this same trend but without the deviation in the 3-year-old site (Table 3).

Table 3: Linear regression for percent vegetation cover and bare ground cover by restoration site.

Percent Cover (r^2 =.638)

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	**150.5**	**1**	**150.5**	**7.038**	**.057**
Residual	**85.6**	**4**	**21.4**		
Total	**236.1**	**5**			

Bare Ground (r^2 =.876)

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	**323.89**	**1**	**323.89**	**28.349**	**.006**
Residual	**45.70**	**4**	**11.43**		
Total	**369.59**	**5**			

Table 4: Mean percent cover of species surveyed in Sunrise Restoration analysis.

Species	Unplanted	2 YR	3 YR	4 YR	5 YR	6 YR	Reference
Abies lasiocarpa	13.0	9.0	9.0	9.0		9.0	2.0
Agoseris aurantiaca							1.0
Anemone occidentalis				2.0			2.0
Antennaria lanata		1.4	3.0		1.3		2.5
Arenaria capillaris							2.0
Aster alpigenus				2.0			2.0
Aster ledophyllus		1.0	1.0	2.0		4.0	3.0
Carex nigricans							1.0
Carex spectabilis	4.0	4.0	2.0	3.0	5.0	7.0	2.0
Castilleja miniata					1.0		1.0
Erigeron perigrinus		3.0	2.0	1.0	2.0	3.0	4.0
Festuca viridula		2.0	3.0	3.0	4.0	11.0	5.0
Hieracium gracile							1.0
Juncus parryi		1.0	1.0	3.0	4.0		3.0
Ligusticum grayi			3.0				2.0
Luetkea pectinata			1.0	3.0		3.0	2.0
Lupinus latifolius					3.0	8.0	3.0
Luzula glabrata					1.0		6.0
Microseris alpestris				1.0	1.0		3.0
Phlox diffusa			3.0				3.0
Pinus albicaulis							3.0
Polygonum bistortoides		1.0	3.0	1.0	4.0	4.0	1.0
Polygonum newberryi	6.0	2.0	13.0	8.0	3.0		3.0
Potentilla flabellifolia		2.0	3.0	3.0	4.0	7.0	3.0
Vaciniium membreanaceum					5.0		
Valeriana sitchensis				1.0			3.0
Veronica cusickii		1.0	1.0	2.0	2.0	18.0	4.0
Total cover	8.0	5.0	15.0	10.0	13.0	24.0	30.0
Bare ground	93.0	93.0	84.0	85.0	79.0	71.0	70.0

Although the six-year-old section was expected to have higher cover than its younger counterparts, it was surprising to find only a 5% difference between the Reference and 6-year-old restoration site (Figure 5). Based on field observations, the 6-year-old site continues to look like a planted landscape compared to adjacent reference communities. Likewise, the higher mean of the unplanted section was unexpected. The unplanted section was visibly bare compared to the two-year-old section which had two growing seasons for plugs to establish. The only plants present in the unplanted quadrats surveyed were from natural recruitment.

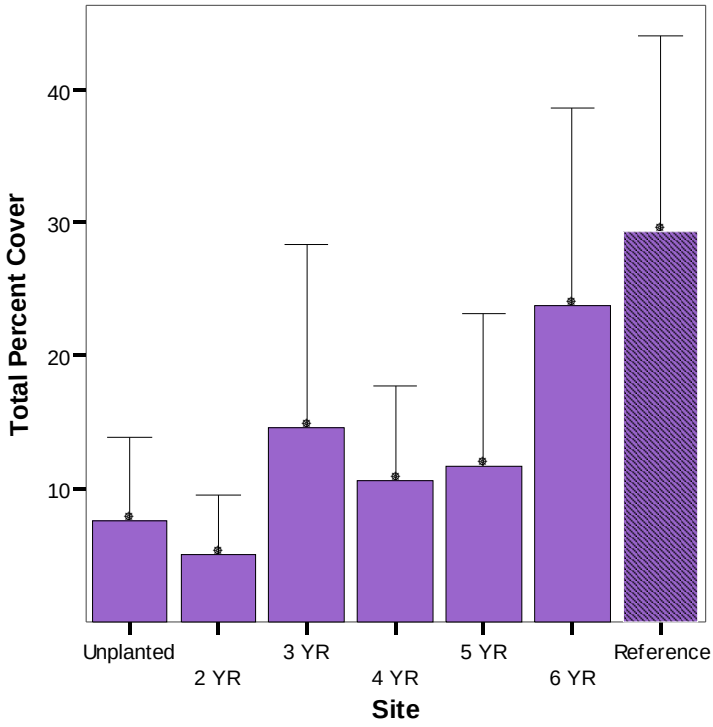

Figure 5: Mean Vegetation Cover by Site

Mean total percent cover of unplanted and revegetated restoration sites and all reference sites. Error bars show mean ± 1.0 standard deviations. Sunrise Restoration Analysis, Mount Rainier National Park.

The species composition of the reference sites was more diverse than that of the restoration sites which was expected since mainly dominant meadow species were propagated and planted in restoration sites. Species with the highest percent cover in the reference sites included *Luzula glabrata, Festuca viridula, Erigeron perigrinus, Veronica cusickii and Polygonum newberryi*. These species had average cover values greater than 3% (Table 4).

The species composition in the restoration sections was less diverse than the reference site. The main species found in all restoration sites include *Carex spectabilis, Erigeron perigrinus, Festuca viridula, and Veronica cusickii* (See Appendix A for the list and number of each species planted). No non-native or invasive species were found in this survey nor were there rare or threatened species. However, *Castilleja cryptantha* has been documented in a wet meadow in the Sunrise/Shadow lake area (Rochefort, NPS Report, unpublished).

3.0.2 Detrended Correspondence Analysis (DCA)

Detrended Correspondence Analysis (DCA) applied to the Sunrise Restoration data including reference sites computed a strong eigenvalue of 0.56 for Axis 1 and 0.31 for Axis 2. Examination of data points for plots and species along axis 1 suggests a gradient based on the age of the restoration site. Figure 6 shows an array of stands from the Sunrise Restoration data including reference sites. As expected, reference and unplanted restoration plots appear at opposite ends of Axis 1. This is not surprising since cover and species composition is higher in the undisturbed reference communities. The 6-year-old plots lie close to reference plots; 4- and 5-year-old data plots hover around the middle of Axis 1 and 3-year-old plots are found closest to unplanted plots. Two-year-old plots are spread across both Axis 1 and 2 and do not adhere to a pattern based on age of the site.

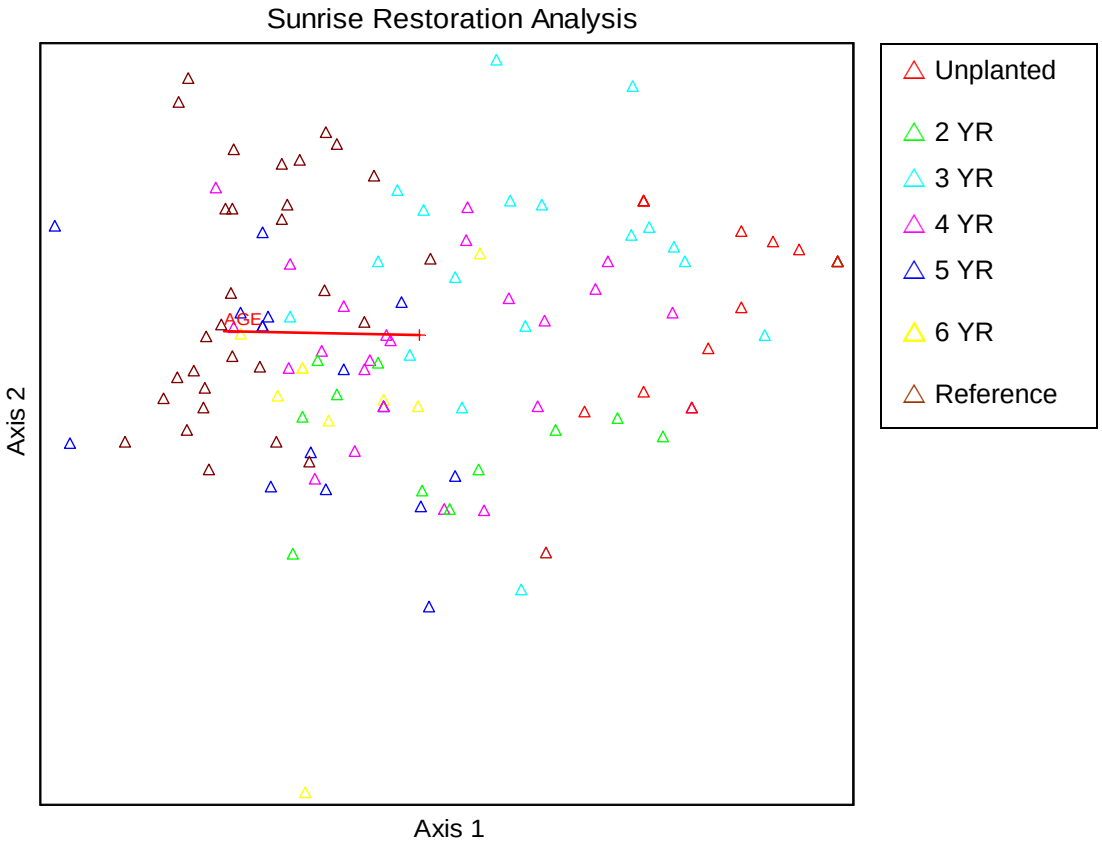

Figure 6: DCA Diagram of Axis 1 and 2 with Site Age Overlay.

Diagram includes an array of stands for all reference and restoration sites. Stands are color coded by site.

Figure 7 shows the arrangement of species along Axis 1 which reflect a gradient based on site. *Festuca viridula* and *Veronica cusickii*, which are ubiquitous throughout the reference and restoration sites hover about the center of the diagram. *Polygonum newberryi*, *Carex spectabilis* and *Abies lasiocarpa* fall on the right side of Axis 1 where all unplanted stands are found. Although these species are seen throughout the restoration and reference stands, they are the only species present in unplanted plots.

