Soil Microsite Conditions of *Festuca roemeri* and *Castilleja levisecta* in Native Prairies of Western Washington

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This is to certify that I have examined this copy of a master's thesis by

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INTRODUCTION

The Pacific Northwest, a region commonly recognized for its mesic, coniferous forests, also contains patches of native grasslands, which are locally known as prairies. In western Washington, prairies occur on fast draining, coarse textured soils derived from glacial outwash or sand over outwash (Ness and Richins 1958, Schlots et al. 1962, Ugolini and Schlichte 1973). The open prairie structure has been maintained by droughty summer conditions in combination with frequent historical burning by Native American people (Norton 1979, Boyd 1999). Similar to trends across North America, native prairies in western Washington State have been greatly reduced over the past two centuries, and are estimated to comprise only 2-4 % of their historical extent (Noss et al. 1995, Chappel et al. 2000). This has resulted in habitat loss for numerous plant and animal species which depend on these ecosystems to survive (Fimbel 2004, Stinson 2005, Dunwiddie et al. 2006).

The loss of native prairies has been attributed to several factors, including fire suppression and exclusion, urban development, agriculture, and invasion by both native and non-native species (Franklin and Dyrness 1988, Crawford and Hall 1997, Dunwiddie 2002). Due to the pronounced reduction in these systems, as well asthe fragmentation of those that remain, it has been suggested that preservation alone is not sufficient to ensure that these ecosystems persist. Ongoing, active restoration is necessary to both maintain prairie remnants and expand their current range (Floberg et al. 2004). In response, several efforts have been made over the past two decades to both protect existing prairie remnants and to restore those degraded by human activity (Dunn and Ewing 1997, Dunn 1998, Ewing 2002, Dunwiddie 2002, Lambert 2006).

Two native grass species that are commonly used in prairie restoration in western Washington are *Festuca roemeri* (Pavlick) Alexeev (Roemer’s fescue) and *Elymus glaucus* Buckley (blue wildrye). *F. roemeri*, a perennial bunchgrass, is considered to be a keystone species in grassland ecosystems of the Puget Lowlands (Lang 1961; Giles 1970; del Moral and Deardorf 1976; Clampitt 1993). It is often employed as an initial component in restoring native prairie structure and composition—either by sowing seed or outplanting seedlings. *F. roemeri* can tolerate extreme conditions and is primarily found in areas with shallow, mineral soil or on steep terrain (Darris et al. 2007). *E. glaucus,* also a native perennial bunchgrass, is often found on the forest edge or in dappled light conditions (Johnson 1999).

Though prairie restoration efforts have primarily focused on establishing native grasses, other projects have worked to increase the population of a more ephemeral species, the federally threatened *Castilleja levisecta* Greenm. (golden paintbrush). *C. levisecta,* a member of the Scrophulariacaea (figwort) family is an herbaceous, hemi-parasitic perennial. Endemic to the Pacific Northwest, *C. levisecta* has been in decline for the past several decades; currently only 11 known populations remain—ranging from southern Washington to British Columbia (Caplow 2004, Arnett and Thomas 2008). *F. roemeri* is a known host species for *C. levisecta* (Wentworth 2000).

A growing body of research has specifically focused on better understanding the habitat requirements of *C. levisecta* (Wentworth 2000, Chappel and Caplow 2004, Lawrence 2005, Lawrence and Kaye 2006,) and developing effective strategies for increasing its populations (Dunwiddie et al. 2000, Swenerton 2003, Wayne 2004, Pearson and Dunwiddie 2006). Concern for this plant continues to grow as even some of the formerly robust extant populations are decreasing in size (Arnett and Thomas 2008).

Though many efforts have been made or are underway to restore native prairies and species therein, managers face numerous restoration challenges and projects have resulted in varying levels of success (Lambert 2006, Pearson and Dunwiddie 2006). Although many factors contribute to the varied success of these efforts, in some cases, differences in microsite conditions could be particularly influential. Indeed, studies have shown that soil heterogeneity can affect nutrient availability and soil moisture on a fine scale (Hook et al. 1991, Jackson and Caldwell 1993, Reynolds et al. 1997); therefore, variability in such soil properties may explain the ability of plants to persist at some sites, or why some studies have identified patches of high survival of outplanted species (Pearson and Dunwiddie 2006). This study examined soil microsite conditions within several remnant prairie sites in western Washington to determine if microsite differences could explain restoration results.

Thus, this research had two main areas of focus:

I. To document soil conditions present at two prairie restoration sites in western Washington: American Camp within San Juan Island National Historic Park, and Ebey's Landing National Historic Reserve. Specifically, to the goal was to characterize soil conditions in locations where outplanted *F. roemeri* has had high survival rates and compare these areas to those where survival rates were lower. Additionally, in order to better understand the habitat of native grass species, extant native communities of *F. roemeri* and *E. glaucus* at American Camp were also monitored.

The following questions were addressed: 1) What are the soil microsite conditions in areas where *F. roemeri* seedlings were planted and resulted in high survival (high-density)? 2) What are the soil microsite conditions present in areas where *F. roemeri* seedlings were planted but, at least initially, had lower survival rates (low density), and how do they compare with areas of high density fescue? 3) What are soil microsite conditions in areas of extant, high-density native grasses (*F. roemeri* and *E. glaucus*)—do they differ?, and 5) What are soil conditions like in an area of high rabbit warren density where future restoration may occur?

II. To characterize soil conditions where *C. levisecta* had been planted (via seed and seedling) and compare areas of high and low *C. levisecta* survival plots at 4 prairie sites in western Washington (3 of which have mounded topography). The following questions were addressed: 1) Is there a difference in soil microsite conditions (e.g. soil moisture and temperature) between areas where *C. levisecta* was planted and survived compared to where it did not survive?, 2) Is there a difference in soil chemical properties between high and low survival areas?, and 3) Do different locations on mounds (top, side, or swales) contain higher or lower amounts of coarse material—possibly affecting microsite conditions in mounded topography?

CHAPTER 1

Soil microsite conditions in four *Castilleja levisecta* (golden paintbrush) restoration sites in western Washington

INTRODUCTION

Castilleja levisecta Greenm. (golden paintbrush), a rare plant endemic to the Pacific Northwest, has been in decline for the past several decades. Historically found from the Willamette Valley in Oregon north into British Columbia (Caplow 2004), recent monitoring efforts have documented only 11 remaining extant populations—all within the Puget Lowlands of Washington State and Vancouver Island, B.C. (Arnett and Thomas 2008). Due to its limited range, *C. levisecta* was listed as a federally threatened species by the U.S. Fish & Wildlife Service in June 1997 (USFW 1997).

C. levisecta, a member of the Scrophulariaceae (figwort) family, is an herbaceous, hemi-parasitic perennial. Being hemi-parasitic, it has the ability to form haustorial roots which can attach and draw resources from the roots of host plants; however, forming these connections is not critical to its survival, at least when resources are plentiful (Wentworth 2000). *C. levisecta* usually has 5-15 branches, with inflorescences that can reach up to 33 cm. The actual flowers of the plant are small and inconspicuous—hidden by the showier, bright yellow bracts. Leaves are broader towards the base of the plant and are covered in soft, slightly sticky hairs (Wentworth 2000, Caplow 2004).