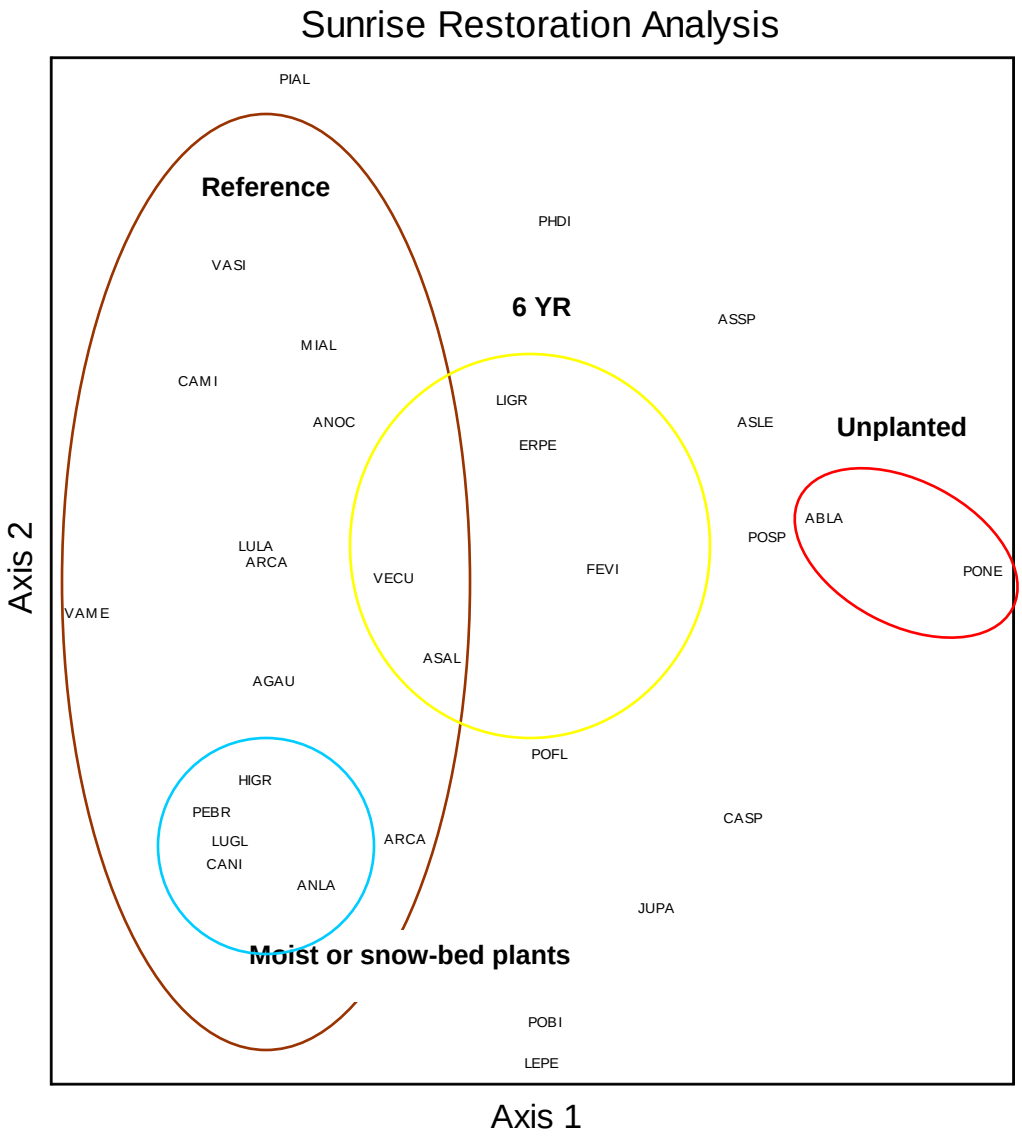

Figure 7: DCA ordination diagram of Species for Axis 1 and 2.

Species codes consist of the first two letters of the genus name and the first two letters of the specific epithet. (See Table 5 on page 28-29 for species code list). Circles represent the areas that encompass the highest concentration of specific site plots. Stands that lie close to the point of a species are likely to have a high abundance of that species. Species points on the edge of the diagram are often rare either because there are few occurrences or they prefer extreme environmental conditions.

Table 5 outlines species surveyed and their habitats. Although many species surveyed can inhabit a range of microenvironments such as “dry to moist meadow,” some species are more frequently found in scree and rocky outcrops (e.g., *Phlox diffusa*) or snow bed communities (e.g., *Carex nigricans*). Although restoration and reference areas are generally homogeneous in appearance, microhabitats with small differences in sun exposure and presence of rock and scree slopes may account for some of this variation. This moisture gradient may account for some of the species distribution along Axis 2.

The eigenvalues for Axis 2 (.31) and Axis 3 (.21) were considerably lower than that for Axis 1 (.56). When Axis 3 is analyzed with both Axis 1 (Figure 8) and Axis 2 (Figure 9) the species distribution is not as clear, although some patterns are still present. Figure 8 which represents axes 1 and 3, shows species typically found in snow bed communities or moist meadows (HIGR, CANI, ANLA, LUGL) are located in the lower left quadrant of the diagram. Other species do not adhere to a pattern based on inferred soil moisture or habitat preference.

Table 5: Species codes and habitats for species surveyed in the Sunrise Restoration.

Species	Code	Family	Habitat
Abies lasiocarpa	ABLA	Pinaceae	Subalpine to alpine slopes
Agoseris aurantiaca	AGAU	Asteraceae	Dry to moist meadows; low to high elevation
Anemone occidentalis	ANOC	Ranunculaceae	Subalpine; alpine meadows and rocky slopes
Antennaria lanata	ANLA	Asteraceae	Moist; snowbed sites; heath
Arenaria capillaris	ARCA	Caryophyllaceae	Dry rocky slopes and mountain meadows. Mid to High Elevation
Aster alpigenus	ASAL	Asteraceae	Subalpine meadow
Aster ledophyllus	ASLE	Asteraceae	Dry Subalpine meadows
Carex nigricans	CANI	Cyperaceae	Snowbeds; wet meadows; high elevation
Carex spectabilis	CASP	Cyperaceae	Moist meadows; forest openings; rocky slopes; low to high elevation
Castileja miniata	CAMI	Scrophulariaceae	Grassy slopes; tidal marshes; widespread and highly variable
Castilleja parviflora	CAPA	Scrophulariaceae	Subalpine and alpine meadows; heath and stream-banks
Erigeron peregrinus	ERPE	Asteraceae	Moist to wet meadows
Festuca viridula	FEVI	Poaceae	Subalpine meadow
Hieracium gracile	HIGR	Asteraceae	Subalpine meadow; heath and snowbed tundra
Juncus drummondii	JUDR	Juncaceae	Moist heaths; snowbeds; meadows; high elevation

Species	Code	Family	Habitat
Juncus parryi	JUPA	Juncaceae	Dry-moist high elevation meadows
Ligusticum grayi	LIGR	Apiaceae	Moist-dry; open/forested; mountain meadows; mid to high elevation
Luetkea pectinata	LUPE	Rosaceae	Meadows; heath; scree slopes
Lupinus latifolius	LULA	Fabaceae	Open areas; widespread
Lupinus lepidus	LULE	Fabaceae	Open habitats; meadows; low to subalpine
Luzula glabrata	LUGL	Juncaceae	Moist sites; meadows; heath; trails; widespread
Microseris alpestris	MIAL	Astereraceae	High elevation meadows open slopes
Pedicularis bracteosa	PEBR	Scrophulariaceae	Moist meadows; clearings in mountains; common at subalpine
Phlox diffusa	PHDI	Polemoniaceae	Open rocky slopes; scree; rock outcropss; mid to high elevation
Pinus albicaulis	PIAL	Pinaceae	At or near timberline on well drained soils
Polygonum bistortoides	POBI	Polygonaceae	Moist to wet meadows at subalpine to alpine
Polygonum newberryi	PONE	Polygonaceae	Rocky; open slopes and redges; often on talus at subalpine to alpine
Potentilla flabellifolia	POFL	Rosaceae	Moist meadows and scree slopes
Vacciunium membreanaceum	VAME	Ericaceae	Moist meadows;open subalpine forest; widespread high elevations
Valeriana sitchensis	VASI	Valerianaceae	Mid to high elevation meadows; moist open slopes
Veronica cusickii	VECU	Scrophulariaceae	High elevation and mountains