This rare species occurs in open, generally grass- or sedge-dominated landscapes, though it sometimes occurs in shrub thickets. One population in the Puget Sound region of Washington State occurs on mounded topography, with soils derived from glacial outwash. Populations close to the waters of Puget Sound often occur on or near steep, grassy coastal bluffs that have a west or southwest aspect (UWFWS 2000). Soils in these locations are often very sandy and, like soils derived from glacial outwash, have a low moisture-holding capacity (Ness and Richins 1958).

One major factor in the decline of *C. levisecta* is the loss and fragmentation of its native prairie habitat. In the Pacific Northwest, a region not usually associated with such ecosystems, native prairies are being lost at a rate similar to that of grasslands throughout the nation (Noss et al. 1995). Chappell et al. (2000) suggest that native prairies in western Washington have been reduced by 96-98% from their pre-contact extent. The reason for the sharp decline in prairies in this region has been attributed to development, agricultural conversion, invasion by both native and nonnative plant species (Franklin and Dyrness 1988), as well as fire suppression and exclusion (Agee 1993, Crawford and Hall 1997). The pronounced decline of native prairies has resulted in a loss of regional biodiversity.

In response to the decline in native prairies and the rare plant species that depend on them, efforts are being made to increase both the extent of native prairies and maintain native biodiversity within these systems. The Reintroduction Plan for Golden Paintbrush (Caplow 2004) emphasizes the importance of increasing our knowledge of site characteristics within extant *C. levisecta* populations, and using such information to guide reintroduction and introduction efforts. A growing body of research has specifically focused on better understanding the habitat requirements of *C. levisecta* (Wentworth 2000, Chappel and Caplow 2004, Lawrence 2005) and developing effective strategies for increasing its populations (Dunwiddie et al. 2000, Pearson and Dunwiddie 2006, Swenerton 2003, Wayne 2004). Concern for this plant continues to grow as even some formerly robust, extant populations are in decline (Arnett and Thomas 2008).

Site characteristics which may influence the success of golden paintbrush include soil conditions and microhabitats. In some environments, soil heterogeneity has been found to be high within a small area, which could influence the survival and/or vigor of certain plant species (Jackson and Caldwell 1993). Pearson and Dunwiddie (2006) conducted a 5-year experimental seeding and outplanting study in south Puget Sound to assess the success of various techniques for planting *C. levisecta* in prairies. This research identified specific patches of high *C. levisecta* survival, which raised the hypothesis that there may be microsite conditions (fine-scale variability) that influence the survival of both seeded and outplanted seedlings of *C. levisecta* at these sites. My study aimed to address this hypothesis. The main objective was to characterize soil conditions in high and low *C. levisecta* survival plots at 5 prairie sites in western Washington (3 of which have mounded topography). Specifically, the following questions were addessed: 1) Is there a difference in soil microsite conditions (e.g. soil moisture and temperature) between areas where *C. levisecta* was planted (either by seed or seedling) and survived compared to where it did not survive?, 2) Is there a difference in soil chemical properties between high and low survival areas?, and 3) Do different locations on mounds (top, side, or swales) contain higher or lower amounts of coarse material—possibly affecting microsite conditions in mounded topography?

METHODS

Site Descriptions

This study was carried out in two general locations within the Puget Sound, referred to as north and south Puget Sound (NPS and SPS respectively). Within these two general locations were a total of five sites: three that were located in SPS and two in NPS (see below**).**

South Puget Sound

Three south Puget Sound (SPS) prairie sites were included in this study: Black River-Mima Prairie Glacial Heritage Preserve (Glacial Heritage), Mima Mounds Natural Area Preserve (Mima Mounds), and Rocky Prairie Natural Area Preserve (Rocky Prairie)—all of which have mounded topography (Figure 1.1). Soils at these locations are mapped as a Spanaway-Nisqually complex, with 2 to 10 percent slopes. This soil series is roughly 60% Spanaway, derived from gravelly glacial outwash with some volcanic ash, and approximately 40% Nisqually, which is comprised of finer, loamy sand (Pringle 1990). The Spanaway soil is described as a Medial-skeletal over sandy or sandy-skeletal, amorphic over isotic, mesic Typic Melanoxerand, and the Nisqually is classified as a sandy, isotic, mesic Vitrandic Dystroxerept (NRCS 2008). Both soil types are very fast draining, though Nisqually soils tend to have higher moisture holding capacity due to their finer texture. Soil examinations concluded that locations of microsite monitoring for this study were primarily located on Spanaway soil. Sites belonging to the Spanaway-Nisqually complex range in elevation from 30-76m (100-250 feet) (Pringle 1990). This area of Washington State receives about 130 cm of rainfall annually (WRCC 2008).

Glacial Heritage and Mima Mounds are in close proximity to one another (1.6 km), while Rocky Prairie lies approximately 14 km to the east. Glacial Heritage consists of 280 hectares of irregularly mounded prairie, while Mima Mounds is 250 hectares of regularly mounded prairie. Mounds are approximately 2-2.5m tall in the center at Mima Mounds, and are generally lower at Glacial Heritage, which has been noted to have a greater occurrence of non-native species than Mima Mounds (Caplow and Chapell 2005). Rocky Prairie is the smallest of the three SPS sites, comprising approximately 16 hectares of irregularly mounded prairie. Though small, it is home to one of the largest extant *C. levisecta* populations (5,000 individuals were counted in 2002) (Chappel and Caplow 2002).

North Puget Sound

The two study sites in north Puget Sound (NPS), Sherman and Bluff sites, are located on the west coast of Whidbey Island, within the 224 hectare Robert Y. Pratt Preserve. This preserve, owned by The Nature Conservancy, is located within the Ebey's Landing National Historical Reserve. The Sherman site has a mean aspect of 135° (SE) with 8-16% slopes; soil is mapped as the San Juan coarse sandy loam series, a Sandy, isotic, mesic Pachic Ultic Haploxeroll.

San Juan soils share many similar characteristics with the Spanaway soils in south Puget Sound. Both are derived from glacial outwash and are coarse-textured—resulting in excessively drained soil. San Juan soil has a layer of sand over outwash, which makes it less gravelly in the A horizon: the texture of the Spanaway is gravelly sandy loam and the San Juan is sandy loam. Both series have a dark, deep A horizon over a more gravelly subsurface horizon. Though the coarse texture of these soils makes them very fast-draining, the high organic matter content helps retain moisture in the A horizon, and also contributes to the dark surface color (Schlots et al. 1962). The San Juan soil series is one of the most common series associated with historical prairie sites in western Washington State (Chappell et al. 2000; Schlots et al. 1962).

The Bluff site has a mean aspect of 240° (SW) and is very steep, with slopes of 8-35%. Soils on the bluff have not been classified (Ness and Richins 1958). Unlike much of Ebey's Landing, this portion was never farmed due to its steep topography. Ebey's Landing receives an average of 46-51 cm (18-20 inches) of rain annually (NWSIT 2008).

Experimental Design

This study was designed to compare soil microsite conditions between two groups: locations where *C. levisecta* was outplanted or seeded and survived (high survival) and where *C. levisecta* was outplanted or seeded and did not survive (low survival). With high survival plots, an effort was made to choose the most prolific plots but, due to a limited number of plots to choose from, some contained only one plant. Plots which had zero survival (as of spring 2006) were also designated as "low survival."

C. levisecta at SPS sites was planted via seed or seedling in 2003 and 2004 in a joint effort by The Nature Conservancy and the United States Fish & Wildlife Service (Pearson and Dunwiddie 2006). When seedlings were planted, six were placed into each 1m x 1m plot and tagged. When seeded, one thousand seeds per plot were sown. Four plots were also included within an extant population at Rocky Prairie to document soil conditions where *C. levisecta* naturally occurs. In some analyses these were grouped into the "high survival" group. In NPS, all *C. levisecta* were planted as seedlings in 2002. The Sherman site was planted by Swenerton (2003) and the Bluff site was planted by The Nature Conservancy staff and volunteers.

Field Work

In May and June of 2006, a total of 64 1-meter square plots were established, with 16 each at Glacial Heritage and Mima Mounds, 8 at Rocky Prairie, 16 at the Sherman site, and 8 at the Bluff site. In total there were 28 high survival plots, 32 low survival plots, and 4. The four extant population plots were located at Rocky Prairie. Percent cover of all vascular species present within the plots was recorded during May and June of 2006 using methodology of Chappell and Caplow (2004). Cover of a species was determined as "trace" when it occurred below 0.5%. Between 0.5% and 15%, crown cover was estimated to the nearest 1%, and to the nearest 5% from 15% to 100% cover. Bryophytes and bare ground was also recorded in percentages.

During each site visit soil moisture and soil temperature were recorded. Plots were monitored approximately twice a month from July through September of 2006, once a month from October 2006 through April of 2007, and then semi-monthly readings resumed and continued until the end of August 2007. Readings were taken between 1200 and 1600 hours in the afternoon. Two readings were not conducted due to technical difficulties (July of 2007 at the NPS sites, and February at the SPS sites).

Soil temperature was measured at 5 cm depth, and surface temperature at approximately 5 cm above the soil surface (in the shade) using a Taylor® digital thermometer. Soil moisture levels, or volumetric water content (VWC), were measured using time domain reflectometry (TDR). TDR provides average VWC over the length of the probe by measuring the time it takes for an electromagnetic pulse to travel to the length of the probe and back to the unit. This value is converted to a dialectic constant and finally to a percent VWC (Grey and Spies 1995).

The initial intention was to install 30 cm long moisture probes in all 64 plots; however, soil at all locations but Sherman was too rocky. Therefore, only the Sherman site was monitored for moisture over both 12 and 30 cm, while the rest of the sites were monitored only for moisture over 12 cm depth. At Sherman, 30 cm probes were installed in June of 2006, which consisted of two stainless steel welding rods spaced 1 cm apart. Rods were driven into the soil perpendicular to the soil surface using a wooden guide and mallet, and remained in place for the duration of the study, which allowed for minimal disturbance to the soil. VWC in the top 30 cm was measured using a Telektronix TDR device and VWC in the top 12 cm was measured using a Campbell Hydrosense® moisture probe. The Hydrosense® was inserted into the soil at each reading. Laboratory tests with soil cores determined that standard calibration curves for both instruments were accurate for the A horizon of the San Juan, Nisqually, and Spanaway soil series and no additional moisture content corrections were applied.

Soil Analysis

Soil samples were gathered from Glacial Heritage, Mima Mounds, and Rocky Prairie to compare the percent of coarse fragment (soil particles > 2 mm) at the top of mounds, side of mounds, and in between the mounds (swales). Nine soil samples were collected from each of the three sites: three from the tops of mounds, 3 from the sides, and 3 from swales. Samples were air-dried and sieved, using a 2 mm sieve, to separate the fine and coarse fragments. These two portions were weighed to compute percentages.

Soil from SPS plots had undergone chemical analysis in 2004 and 2005. Most samples were gathered during June of 2004, while other samples were gathered in July of 2005. SPS samples were analyzed for CEC using ammonium acetate. Available nitrate was measured using a potassium chloride extraction with cadmium reduction analysis of nitrate; available phosphorous was measured using Bray-1. All samples from SPS sites were processed by A & L Western Agricultural Laboratories in Portland, OR. To compare chemical properties, soil samples were collected from the Sherman and Bluff sites in May and June of 2006, air dried, and sieved to <2 mm. Soil was collected from the top 20 cm using a soil corer (inserted just outside plot boundary) and A and B horizons were separated, where applicable. All chemical data reported are from A horizons. Soils from NPS were tested for total carbon and nitrogen, available nitrogen and phosphorous, pH, cation exchange capacity (CEC) and exchangeable cations.

Total carbon and nitrogen content were determined using a Perkin Elmer (Series II) Analyzer, model #2400. Available nitrogen (ammonium and nitrate) was extracted using a 2 M potassium chloride extraction (Keeney and Nelson 1987). The weak Bray method (Bray-1) was used to measure available phosphorous (Bray and Kurtz 1945). Soil samples were prepared for pH analysis using a 1:2 (dry soil: DI water) ratio. Samples were mixed thoroughly and allowed to sit for 30 minutes, and then measured using a calomel pH probe. CEC and exchangeable cations were determined using an unbuffered 1 M ammonium chloride extraction followed by a 1 M potassium chloride rinse (Skinner et al. 2001).

Statistical Analyses

Analysis of variance (ANOVA) was used to compare physical and chemical data of high and low *C. levisecta* plots. Five groups were compared using ANOVA: SPS high and low survival plots, NPS high and low survival plots, and the extant population at Rocky Prairie. Physical parameters analyzed with ANOVA included cover type, seasonal averages of soil moisture and temperature, and maximum and minimum values of moisture and temperature ($\alpha = 0.10$). Statistical differences were further analyzed with a Tukey's HSD post-hoc multiple comparison test ($\alpha = 0.10$). Due to notable differences in vegetation cover among sites, cover was analyzed using a two-sample t-test to compare high and low survival plots at each site individually as well as all sites pooled together.

Binary logistic regression was used to assess the strength of relationships between *C. levisecta* survival and cover type, soil physical properties and soil chemical data. Continuous soil moisture and temperature data were displayed graphically and analyzed for qualitative differences. Because not all SPS plots included in this study were tested for soil chemical properties, additional known high and low survival plots from Pearson and Dunwiddie's study (2006) were included in analyses.