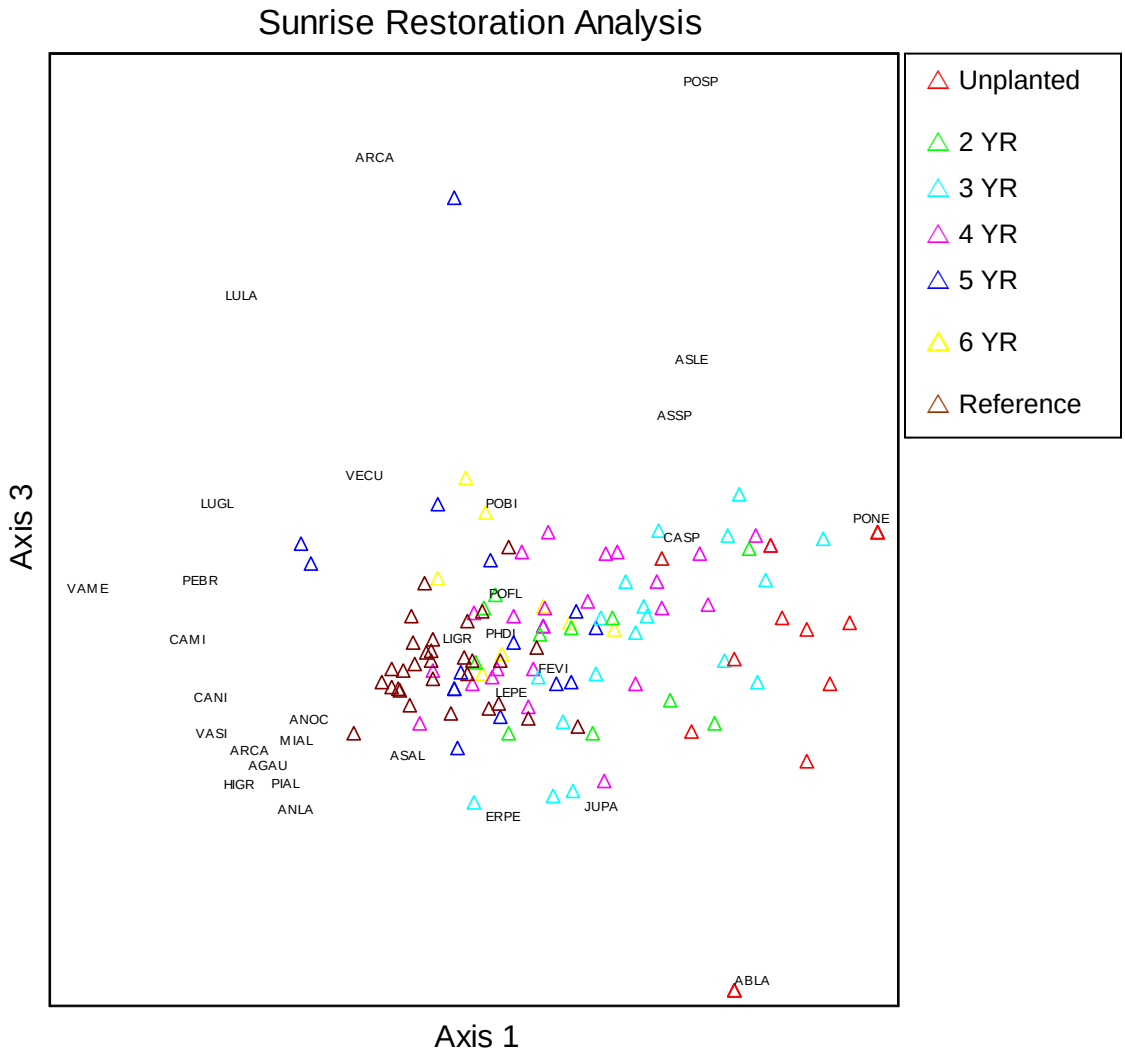

Figure 8: DCA ordination diagram of stands and species for axes 1 and 3.

Species codes consist of the first two letters of the genus name and the first two letters of the specific epithet. (See Table 5 on page 28-29 for species code list). Stands (color coded by site) that lie close to the point of a species are likely to have a high abundance of that species. Species points on the edge of the diagram are often rare either because there are few occurrences or they prefer extreme environmental conditions. Sunrise Restoration Analysis, Mount Rainier National Park.

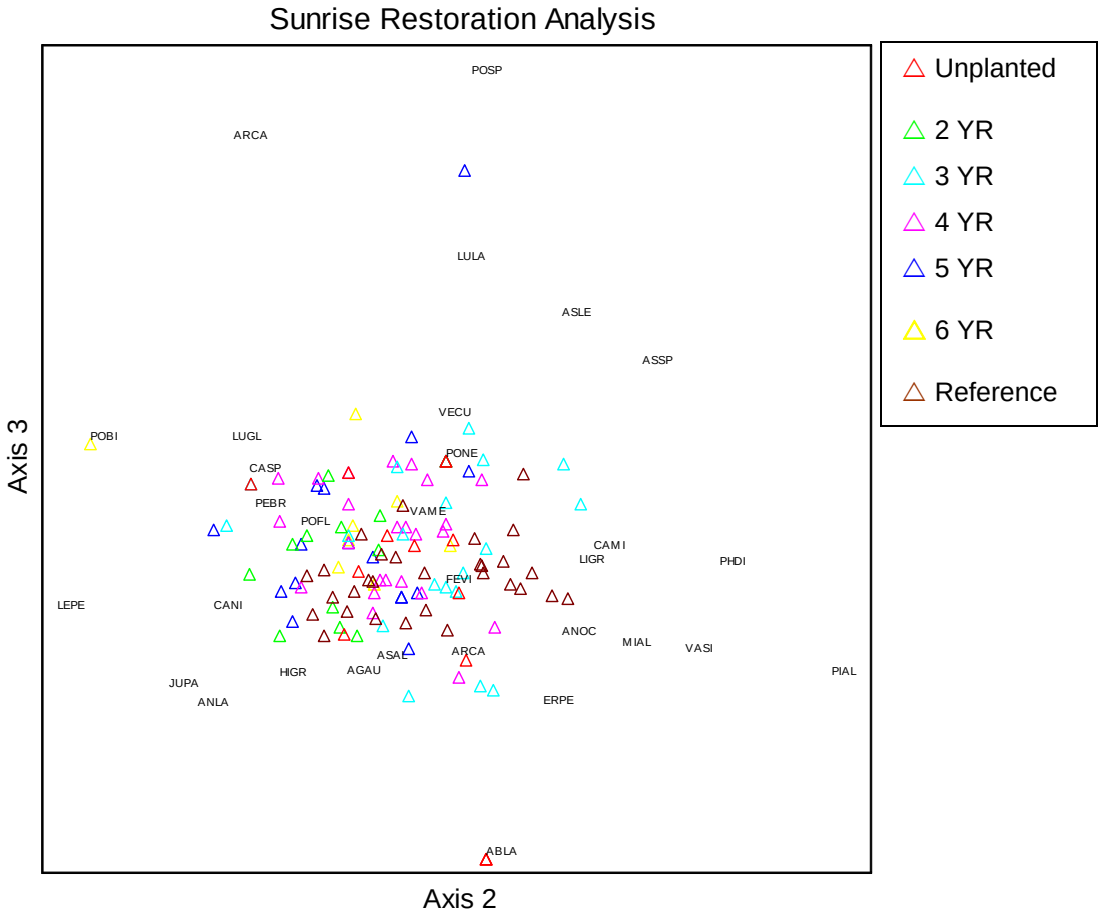

Figure 9: DCA ordination diagram of stands and species for axes 2 and 3.

Species codes consist of the first two letters of the genus name and the first two letters of the specific epithet. (See Table 5 on page 28-29 for species code list). Stands (color coded by site) that lie close to the point of a species are likely to have a high abundance of that species. Species points on the edge of the diagram are often rare either because there are few occurrences or they prefer extreme environmental conditions. Sunrise Restoration Analysis, Mount Rainier National Park.

3.0.3 DCA: Revised analysis with overlay of soil variables

Environmental data was not collected for all restoration sites. However, in instances where soil variables were studied, a secondary matrix was overlayed for further interpretation of the stand and species distribution. In order to examine C:N, %C and soil moisture, the original vegetation data was edited to include only those sites where soil data was collected. Soil variables were tested in the unplanted section, 4- and 6 year-old sections and reference sites. When the 2-, 3-, and 5- year-old restoration sections were removed similar vegetation associations were found when compared to the ordination of the full data set.

The DCA joint plot diagram (Figure 10) graphically confirmed the analysis of the original data set. Axis 1 continued to have a strong correlation with the site age with a small increase in the eigenvalue to 0.64. Unplanted and reference stands appeared on opposite sides of the ordination diagram, 4-year-old stands lie between unplanted and 6-year-old stands and 6-year-old stands lie between 4-year-old restoration stands and reference stands. There was little change in Axes 2 and 3 as well, with eigenvalues of 0.33 and 0.21 respectively.

When site age, C:N, %C and soil moisture data were overlayed onto the main matrix, site age, C:N and %C showed an increase from right to left. Therefore, those values increase from the unplanted restoration sites to the reference sites. The absence of an arrow for soil moisture simply means that there was no apparent trend with the axes.