RESULTS AND DISCUSSION

Physical Properties: cover type, soil temperature, soil moisture, and % coarse fragments

Cover Type

Using data from all study plots (n=64), logistic regression analysis suggests that the presence of *F. roemeri*, a known host plant for *C. levisecta*, may increase the chance of *C. levisecta* surviving (when planted via seed or seedling). When all other factors are held constant, for each 1% increase in *F. roemeri* cover, the probability of a plot being in the high survival group increased by 51% (p=0.05). Cover of *F. roemeri* in study plots ranged from 0 to 50%. It is worth noting that, because this is a non-linear model, the probability of survival would not be predicted to double with a 2% increase.

Results of the two-sample t-test also found that the cover of *F. roemeri* was higher in the high survival plots than in the low survival plots when all sites were pooled together (Table 1.1), though this was not true for each individual site. Sites which had significantly higher cover of *F. roemeri* in the high survival plots include Glacial Heritage in SPS and the Bluff site in NPS ($p < 0.05$). Cover of another known host species, *Eriophyllum lanatum* (Pursh) Forbes (common woolly sunflower) was also higher in high survival plots at two sites (Rocky Prairie and the Bluff; $p < 0.10$ and <0.001 respectively), though not when all plots were pooled together.

Vegetation cover appears to play an especially important role in the survival of outplanted *C. levisecta* at the Bluff site in NPS compared to other locations. Not only did areas of high survival tend to have higher cover of *F. roemeri* and *E. lanatum*, but had an overall higher presence of native perennials, whereas non-native annuals were less abundant in these areas. Though *C.levisecta* is considered a hemi-parasite and is able to survive without a host, the presence of a host may be more critical at sites with more extreme conditions such as the Bluff. With its steep terrain, shallow soil, and SW facing aspect, soil at this site gets exceptionally hot and dry during summer months (see “Soil Temperature” and “Soil Moisture” sections below). The ubiquitous non-native annual grass, *Bromus diandrus* Roth ssp. *rigidus* (Roth) Lainz (ripgut brome) at the Bluff likely offers no additional moisture or shading for *C. levisecta* due to its annual lifecycle (P. Dunwiddie personal communication 2008).

In recent years numerous studies have focused on assessing the effects of *C. levisecta* growth and/or survival when grown with or without a host plant—and results have varied with different settings and locations. Wentworth (2000) and Lawrence (2005) found in greenhouse studies that *C. levisecta* was able to survive and flower without a host plant. In fact, Lawrence found that *C. levisecta* seedlings planted with *F. roemeri* exhibited poorer growth in the greenhouse compared to seedlings that had no host or were planted with a different host species, *E. lanatum*. This may be a result of overcrowding of fescue in the plots (Caplow 2004). However, when these same seedlings were outplanted in the field, survival was lower in *C. levisecta* planted with *E. lanatum* due to a higher incidence of vole tunneling and herbivory in *E. lanatum* areas. Thus, Lawrence recommends outplanting *C. levisecta* with *F. roemeri*.

In studies on Whidbey Island, Wayne (2004) did not measure a difference in survival rates between *C. levisecta* outplanted with a host versus without, but did count significantly more flowering stems on *C. levisecta* outplanted with *F. roemeri* than without. However, Pearson and Dunwiddie (2006) observed that *C. levisecta* outplanted with *E. lanatum* had the highest production of flowering stems and seed capsules compared to those outplanted with *F. roemeri* or no host.

These results illustrate that factors involved with the survival and subsequent vigor of *C. levisecta* may be quite site specific and vary depending on herbivory levels, climate, location, and site treatments prior to outplanting. These results also indicate that *F. roemeri* may create favorable microsite conditions for *C. levisecta* and increase its survival, which may be due to haustorial connections supplying water and nutrients, or simply by *F. roemeri* shading the soil during extreme conditions. Whatever the exact mechanism (and likely it involves both factors mentioned above) this relationship may be especially critical during times of extreme drought and high temperatures (Lawrence 2005).

Though presence of *E. lanatum* was not as strong of an indicator of *C. levisecta* survival as *F. roemeri*, considering the findings of other studies, as well as the increased presence within high survival plots at some locations within this study, it appears that planting *C. levisecta* near *E. lanatum* can be beneficial at some sites.

Soil Temperature

C. levisecta plants withstood a wide range in soil temperatures throughout the study period, though there was not a difference in soil temperature at 5 cm between high survival (HS) and low survival (LS) sites (Figure 1.2). During the summer of 2006, when temperatures exceeded regional averages (Table 1.2), average and maximum summer temperature readings were higher at all sites compared to 2007. The exposed, SW-facing Bluff site in NPS consistently had the highest temperatures during summer months. In 2006, maximum soil temperatures on the bluff, which were not different between HS and LS plots, averaged 37.4 °C (99.3 °F) (36.5 °C in high survival plots and 38.3 °C in low survival plots). The Sherman site had the lowest maximum soil temperatures during the summer of 2006 (27.1 °C), likely due to the shade cast by the non-native grass *Lolium arundinaceum* (Schreb.) S.J. Darbyshire (tall fescue; formerly known as *Festuca arundinacea* Schreb.), which is dominant at this site. In 2007, temperatures were generally lower, though the Bluff again exhibited the highest maximum temperatures (35.0 °C). This was approximately 10 degrees higher than mean maximum readings in SPS.

Some *C. levisecta* individuals can obviously tolerate very high soil temperatures; however, if summer temperatures continue to rise as predicted in climate change models, conditions on the Bluff and at other similar sites may be more affected than other, more protected sites. This may have consequences for the extant population approximately 2 km southeast of the Bluff site, which has been negatively affected by two accidental fires in the last 6 years. This population, on similar topography, has decreased from several thousand individuals in 2000 to approximately 600 when last counted in 2008. The combination of summer fires and hot summer temperatures may both be factors in the increased mortality at this site (Arnett and Thomas 2008). It is unclear how hot soil conditions can become and still remain within the threshold of *C. levisecta* tolerance.

Soil Moisture

Soil moisture data suggest that *C. levisecta* fares better in microsites that retain slightly more moisture during extreme droughty conditions, but are not overly saturated during winter months. Logistic regression analysis detected a positive relationship between minimum summer moisture values and the survival of *C. levisecta*. For each 1% increase in minimum summer VWC in 2006, the chances of a plot being classified as "high survival" increased by 77% ($p < 0.05$). It should be noted that the range in minimum soil moisture levels during the summer of 2006 was small (plots only ranged from between 2 and 4% VWC from mid-June to mid-September). However, this suggests that there may be a meaningful difference in microsite conditions between 2, 3 and 4% VWC, and that these differences might be critical to the survival of *C. levisecta*. High survival plots in SPS had slightly but consistently greater moisture in the top 12 cm than the low survival plots (Figure 1.3) during the summer of 2006; during the six days that measurements were taken from June through August, the high survival plots had the highest moisture readings in every case.