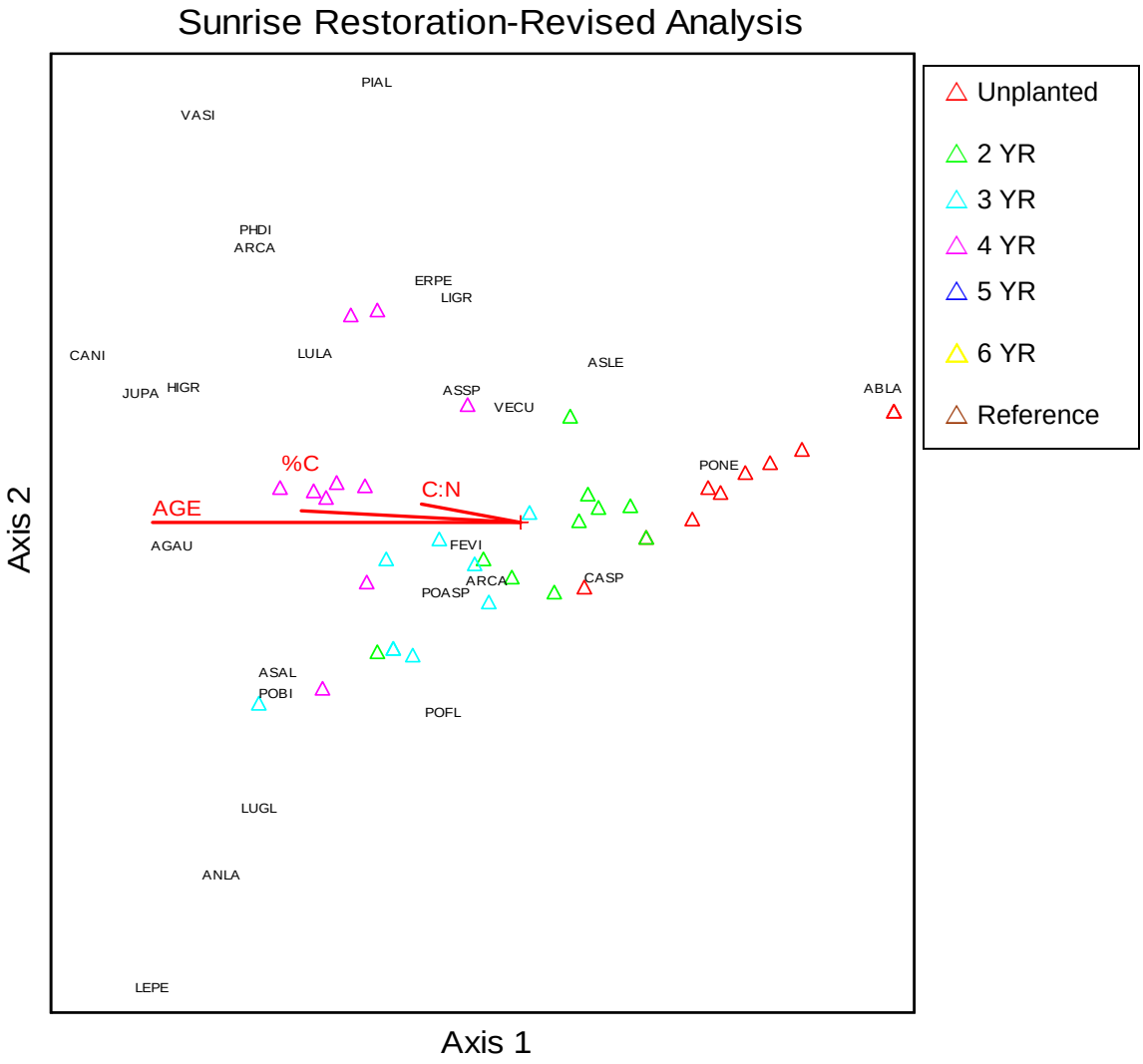

Figure 10: Revised DCA with Age and Soil Matrix Overlays for Axis 1 and 2.

Species codes consist of the first two letters of the genus name and the first two letters of the specific epithet. (See Table 5 on page 28-29 for species code list). Stands (color coded by site) that lie close to the point of a species are likely to have a high abundance of that species. Species points on the edge of the diagram are often rare either because there are few occurrences or they prefer extreme environmental conditions. Sunrise Restoration Analysis, Mount Rainier National Park.

3.1 *Festuca Viridula* : Percent Cover and Aboveground Biomass

Consistent with Hypothesis 3a, the mean percent cover of *Festuca viridula* increased as the age of the restoration site increased. The linear regression model applied to the restoration data had strong explanatory power with an r^2 of .731 (Table 6). When restored sites were compared with reference sites, it was surprising to find that the mean percent cover of *Festuca viridula* was 5% lower than on the 6-year-old site (Figure 11).

Table 6: Linear regression for percent cover of *Festuca viridula* by restoration site.

Percent Cover (r^2 =.731)

Source	Sum of Squares	df	Mean Square	F	Sig.
Regression	**46.671**	**1**	**46.671**	**10.852**	**.030**
Residual	**17.204**	**4**	**4.301**		
Total	**63.875**	**5**			

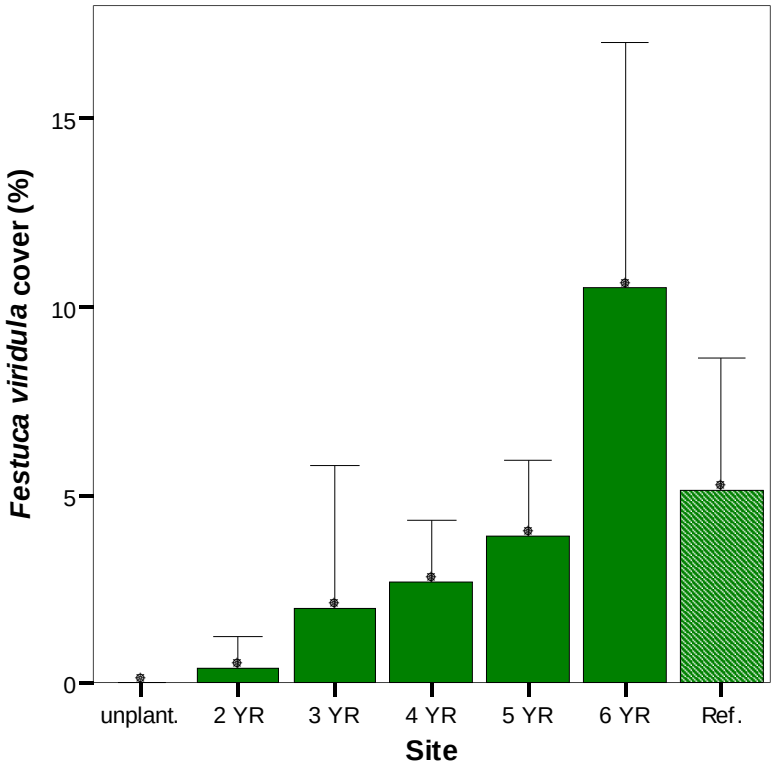

Figure 11: Mean Percent Cover of *Festuca viridula* by Site.

Includes both reference and restoration sites. Error bars show mean ± 1.0 standard deviations. Sunrise Restoration Analysis, Mount Rainier National Park.

The results of aboveground biomass analysis generally supported Hypothesis 3b which stated that estimated biomass of *Festuca viridula* per area would increase as the restoration sites matured (Figure 12). There was an average increase of 28 grams/m^2 between the 2-year-old site and the older restoration sites. Although the 6-year-old site was expected to have higher biomass per area than both the 2- and 4-year-old sites, a difference of only one gram/m^2 was found.

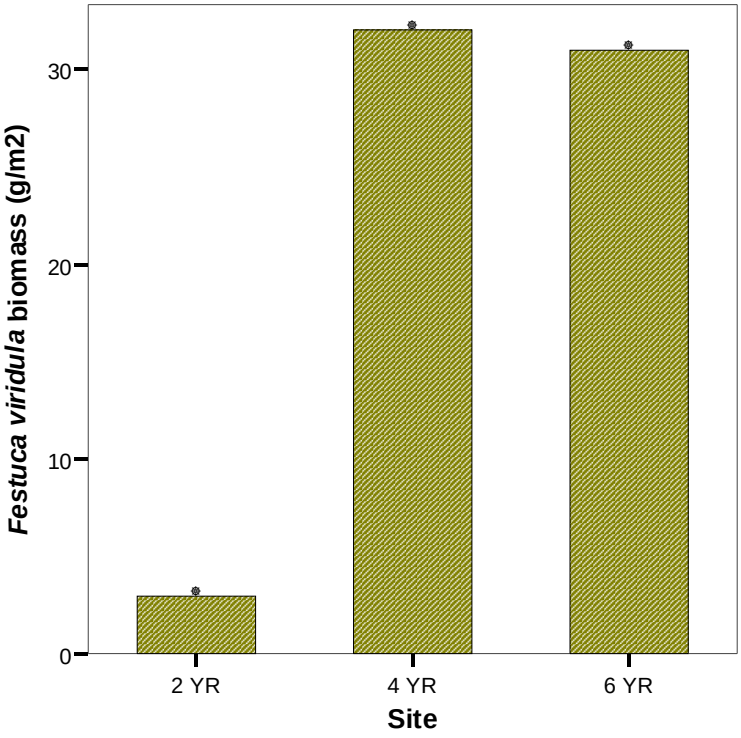

Figure 12: Mean Aboveground biomass of *Festuca viridula* by Area.

Samples collected from 2-, 4- and 6-year-old restoration sites to assess productivity of restored sites using greenhouse grown plants. Sunrise Restoration Analysis, Mount Rainier National Park.

3.2 SOIL ANALYSIS: PART I

Soils in both the Sunrise restoration and reference meadows are classified as Andisols (Riedel, personal communication; Field observations). Andic soils are immature and poorly developed with a high content of volcanic ash. Soil development is primarily due to rapid weathering. A combination of organic matter, ash and minerals (primarily iron and aluminum) produce light, fluffy soils with high water-holding capacity. The soil textural class on all sites is sandy loam and was determined by hand texturing (Brady and Weil 1999).

3.2.1 Percent Carbon and C:N

Overall, C:N were similar across both reference and restoration sites. The largest difference in C:N was found between the unplanted restoration section and the reference sites. The unplanted restoration section had an average C:N of 14 (± .87), whereas C:N in reference sites averaged to 17 (± 1.62). The 4- and 6-year-old sites, however, do not adhere to the increasing trend. This does not support Hypothesis 4a. Figure 13 graphically shows that although C:N did increase from the unplanted restoration site to the reference site, the 4-year-old site had slightly higher C:N than the 6-year-old site.

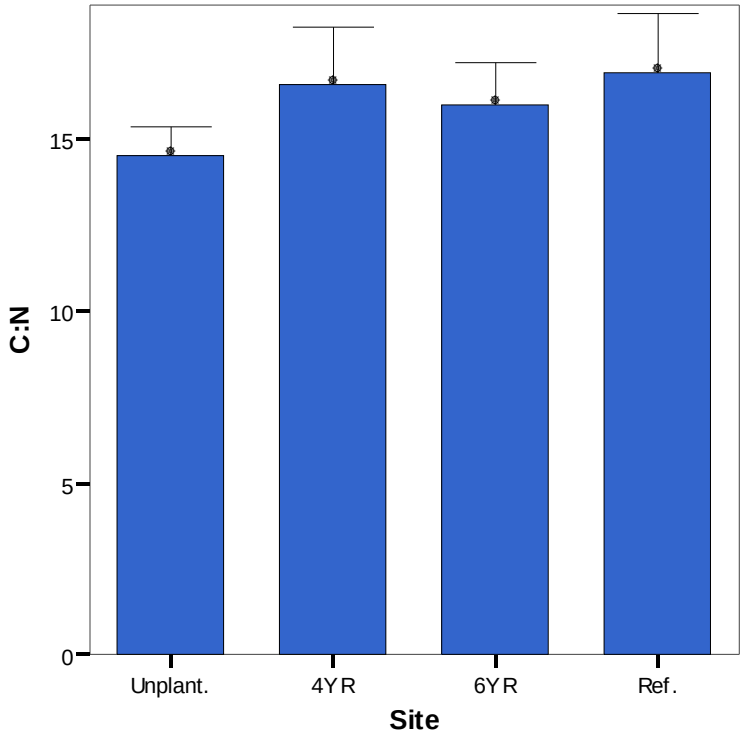

Figure 13: Mean C:N by Site.

Includes unplanted restoration, 4- and 6-year old restoration sites and reference sites. Error bars show mean ± 1.0 standard deviations. Sunrise Restoration Analysis, Mount Rainier National Park.

Figure 14 graphically demonstrates that, unlike C:N, mean percent carbon increased with site age which supports Hypothesis 4b. Highest mean percent carbon was found in the reference sites (3.9±1.1) and lowest mean percent carbon was found on the unplanted restoration site (1.7±.14).

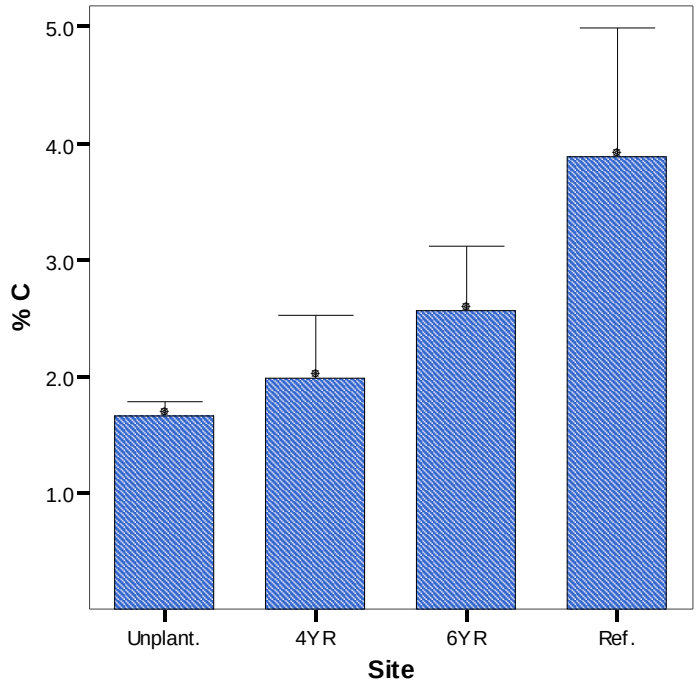

Figure 14: Mean %C by Site.

Includes unplanted restoration, 4- and 6-year old restoration sites and reference sites. Error bars show mean ± 1.0 standard deviations. Sunrise Restoration Analysis, Mount Rainier National Park.

3.2.2 Soil Moisture

Wide variation in soil moisture was found on all reference and restoration study sites. Percent gravimetric moisture from August 2002 ranged from 4.2% to 17.0% on restoration sections and 4.0% to 19.3% on reference sites (Table 7). Soil moisture increased as the age of the restoration site increased, which supports Hypothesis 6.

However, this pattern did not hold true for average moisture levels on the reference sites which nearly equaled that found on the unplanted restoration section (Figure 15).

Table 7: Descriptive Statistics for Soils Study Part I
C:N, % Carbon, % Nitrogen and Gravimetric Soil Moisture on Reference and Restoration Sites. Sunrise Restoration Analysis, Mount Rainier National Park.

Variable	Site	n	Mean	Std. Deviation	Minimum	Maximum
Soil Moisture (%)	unplanted	10	8.2	2.2	4.2	12
	4 YR	10	11	2.6	5.3	15
	6 YR	8	13	3.0	9.3	17
	reference	26	8.2	4.0	4.0	19
C:N	unplanted	10	14	.87	14	16
	4 YR	10	16	1.7	14	20
	6 YR	10	16	1.4	15	19
	reference	26	17	1.6	13	20
Carbon (%)	unplanted	10	1.6	.14	1.5	1.9
	4 YR	10	1.9	.56	1.3	3.2
	6 YR	10	2.6	.54	2.1	3.9
	reference	26	3.9	1.1	2.1	6.1
Nitrogen (%)	unplanted	10	.11	.01	.10	.14
	4 YR	10	.12	.03	.07	.16
	6 YR	10	.16	.04	.13	.27
	reference	26	.23	.06	.13	.33

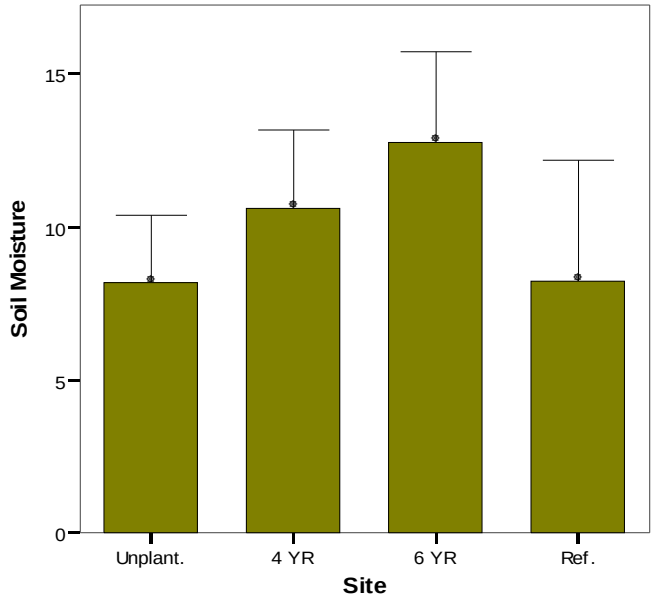

Figure 15: Mean Gravimetric Soil Moisture (%) by Site.
Includes unplanted restoration, 4- and 6-year old restoration sites and reference sites. Soil samples collected in early August about three weeks after snowmelt. Error bars show mean ± 1.0 standard deviations. Sunrise Restoration Analysis, Mount Rainier National Park.

3.3 Soil Analysis: Part II

The second part of the soils study compared the unplanted and 6-year-old restoration sites with the reference sites. Variables studied include microbial activity and biomass, nitrogen mineralization and soil pH.

3.3.1 Microbial Activity and Biomass

Results for both the laboratory and field experiments revealed an increase in microbial activity and biomass from the unplanted site to the reference sites (Table 8). Higher microbial activity and biomass levels were expected in the 6-year-old restoration section compared to the unplanted section. However, this was not evident in either lab or field

analysis, which does not support Hypothesis 8. Microbial biomass was notably higher in the reference sites (3.62 mg g^{-1}) compared to the unplanted (.12 mg g^{-1}) and 6-year-old sites (.14 mg g^{-1}). However, the unplanted and 6-year-old sites had similar biomass values (Figure 16). Although reference sites had higher soil respiration rates (.36 g m^{-2} $24h^{-1}$) than both the unplanted and 6-year old sections, the unplanted restoration section had higher soil respiration values (.14 g m^{-2} $24h^{-1}$) than the 6-year-old section (.02 g m^{-2} $24h^{-1}$) (Figure 17).

Table 8: Descriptive Statistics for Soils Study Part II. Includes the unplanted and 6-year-old restoration and reference sites. Sunrise Restoration Analysis, Mount Rainier National Park.

Variable	Site	n	Mean	Stnd Dev.	Max	Min
CO_2 detection by soda lime (field experiment)	Unplanted	10	.14	.20	.00	.30
(CO_2 g m^{-2} $24h^{-1}$)	6 YR	10	.02	.04	.00	.10
	Reference	10	.36	.07	.30	.50
CFI (lab experiment)	Unplanted	10	.12	.39	.00	1.22
(mg g^{-1})	6 YR	10	.14	.34	.00	1.05
	Reference	10	3.62	2.87	.00	7.87
Soil pH	Unplanted	10	5.5	.21	5.1	5.9
	6 YR	10	5.9	.39	5.1	6.4
	Reference	10	5.6	.22	5.2	6.0
Net NH_4 (mg g^{-1})	Unplanted	10	-.0006	.00040	-.0014	.0001
	6 YR	10	-.0004	.00047	-.0012	.0003
	Reference	10	-.0005	.00038	-.0013	-.0001
Net NO_3 (mg g^{-1})	Unplanted	10	.0013	.00240	-.0009	.0073
	6 YR	10	.0023	.00067	.0015	.0036
	Reference	10	.0093	.00331	.0048	.0157
Total Nitrogen (mg g^{-1})	Unplanted	9	1.13	.11	1.01	1.35
	6	10	1.56	.43	1.14	2.72
	Reference	27	2.25	.55	1.27	3.31

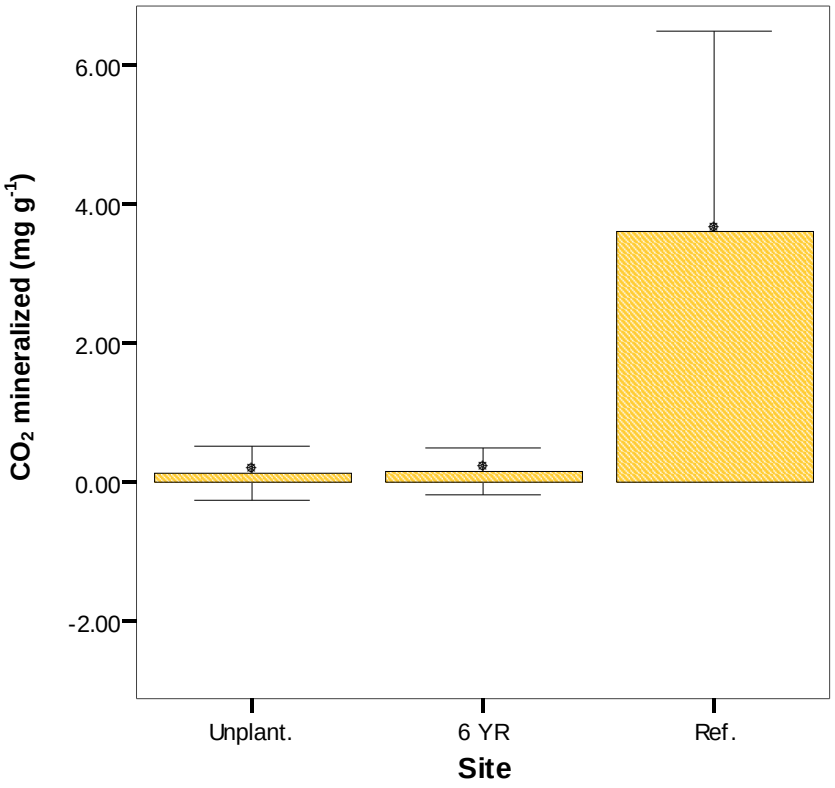

Figure 16: Mean Microbial Biomass by Site - Chloroform Fumigation Incubation
Used to determine Microbial Biomass in milligrams of CO_2 mineralized per gram of soil. Soil samples collected in early September 2002 and refrigerated until analysis was conducted in early October 2002. Error bars show mean ± 1.0 standard deviations. Sunrise Restoration Analysis, Mount Rainier National Park.