This pattern was not repeated during the summer of 2007, when weather conditions were cooler and wetter. While in 2006, summer rainfall at SPS sites (6.7 cm) was less than half the normal amount (13.8 cm), in 2007 precipitation levels (15.1 cm) were higher than average (Table 1.3). In addition, during July of 2007, SPS sites received approximately twice as much rain in July as the NPS sites, and this is reflected in higher average and minimum summer VWC readings in SPS (Table 1.2). Therefore, during the summer of 2007, differences were more notable between NPS and SPS sites than between areas of high and low survival. The position of NPS sites in the rain shadow of the Olympic Mountains results in, on average, 25% less precipitation during the months of June through September than the SPS sites.

It was during the winter months that we saw the greatest variation in soil moisture occurred between groups (Figure 1.2). Opposite to the pattern observed with summer moisture, low survival plots at SPS had the highest average VWC (mid-November to mid-April) and greatest mean maximum moisture than all other plots, significantly higher than NPS sites. Of all SPS groups, the extant population at Rocky Prairie had the lowest moisture levels during the winter of 2006-2007.

These data suggest that *C. levisecta* outplants have higher survivorship in microsites that retain even slightly more moisture in the top 12 cm of soil during extremely dry summer conditions. It also suggests that, especially in south Puget Sound sites, *C. levisecta* does better if it does not have extremely wet soil for extended periods—preferring areas that are less saturated during winter months.

Texture and topography (SPS study sites)

Analysis of the location of plots on the mounds in SPS (top of mound, side or swale) found that the cover of *C. levisecta* was greater in plots on top of the mounds than those in the swales ($p = 0.005$). There was a smaller difference in the survival rates (high vs. low) of *C. levisecta* in relation to placement on the mound: within the high-survival plots, a greater number of plots were located on the top of the mound (5 out of 20) than the low survival plots (1 out of 20) ($p = 0.11$). Nevertheless, 10 of the high survival plots were located in the swale, while 15 of the low survival plots were located in the swale. These results are preliminary—a similar analysis of all plots that were set up by Pearson and Dunwiddie could provide a clearer picture of the role of *C. levisecta* survival and/ or vigor in relation to placement on the mound. Unfortunately, with this data set there were an insufficient number of plots on the sides of mounds to statistically test aspect as a factor.

A comparison of % coarse fragments found small differences between various locations on the mounds. Mean values suggest that there are higher amounts of coarse material (soil particles > 2 mm in diameter) on the top of mounds, though this was only slightly higher than levels found in the swales (p=0.16) (Table 1.4.) A higher amount of fine material in the swales would suggest that these areas might be able to hold more moisture in times of drought. So, why is *C. levisecta* generally faring better on top of the mounds? One explanation may be depth of A horizon, which is greater on the top of the mounds compared with between mounds. It does not appear to be related to the percent of organic matter in the soil, which was found to be very similar in these three locations (24-25% OM; p=0.99). Furthermore, samples that were gathered from high and low survival plots were all hand textured and found to be sandy loam. Therefore, there does not appear to be an easy way for managers on the ground to assess favorable microsites for *C. levisecta* in terms of soil texture. Favorable microsite conditions are most likely the result of a complex combination of texture, site, aspect, and vegetation cover.

Chemical Properties

Due to variation in chemical analysis methods, difficulties arose in comparing soil chemical properties between NPS and SPS. Soil from SPS was analyzed in a different laboratory than NPS soil. Therefore, statistical analyses of the data from NPS and SPS provided here were done separately for both— focusing on specifically examining differences between high and low survival areas within the two general locations (NPS and SPS). Some comparisons are made beyond these groups, where appropriate. In general, differences in soil chemical analysis methods made it difficult to compare data with other studies which also, at times, employed different methods of analysis, such as Lawrence and Kaye (2006) and Swenerton (2004).

Within SPS sites, some differences in chemical properties were evident between high and low survival plots (Table 1.5). Analysis of variance tests highlighted differences in pH, total available phosphorous, calcium, and magnesium. Differences in pH were small but significant (p=0.05). High survival plots tended to be slightly more alkaline (5.1) than low survival plots (5.0). These differences, though significant (based on low variability in the data), are small and unlikely to affect the survival of these species. Extractable phosphorous in the soil from SPS varied with different methods. Results of the Bray 1 method do not indicate a difference; however, the Olsen method resulted in significantly higher levels of P in the low survival plots. Conversely, both calcium and magnesium levels were higher in the high survival plots.

In their study of *C. levisecta* habitat, Lawrence and Kaye (2006) found higher levels of calcium and magnesium in soils from the Puget Trough region than in the Willamette Valley. They attribute this to the close proximity of these sites to salt water, which may increase magnesium, calcium, and sodium levels in soils through salt spray. Soil that they tested from Rocky Prairie (the most inland site within Puget Trough sites) was indeed lower in magnesium than all other sites in Washington. Similarly, results from the study presented here found much higher levels of magnesium (as well as calcium) in soil from NPS sites compared to SPS sites. Future research could explore whether levels of macronutrients play a critical role in the survival and vigor of *C. levisecta*.

Pearson and Dunwiddie (2006), using multivariate logistic regression, found that sodium levels had a positive influence on *C. levisecta* seed germination at SPS sites, while nitrates had a negative influence on germination. However, binary logistic regression results found no relationship between soil chemical properties and planted *C. levisecta* survival in NPS or SPS sites.

Soil from NPS sites proved to be very similar between high and low survival groups. The most pronounced difference was again pH (*p*=.06). However, unlike SPS sites, high survival plots were slightly more acidic (6.1) than low survival sites (6.2). Again, these differences in pH levels are small and not likely to affect the survival of this species. What is perhaps more interesting is the comparison between SPS and NPS sites: NPS sites are more alkaline, resulting in higher nutrient availability than the more acidic soils of SPS. The acidic nature of the SPS soils coupled with the presence of volcanic ash may mean that more aluminum is soluable, displacing nutrients that would otherwise be available to plants (Brady and Weil 2002). The affect of aluminum levels on the growth of *C. levisecta* would be an interesting topic for future research.

Overall, in NPS, chemical properties do not appear to play a defining role in the survival of outplanted *C. levisecta*. The fact that this species grows in both NPS and SPS suggests that it can tolerate a range in soil conditions. Factors that are more influential appear to be cover of host species (specifically *F. roemeri*) and minimum soil moisture levels during extremely droughty conditions. Another important factor, though not measured in this study, is the impact of herbivores at these sites. Herbivores (presumably deer) had a large impact on *C. levisecta* individuals during the flowering stage in 2006 and 2007 at the Sherman site, but did not appear to affect the individuals on the bluff. Regardless of cover and moisture, if herbivory pressure is great, *C. levisecta*, a conspicuous plant while flowering, will be prevented from setting seed, which could have negative consequences for a rare species that is presumed to be short lived (Dunwiddie et al. 2000).

CONCLUSIONS

The survival of planted *C. levisecta* was more strongly associated with physical microsite conditions, such as vegetation cover and soil moisture levels, than chemical properties. An increase in the cover of its host species, *F. roemeri*, had a positive influence on *C. levisecta* survival. It also appears that this rare plant species fares better in microsites that are able to maintain slightly more moisture during extremely dry conditions, but are not overly saturated in the winter months. Minimum soil moisture levels had the strongest influence on survival: plots with higher survival of *C. levisecta* exhibited, on average, less extreme droughty conditions during the summer of 2006. This finding implies that populations in more extreme environments (e.g. the Bluff site on Whidbey Island) may be more vulnerable to increased summer temperatures and/or decreased summer rainfall and, therefore, it may be more critical at such sites to outplant *C. levisecta* near a host species.

In the mounded prairies of SPS, data suggest that *C. levisecta* vigor, measured as canopy cover, is higher when planted on the top of mounds. However, this finding is not universal, as some outplanted seedlings appear to be thriving in the swales (S. Sprenger personal observation). Study of the percent coarse fragment in different locations on the mounds found that the tops of the mounds tended to have higher amounts of coarse material than the swales, which were higher in fine material content, though soil on top of the mounds may be able to retain more moisture in extreme conditions due to deeper soil in these areas. Chemical properties were not indicative of survival in NPS sites, but some differences arose between high and low survival plots in SPS. Both calcium and magnesium levels were higher in high survival plots at SPS sites. Future research would be needed to determine if these macronutrients play a role in the survival and/or vigor of *C. levisecta*.

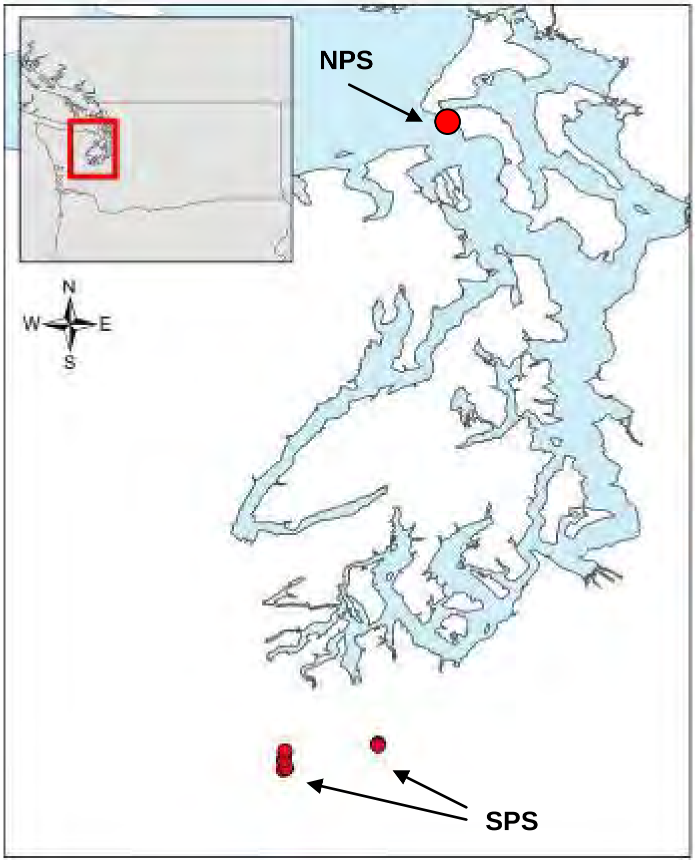

Figure 1.1. Map of *C. levisecta* study sites. NPS includes the Sherman and Bluff sites within the Pratt Preserve, Whidbey Island. SPS includes Glacial Heritage, Mima Mounds, and Rocky Prairie.

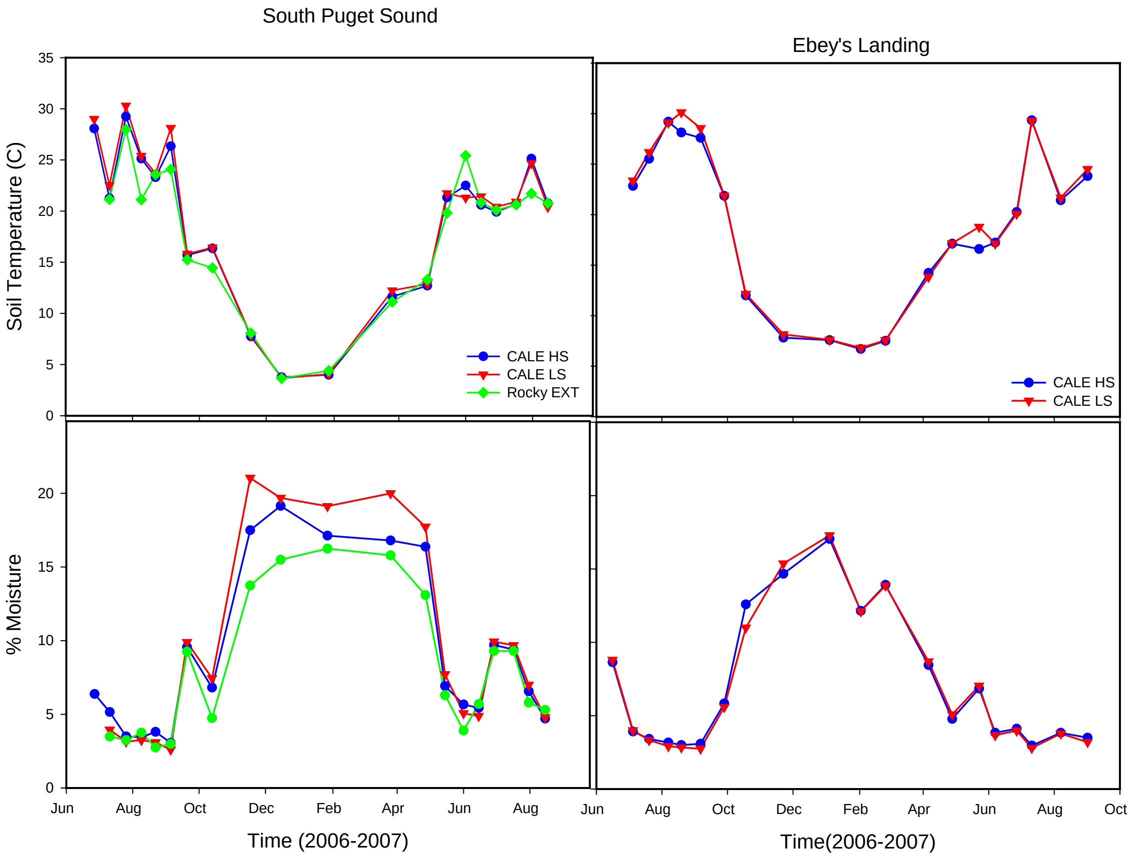

Figure 1.2. Soil moisture and temperature at SPS (left) and NPS (right) sites. CALE-HS: high survival C. levisecta plots; CALE-LS: low survival C. levisecta plots; Rocky-EXT: plots within extant population at Rocky Prairie. Soil moisture was measured to a depth of 12 cm and temperature was measured at 5 cm depth.