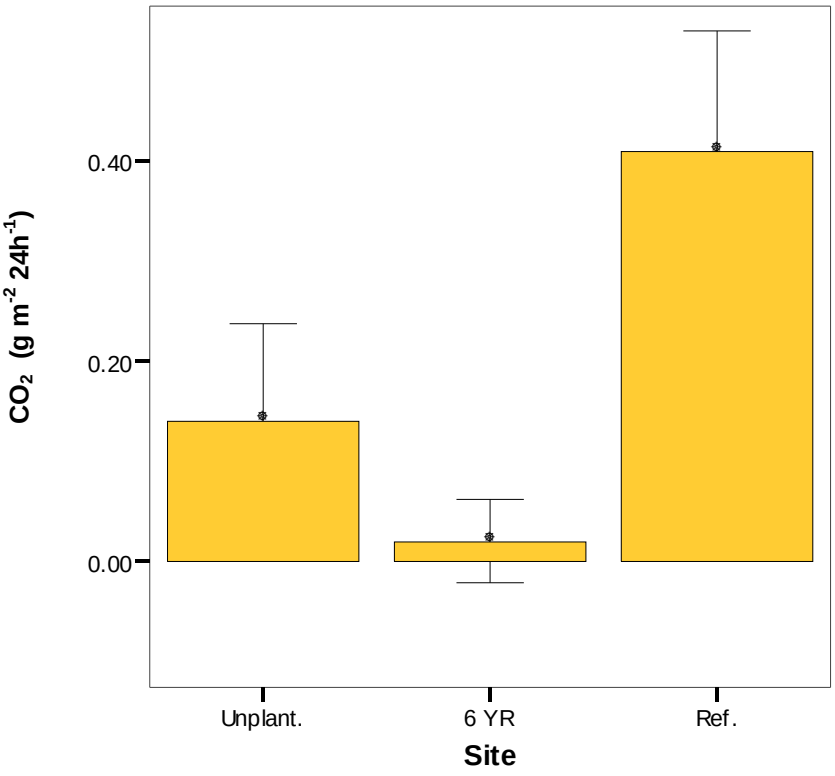

Figure 17: Mean Soil Respiration by Site - CO_2 Detection by Soda Lime Absorption.
This experiment measures both plant root respiration as well as microbial respiration and is considered a good surrogate for microbial activity. Error bars show mean ± 1.0 standard deviations. Sunrise Restoration Analysis, Mount Rainier National Park.

3.3.2 Total and Available Nitrogen

On all three sites surveyed, both total and available nitrogen increased from the unplanted control to the reference sites (Table 7). Available ammonium had negative values compared with available nitrate which had increasing positive values. Figure 18 illustrates that reference sites had more total and available nitrate than both restoration sections. And as hypothesized there was more total and available nitrate on the 6-year-old restoration section than the unplanted section.

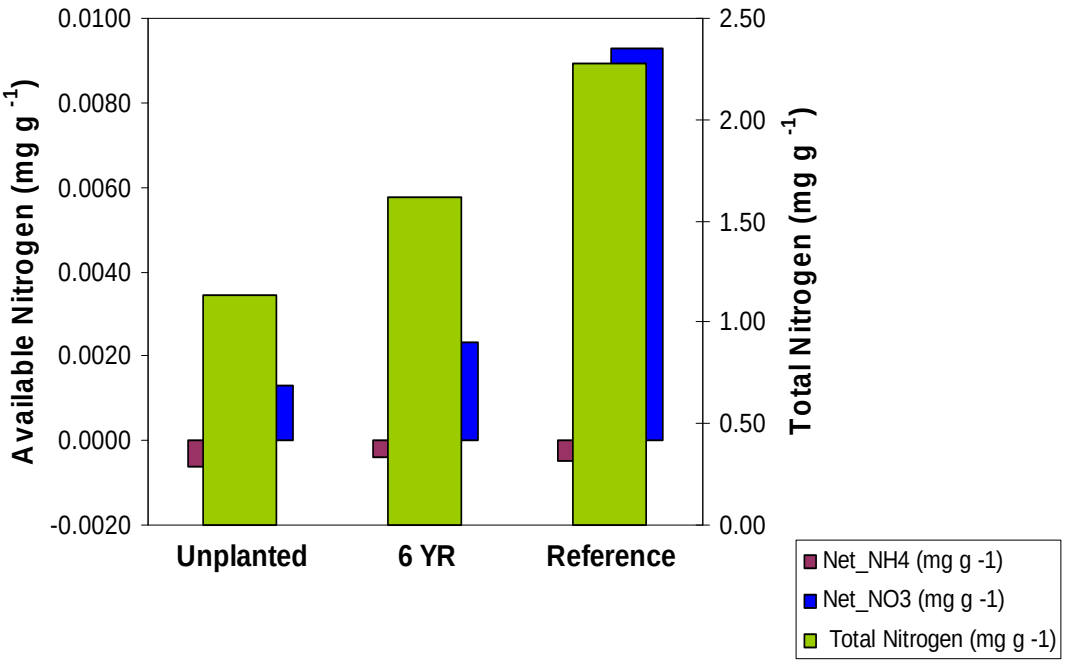

Figure 18: Mean Total and Available Nitrogen by Site.

Total nitrogen is plotted on a separate y-axis from Available Nitrogen. Ammonium (NH_4) has negative numbers due to its conversion to nitrates (NO_3). Negative NH_4 data is the result of immobilization and nitrification. Sunrise Restoration Analysis, Mount Rainier National Park.

3.3.3 Soil pH

Soil pH is a measure of the acidity or alkalinity of the soil solution. The soil pH of the rhizosphere affects plant growth by controlling nutrient availability. For most plants, for example, phosphorus is most available at pH of 6.0 (Killham 1999). Soil pH is directly affected by soil parent material as well as the concentrations of different minerals in the soil. Under strongly acidic soils (pH < 5.0) aluminum and iron contribute to pH measurements (Brady and Weil 1999). pH is also affected by nitrogen uptake by plant roots. If ammonium is the primary source of nitrogen in the soil solution, pH will most likely decrease. If nitrate is dominant, pH will most likely increase.

pH levels were moderately acidic on both the restoration and reference sites (Acidic soils are those with pH below 7.0). Figure 19 graphically describes the small increase in average pH from the unplanted restoration section (5.5±.21) to the 6-year-old section (5.9±.39) which is consistent with Hypothesis 7. However, average pH of the reference sites (5.6±.22) was equal to the unplanted restoration site (Table 8).

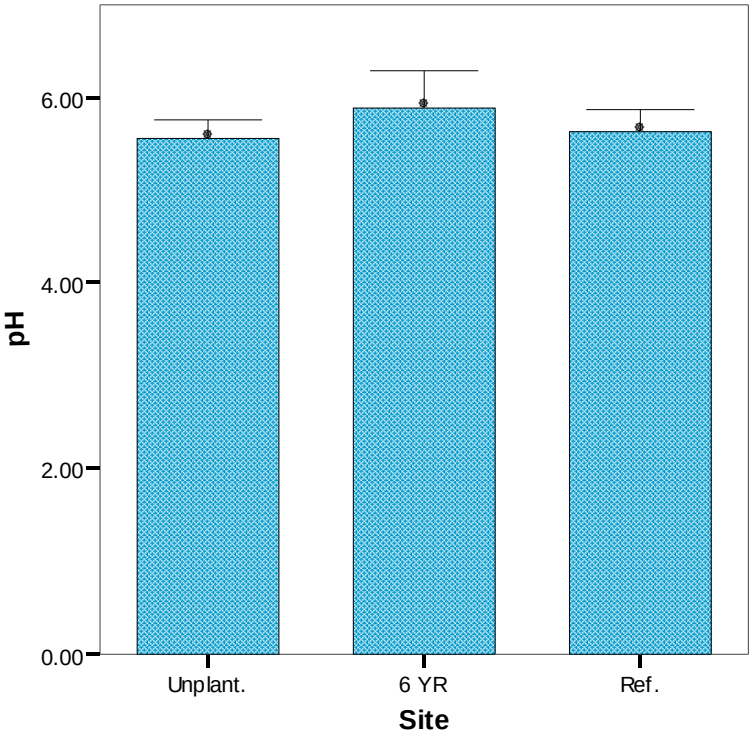

Figure 19: Mean Soil pH by Site.

Illustrates that soil pH was very similar between the reference sites and the unplanted restoration site. pH was moderately acidic on all sites. Error bars show mean ± 1.0 standard deviations. Sunrise Restoration Analysis, Mount Rainier National Park.