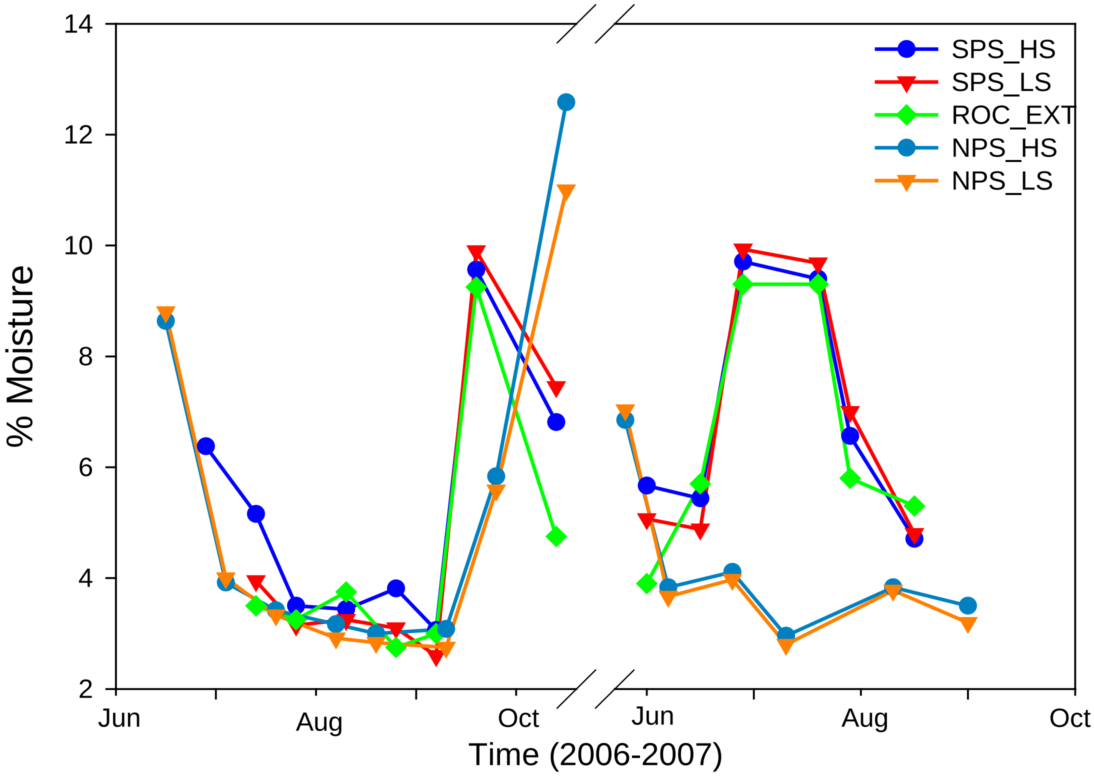

Figure 1.3. Detail of soil moisture levels in top 12 cm during summer months. SPS-HS: all SPS high survival plots; SPS-LS: all SPS low survival plots; Roc-EXT: plots within extant population at Rocky Prairie; NPS-HS: all NPS high survival plots; NPS-LS: all NPS low survival plots.

Table 1.1. Percent canopy cover recorded in May and June of 2006. Values listed are averages with 1 standard deviation in parentheses. Differences in cover between high and low *C. levisecta* survival plots are noted with a "*". ($p \leq 0.10$).

	GLACIAL		MIMA		ROCKY		SHERMAN		BLUFF		OVERALL	
	high	low	high	low	extant	low	high	low	high	low	high	low
n	8	8	8	8	4	4	8	8	4	4	32	32
Bare ground	2 (2)	6 (10)	3 (5)	4 (6)	2 (2)	3 (5)	0.3 (0.4)	0.8(1.0)	5 (1)	3 (2)	2 (3)	3 (6)
Litter	49 (31)	49 (27)	10 (13)	8 (9)	81 (8)	63 (28)	95 (0)	93 (5)	73 (9)	75 (4)	58 (37)	55 (36)
Moss	12 (10)	18 (14)	24 (21)	23 (19)	7 (2)	10* (0)	0	0	0	0	10 (14)	12 (15)
C.. levisecta	2 (0.5)	0	3.4 (2)	0.1 (0.2)	2.8 (1)	0	1.9 (2)	0	2.8 (2)	0	2.6 (1)	0.03 (0.1)
F. roemeri	24 (13)	10* (10)	15 (14)	12 (13)	10 (7)	12 (16)	18 (7)	13 (7)	12 (10)	0.1*(0.3)	17 (12)	10* (11)
E. lanatum	1 (1)	0.2(0.4)	1 (2)	0.3 (0.5)	3 (2)	0.4*(0.5)	0	0	25 (7)	10* (10)	4 (9)	1 (4)
Native perennials	29 (24)	21 (17)	35 (18)	21 (14)	40 (15)	38 (11)	22 (6)	16* (7)	43 (11)	14* (9)	32 (17)	21 (14)
Non-native annuals	2 (2)	1 (2)	0.3(0.7)	8* (9)	0.5(0.6)	0.6 (0.5)	0.6 (0.4)	0.8(0.4)	19 (21)	59* (14)	3 (9)	10 (20)

Table 1.2. Comparative results of soil temperature and moisture from all study sites. Values listed are averages with 1 standard deviation in parentheses. Values in rows not sharing a common letter are significantly different ($p \leq 0.10$). All soil moisture values presented below represent moisture over a 12 cm depth. SPS-HS: South Puget Sound high survival CALE plots; SPS-LS: South Puget Sound low survival CALE plots; ROC-EXT: Rocky Prairie Extant CALE plots; NPS-HS: North Puget Sound high survival CALE plots, NPS-LS: North Puget Sound low survival CALE plots.

	SPS-HS	**SPS-LS**	**ROC-EXT**	**NPS-HS**	**NPS-LS**
n	16	20	4	12	12
TEMPERATURE (°C)					
Summer2006 (6/15-9/15)					
Avg soil temp	25.4 (1.9)	26.1 (2.1)	23.6 (1.0)	26.7 (4.0)	27.0 (3.7)
Max soil temp	29.8 (2.0)	31.1 (2.8)	28.0 (2.3)	30.1 (5.2)	31.0 (5.7)
Summer2007 (6/15-9/15)					
Avg soil temp	21.7 (1.1)	21.7 (0.9)	21.6 (0.6)	22.8 (3.1)	22.7 (3.6)
Max soil temp	26.0^{a} (1.7)	24.7^{a} (1.5)	25.4^{ab} (2.2)	29.3^{b} (3.8)	29.4^{b} (5.3)
MOISTURE (%VWC)					
Summer2006 (6/15-9/15)					
Avg VWC	4.2^{a} (0.8)	3.5^{b} (0.7)	3.3^{bc} (0.4)	4.2^{a} (0.2)	4.1^{ac} (0.4)
Min VWC	2.9^{a} (0.6)	2.5^{b} (0.5)	2.5^{ab} (0.6)	2.9^{a} (0.3)	2.6^{ab} (0.5)
Winter 2006-2007 (11/15-4/15)					
Avg. VWC	17.4^{a} (3.4)	20.1^{a} (5.3)	15.3^{ab} (2.4)	13.2^{b} (0.8)	13.3^{b} (1.2)
Max VWC	19.6^{ab} (3.8)	22.3^{a} (6.0)	17.4^{ab} (3.0)	17.0^{b} (1.5)	17.7^{b} (1.6)
Summer 2007 (6/15-9/15)					
Avg VWC	6.8^{a} (0.7)	6.7^{a} (1.0)	6.5^{a} (0.8)	3.7^{b} (0.3)	3.6^{b} (0.2)
Min VWC	4.6^{a} (0.6)	4.3^{a} (1.0)	3.8^{ac} (1.0)	2.8^{bc} (0.4)	2.6^{b} (0.5)

Table 1.3. Rainfall data during summer months for areas near NPS and SPS sites.