CHAPTER IV DISCUSSION

4.0 VEGETATION ANALYSIS

The vegetation analysis conducted for this evaluation shows an overall increase in plant cover as the age of the planting site increases, which supported Hypothesis 1. Although percent cover fluctuates between years 3 to 5, there is an overall increase in plant cover of 18% from the 2-year-old site to the 6-year-old site. In addition, there was only a 5% difference in cover between the 6-year-old restoration site and the reference site indicating plant cover target conditions have nearly been achieved. The positive relationship between plant cover and age of restoration section was supported in both regression and ordination analysis. These results are promising for restoration progress since they reflect continued plant growth and cover as the sites mature.

The percent cover in the reference areas was lower than cover values documented in other floristic studies of the Sunrise meadows (Frank and del Moral 1985; Henderson 1974). The species composition of the reference sites was more diverse than that of the restoration sites. This was expected since primarily dominant meadow species were propagated and planted in restoration sites. Species with the highest percent cover in the reference sites included *Luzula glabrata, Festuca viridula, Erigeron perigrinus, Veronica cusickii and Polygonum newberryi*. These species had average cover values greater than 3% (Table 4). The prominence of *Festuca viridula* and *Veronica cusickii* was also noted by Frank and del Moral (1985).

Despite the progress in terms of plant cover, the 6-year-old site lacked the species diversity of the reference sites and continues to resemble a planted landscape. Overall, a greater number of species was found on reference sites (26 species) compared to the five revegetated sections (average of 12 species). And the older restoration sites did not have higher species diversity than younger restoration sites based on immigration of those

species not planted during restoration. These results did not support Hypothesis 2. Natural recruitment of *Festuca viridula* and other species could not be experimentally determined at the Sunrise sites since a seed mix was applied to some of the restored sections. Within the restoration sites *Polygonum newberryi* and *Abies lasiocarpa* were the only natural recruiters. *Polygonum newberryi* is recognized as a seral or pioneer species and is generally found on disturbed sites in the subalpine grasslands of Mount Rainier (Henderson 1974).

There has been no invasion of *Festuca viridula* or *Lupinus latifolius* into the unplanted restoration section, which is consistent with observations made in other studies (Frank and Del Moral 1985). These two species, which are considered dominant, climax species in other parts of the Sunrise bench, exhibit slow rates of recovery attributed to the production of few viable or poorly dispersible seeds (Frank and Del Moral 1985).

Other studies have shown that experimental increase in "safe-site" availability increased recruitment of immigrant species as well as plant density in alpine restoration sites (Urbanska 1997; Urbanska and Fattorini 1998; Chambers 1997). The use of greenhouse grown plants and other restoration practices (e.g. erosion control mats) in the Sunrise restoration were expected to act as seed sources and safe sites for new seedlings. Mulches similar to those used in Urbanska's study were used on most of the Sunrise restoration plots. In light of this, why do we not see immigration of other meadow species into the restoration sites?

Ultimately, the results are consistent with what is known about high elevation restoration-specifically, that plant growth and recovery is slow due to short growing seasons and extreme climatic factors. The results at Sunrise can be attributed to a number of factors limiting natural recruitment at disturbed high elevation sites. These factors include seed

availability, seed germination and seedling establishment (Zabinski *et al.* 2000). Soil surface temperatures can reach or exceed 100° F (38° C) in the Sunrise meadows (Henderson 1974). Heat stress, coupled with summer drought conditions, makes seed germination and establishment exceedingly difficult. Seed production and availability is already limited in undisturbed high-elevation systems (Bliss 1985). This problem is compounded with disturbance to the soil seed bank and loss of propagule resources. Due to the climate restraints, alpine plants have adapted by developing leaves and flowers over many growing seasons (Korner and Larcher 1988), thus taking years before they are reproductively active.

Six years may simply not be enough time to detect progress in plant community development aside from vegetative cover. More time may be needed before conditions are favorable enough for dominant and secondary species to migrate to restoration sites, successfully compete for resources and survive the harsh subalpine growing environment.

4.1. *FESTUCA VIRIDULA* COVER AND ABOVEGROUND BIOMASS

Festuca viridula is a tufted clump-forming perennial grass commonly found on subalpine and alpine slopes, rock slides and meadows above timberline. *F. viridula* is the dominant species found in the Sunrise meadows and the primary species planted throughout the restoration sites. The survival and growth of *F. viridula* is important to the success of revegetation efforts.

The linear regression model used to correlate percent cover of *Festuca viridula* biomass with the age of the planting site had strong explanatory power (r^2=.731). Consistent with Hypothesis 3a, *Festuca viridula* cover increased among the restoration sites with zero cover on the unplanted restoration and 11% cover on the 6-year-old site. The lack of Festuca viridula on the unplanted site reflects the lack of natural recruitment. This result

is not completely unexpected since *Festuca viridula* is considered a late seral species for the subalpine grasslands of Sunrise (Frank and del Moral, 1986).

Festuca viridula biomass per area (m^2) increased with the age of the restoration sites, which supports Hypothesis 3b. This is consistent with the results of a chronosequence study at high elevation restoration sites in the Canadian Rockies where aboveground biomass ($g\ m^{-2}$) increased with site age (Fyles *et al* 1985). Although there was no difference between the 4- and 6-year-old sites, an average difference of 28 grams/m^2 was seen between these sites and the 2-year-old site.

A suite of variables could be responsible for the lack of difference between 4- and 6-year-old biomass results including horticultural practices in the greenhouse or during out-planting (e.g., planting density, breaking up of root ball), yearly variation in environmental conditions (e.g., snow pack and precipitation) or site differences in restoration plots such as depth to bedrock and soil characteristics.

Little is known about the effect of horticultural practices in the greenhouse on native plant establishment in subalpine and alpine restoration sites. However, it is possible that qualitative differences in plant material due to yearly variations in greenhouse practices may be responsible for the higher biomass of *Festuca viridula* on the 4-year-old restoration section.

Soil nutrient content, duration of snow pack and length of growing season affect production of aboveground biomass as well as litter production (Korner 1999). Thus slight variations in aspect, slope and snow pack duration could also be responsible for the high above-ground biomass of the 4-year-old site.

4.2 CARBON AND NITROGEN DYNAMICS

4.2.1 Percent Carbon and C:N

Soil carbon is an important component of soil ecological health. Soil carbon is made up of plant, animal and microbial biomass in various stages of decay. It is a driving force in decomposition and nutrient cycling, water holding capacity, aggregate stability, infiltration, and cation exchange capacity of the soil (Brady and Weil 1999; Killham 1994). Vegetation cover directly contributes to the soil carbon pool and acts as a reservoir of soil nutrients through root exudates and litter fall from senescent leaves.

As vegetation cover increases over time and carbon inputs into the soil increase, % C and C:N was expected to increase. The results for % C support Hypothesis 4a which states that mean soil carbon would increase as the restoration site matured. As expected, the lowest %C was found on the unplanted restoration sites and the highest %C was found on the reference sites. This is consistent with results of research conducted in subalpine campsites of the Eagle Cap Wilderness in Oregon where undisturbed soil both beneath and between vegetation had significantly higher %C than disturbed soils (Zabinski *et al.* 2002).

C:N ratios did not differ substantially among reference and restoration sites and no clear trend was present based on the time of restoration. These results did not support Hypothesis 4b. The range of C:N (13 to 20) in the undisturbed reference sites reflects the spatial variability present in subalpine grasslands. The range of C:N (14 to 16) was narrower on the unplanted restoration site, which is indicative of the homogeneity on the site and lack of vegetative cover. These results are consistent with C:N ratios documented in other studies on subalpine grassland and meadow communities (Chambers 1997; Korner 1999; Sanscrainte 1999). The largest difference determined was between the

unplanted restoration section and the reference site with average C:N of 15 (± .87) and 17 (± 1.62) respectively. C:N of 20:1 are considered an optimal threshold for net mineralization and net immobilization of nitrogen (Killham 1994). Therefore, the C:N ratios across all the study sites are slightly low and at good levels for nutrient uptake by plants.

4.2.2 Total and Available Nitrogen

With an increase in plant cover, litter fall and carbon inputs into the soil system the conditions for decomposition and nutrient cycling improve. In alpine soils, concentrations of total nitrogen are positively correlated with the organic matter content of the soil (Korner 1994). Therefore it was hypothesized that total and available nitrogen would increase as the restoration sites matured (Hypothesis 5). Both total and available nitrogen results support this hypothesis. Net nitrogen mineralization was lower in the unplanted restoration compared to the planted restoration sites. And the reference sites were higher than both restoration sites. This same trend held true for total nitrogen across all study sites.

Available nitrogen usually occurs as both ammonium (NH_4) and nitrate (NO_3). Chambers (1997) notes that nitrification is low in alpine ecosystems resulting in greater abundance of Ammonium-N. This is not consistent with the results of the nitrogen mineralization experiment for this study. Nitrate-N was present in greater abundance than Ammonium-N, which had negative values in both restoration and reference sites. Ammonium mineralized from inputs of organic matter does not remain in the soil for long and is rapidly transferred to other nitrogen pools. These higher levels of nitrate reflect the immobilization of ammonium as well as nitrification due to temperature and moisture regimes during the short-term laboratory incubation (Makarov *et al.* 2003).

Soil nutrient concentrations are spatially and temporally variable in alpine and subalpine soils. Nitrate and ammonium levels tend to be low compared with total nitrogen present in the soil system and are strongly influenced by C:N, microbial activity, temperature, soil moisture, physiological needs of plants and landscape effects such as duration of growing season and snow free dates (Chambers 1997; Makarov *et al.* 2003; Zeller 2000).

Studies comparing soil nutrient concentrations on disturbed and undisturbed subalpine and alpine soils have been inconsistent. Some studies found increases in available nitrate and ammonium on disturbed sites but lower total nitrogen compared to reference sites in the northern Bitterroot Mountains of Montana (Zabinski and Cole 2000). de Gouvenain (1996) reported higher percent carbon and nitrogen on disturbed sites in the North Cascade Mountains of Washington, while another study reported lower available and total nitrogen pools on disturbed soils in the Eagle Cap Wilderness of Oregon (Zabinski *et al.* 2002).

4.3 SOIL MOISTURE AND PH

Soil moisture results supported Hypothesis 6 which states that soil moisture would increased each year within the restoration sites. However, the unplanted restoration and reference sites had identical soil moisture levels (8.2 %). This result was surprising given the differences between the unplanted and reference sites in both vegetative cover and soil carbon content. One explanation for this finding is simply that the increase in plant cover resulted in the uptake of more water from the soil. The unplanted site may not be retaining water due to the lack of plant litter and vegetative cover. Site variability could also be causing these differences including microclimate and depth to bedrock. Without replication of restoration sections or an investigation into geologic substrate, this is difficult to determine.

Given the other differences found in vegetation cover, %C and available nitrogen, the Sunrise results don't fully support Hypotheses 7 which states that soil pH would change as a function of soil and plant development over time. Soil pH showed little change between the reference and the unplanted restoration sites. However, there was an increase from the reference site to the 6-year-old restoration sites. All sites had moderately acidic pH results. Studies comparing pH on disturbed or restoration sites with undisturbed sites have variable results. One study from the Cascade Mountains of Washington reported an increase in pH following disturbance in subalpine plant communities (de Gouvenain 1996). However, a chronosequence study of restored grasslands in Nebraska (Baer *et al.* 2002) did not report significant differences in pH between natural and restored sites and did not find any patterns as the age of the restoration site increased. With this in mind, the variable pH levels in restoration and reference sites of the Sunrise analysis is not surprising.

4.4 MICROBIAL ACTIVITY AND BIOMASS

Despite the increase in total plant cover found between the unplanted (7%) and 6-year-old restoration section (24%), a significant increase in microbial activity is not seen as the age of the restoration site increases. This does not support Hypothesis 8a outlined in Chapter 2. Although plant cover in the reference sites was only 6% higher than the 6-year-old restoration, it is likely that the higher CO_2 evolution on reference sites is due to higher root biomass of well established plants in undisturbed reference meadows. Hypothesis 8b, which expected an increased microbial biomass with the age of the restoration site, was also unsupported by this study. The unplanted and 6-year-old sites showed no increase in microbial biomass.

However, laboratory and field experiments confirmed that disturbance negatively affects microbial activity and biomass in the subalpine grasslands on the Sunrise bench. Six

years after revegetation carbon dioxide evolution is substantially lower in both of the restored sites. This is consistent with other studies of disturbed alpine areas where microbial biomass (Vance and Entry 2000), microbial activity (Belnap 1998; Zabinski *et al*. 2002), or functional diversity (Zabinski and Cole 2000) decreased after disturbance.

The overall microbial activity determined in both experiments was very low across all sites. Low microbial activity is not surprising given the lack of plant litter, low % C and the high percentage of bare ground documented in these meadows. Plant community dynamics are a key component to soil microbial processes and provide access to carbon from the decay of above and belowground plant biomass, root exudation and mycorrhizal fungi (Johnson *et al.* 2003).

The presence of negative biomass values in both experiments raises questions about the efficacy of the methods for this plant community. Negative numbers are sometimes found in field experiments under extremely cold temperatures or in lab experiments conducted on clay soils that would inhibit soil microbial activity. Since these soils are sandy loam, the latter explanation does not apply. However, it would be worth further investigation to determine if the ash content of the soil may be inhibiting microbial respiration (Edmonds, personal communication). Although field tests were run in late August with daytime temperatures ranging from 75 to 85 degrees Fahrenheit, it is possible to see temperatures close to freezing at night. For purposes of this analysis, negative respiration values were represented as zero, assuming minimal microbial activity.

CHAPTER V CONCLUSIONS

Total percent vegetation cover increased as the age of the restoration site increased with the highest cover found on the adjacent reference grasslands. Species composition

continued to be highest on the reference grasslands. The only species found on restored sites that weren't planted were *Polygonum newberryi* and *Abies lasiocarpa*. *Festuca viridula* showed an increase among restoration sites, however, *F. viridula* cover was lower on reference sites than on the 6-year-old site. Biomass of *Festuca viridula* (g m^{-2}) was higher on 4- and 6-year old restoration sites compared to the 2-year-old restoration site.

C:N was similar between revegetated and reference sites whereas %C increased with site age among restoration and reference sites. Total and available nitrogen also increased with site age. And although soil moisture on reference sites equaled that found on the unplanted restoration, an increase in soil moisture was found as the age of the restoration site increased. Soil pH did not adhere to a pattern based on age and showed similar results between the reference and the unplanted restoration site. Soil microbial activity and biomass showed clear differences between reference and restoration sites, but there was no increase in microbial activity or biomass between the unplanted and 6-year-old restoration site.

Overall, these results confirm that the restoration sites at Sunrise are on a trajectory toward recovery. The increase in vegetation cover and *Festuca viridula* biomass coupled with the increase in %C, soil moisture and total and available nitrogen on revegetated sites, reflect continued growth of greenhouse plants, litter accumulation and the increase of nutrients in the soil.

However, there were two hypotheses not supported by the results of this research. Although microbial biomass and activity was higher on reference compared to restored sites, microbial activity observed on restoration sites had zero and negative values, which requires further scrutiny. With the increase in carbon inputs into the soil as a result of

increased vegetative cover and %C, microbial activity and biomass were expected to increase.

Since the microbial community plays such a critical role in decomposition and nutrient cycling, a more comprehensive investigation into microbial activity and biomass is necessary. This investigation could include an assessment of microbial biomass C and N, soil respiration as well as the methods used to examine these factors. No research has assessed microbial activity, biomass or microbial functional diversity of the *Festuca-viridula* grasslands on Mount Rainier. Most research on microbial activity or biomass has been conducted in high elevation grasslands of Europe or the Rocky Mountains with different plant communities and management histories including mineral extraction, livestock grazing and heavily impacted campsites (Johnson *et al*. 2003; Zabinski and Gannon 1997; Zeller *et al.* 2001). The primary disturbances related to the Sunrise Road Restoration have been restoration activities such as road removal and revegetation efforts as well as recreational impacts such as hiking and mountaineering.

The second hypothesis not supported by the results of this study states that natural recruitment of unpropagated species would increase with site age. Although the species composition of revegetated sites was technically more diverse than the unplanted site, this was due to the installation of greenhouse plants and salvaged plant clumps during the road restoration. The vegetation survey did not produce evidence of natural recruitment of unpropagated species into restoration sites except for two species, *Polygonum newberryi* and *Abies lasiocarpa*.

In the unplanted restoration site, these were the only two natural recruiters. This has important implications for restoration strategies, particularly when the restoration objective is to restore species composition and cover as quickly as possible. The sparse

cover on the unplanted restoration site as well as the low %C, low levels of total and available nitrogen and microbial biomass and activity confirms that revegetation efforts speed the recovery of impacted subalpine plant communities, not simply in terms of vegetation cover but in soil ecological processes as well.

To elucidate the viability of the plant community on the Sunrise restoration, a long-term demographic monitoring project similar to those conducted by Urbanska (1994) on restoration plots in the Swiss Alps would be useful. Demographic monitoring examines the age-state structure of plants including flower and seed production. This coupled with further soil analysis would assist in analyzing the trajectory of the restoration sites.

In the harsh subalpine ecosystem, survival and continued growth of greenhouse grown plants is an important first step to restoration success. Ultimately, it will be necessary to revisit the Sunrise Restoration over the next 10 to 20 years to assess plant cover and soil ecological processes. Only with time, will the trajectory and success of the Sunrise Restoration be determined.

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APPENDIX A: List and quantity of greenhouse plugs in restoration

Information in table provided by Mount Rainier National Park Restoration Program

SPECIES	**1997**	**1998**	**1999**	**2000**	**2001**
Anemone occidentalis		46			
Antennaria lanata	44	488	440	1127	1744
Aster alpigenus	1952	997	1274	637	504
Aster ledophyllus		135			
Carex nigricans			980	2192	697
Carex species					
Carex spectabilis	1666	980	2428	6266+4pf	6,552 + 1pf
Cassiope mertensiana			169	266	78
Deschampsia atropurpurea					
Erigeron peregrinus	2813	908	3724	5213+4pf	2,257
Festuca viridula	5090	9191	12283	11893	4,168
Graminoid species				49	
Juncus drummondii		1930		6168	1,143 + 4pf
Luetkea pectinata		40			
Lupinus lepidus	22				
Phyllodoce empetriformis			197	63	
Polygonum bistortoides				38	
Potentilla flabellifolia	3471	1268	3036	5711+1.5pf	2,519 + 2.5pf
Veronica cusickii		362	638	1495	1,920 + 1pf

p.f.: planting flat

APPENDIX B: Photographs of Restoration and Reference Soils

Figure 1: Photograph of Reference Soil.

Samples collected from top 15 cm of the soil surface. Depth increases from right to left. The coloration reflects variations in moisture content and not horizonation. Note plant roots in middle portion of soil sample. Sunrise Restoration Analysis, Mount Rainier National Park.

Figure 2: Photograph of Unplanted Restoration Soil.

Samples collected from top 15 cm of the soil surface. Depth increases from right to left. The coloration reflects variations in moisture content and not horizonation. Note presence of pumice, rocks and litter on soil surface (far right). Sunrise Restoration Analysis, Mount Rainier National Park.

Figure 3: Photograph of 6-year-old Restoration Soil.

Samples collected from top 15 cm of the soil surface. Depth increases from right to left. The coloration reflects variations in moisture content and not horizonation. Note presence of degraded coir matting on surface of soil (far right) as well as residual greenhouse fertilizer pellets (green dots) on soil surface. Sunrise Restoration Analysis, Mount Rainier National Park.

APPENDIX C: Photographs of 6-year-old restoration site and adjacent reference meadows.

Figure 4: Photograph of 6-year-old Restoration Site.

Figure 5: Photograph of the 5- and 6-year-old Restoration Sites.

Shows hiking trail that runs through sites 5 YR and 6 YR with Little Tahoma in the background.