	Precipitation (cm)			
	Total 6/1/06 – 9/30/06	Total 6/1/07– 9/30/07	Average (normal) 6/1 – 9/30	Total 7/2007
NPS (Coupeville, WA)	9.5	11.4	10.3	2.2
SPS (Olympia, WA)	6.7	15.1	13.8	4.7

Table 1.4. Percent of fine and coarse soil fragments in different locations of mounds at SPS sites.

Location on Mound	**% Coarse Fragment (> 2mm)** n = 9	**%Fine Fragment (< 2mm)** n = 9
Top	68.6 (6.7)	31.4 (6.7)
Side	64.0 (7.7)	36.0 (7.7)
Swale	56.2 (11.7)	43.8 (11.7)

Table 1.5. Average and standard deviation of various soil chemical properties at SPS and NPS sites. Data from SPS sites was generated by A & L Western Agricultural Laboratories in Portland, OR. Soil from NPS sites was analyzed at the College of Forest Resources, University of Washington.

Soil Property	**SPS-HS**	**SPS-LS**	**NPS-HS**	**NPS-LS**
n	19	10	10	10
pH	5.1 [a] (0.13)	5.0 [b] (0.17)	6.1 (0.1)	6.2 (0.1)
Total %C	--	--	1.7 (0.4)	2.0 (0.5)
% OM	24.0 (5.0)	26.0 (6.0)	--	--
Total %N	--	--	0.2 (0.06)	0.2 (0.06)
C:N	16 (2.5)	15 (2.0)	10 (3)	10 (2)
CEC($\mathrm{cmol_c}$/kg)	4.3 (1.8)	3.3 (1.3)	7.8 (0.7)	8.5 (1.1)
NO_3-N(mg/g)	10.1 (8.5)	10.2 (7.8)	4.8 (2.2)	4.2 (2.0)
NH_4-N(mg/g)	--	--	0.42 (.2)	0.52 (.2)
P (Bray 1)	24.5 (24.5)	20.1 (20.1)	4.4 (1.4)	4.8 (1.5)
P (Olsen)	19.0 [a] (5.0)	23.2 [b] (5.7)	--	--
Ca (µg/g)	370 [a] (180)	260 [b] (130)	642 (105)	666.0 (130)
K (µg/g)	69.0 (19.0)	65.0 (19.0)	99.0 (46.0)	126 (48.0)
Mg (µg/g)	73.5 [a] (36.0)	50.0 [b] (27.0)	380.0 (42.0)	428 (57.0)
Na (µg/g)	22.5 (3.0)	20.0 (5.0)	36.5 (15.0)	36.0 (18.0)
%BS	67	65	86	86

CHAPTER 2

A comparison of soil microsite conditions in two native grassland restoration sites in western Washington

INTRODUCTION

Regional assessments estimate that native prairies in the Puget Lowlands of Washington State cover approximately 2-4% of their historical, pre-settlement range (Chappell et al. 2000). This sharp decline has been attributed to several factors such as fire suppression (and exclusion), urban development, and the invasion of prairies by both native and non-native species (Crawford and Hall 1997, Franklin and Dyrness 1988). The reduction of native prairie landscapes in our region has resulted in the loss of habitat for rare and endangered species, regional biodiversity and cultural resources for First Nations. The remaining fragments of native prairie in the Puget Lowlands are of such limited extent that some ecologists argue that preservation alone is insufficient to ensure their survival, and restoration is necessary to expand their range (Floberg et al. 2004).

In response, many efforts have been made in our region to restore and expand the range of native grasslands (Dunwiddie 2002, Ewing 2002, Lambert 2006). Yet, these efforts have had varying levels of success, and land managers continue to strive to better understand this rare ecosystem and to develop more effective restoration techniques. The majority of prairie restoration projects in our region have used specific on-the-ground restoration strategies such as combinations of fire and herbicide, and introductions of plants by outplanting of seedlings or by seed. While such work is critical, it does not always offer specific clues to the mechanisms which cause success in one area and failure in another (Fowler 1988).

Many factors contribute to the varied success of restoration efforts. In many cases, differences in microsite conditions can be particularly influential. Soil heterogeneity has been found to vary greatly within a small area (Jackson and Caldwell 1993), and hence variability in soil moisture, temperature, and nutrient levels may explain the ability of natives to persist at some sites, or why restoration efforts succeed in some areas but not at others (Pearson and Dunwiddie 2006). If microsite conditions that favor certain native prairie species can be identified, restoration efforts could be focused on sites known to exhibit particular microsite conditions or sites could be modified/amended to improve restoration success.

Festuca roemeri (Pavlick) Alexeev (Roemer's fescue) is considered to be a keystone species in grassland ecosystems of the Puget Trough (Lang 1961; Giles 1970; del Moral and Deardorf 1976; Clampitt 1993) and is often planted or seeded as an initial step in restoring native prairie structure and composition. Until recently, *F. roemeri* was considered to be a subspecies of *Festuca idahoensis* (Idaho fescue), and was called *Festuca idahoensis* Elmer ssp. *roemeri* (Pavlick) S. Aiken. It is now widely accepted as its own species. Several prairie restoration projects in western Washington have focused on establishing *F. roemeri* either by sowing seed or outplanting seedlings (Dunwiddie 2002, Lambert 2006).

Though *F. idahoensis* is a ubiquitous native grass in the western U.S., *F. roemeri* is considered uncommon in its native range of northwestern California to western Oregon and Washington—primarily as a result of habitat loss. It is a low, densely leaved perennial bunch grass with culms that grow 35-100 cm high, and inflorescences that are 9.5-16 cm long (Darris et al. 2007, Kozloff 2005). Because *F. roemeri* is a mid to late seral species, a well-established community is considered an indicator of a relatively undisturbed ecosystem. It is slow growing, but once established, its dense form can outcompete weedy species. Current extant populations are primarily restricted to areas with shallow, highly mineral soil or on steep terrain (Darris et al. 2007).

Another native grass species frequently used in Pacific Northwest prairie restoration is *Elymus glaucus* Buckley (blue wildrye). *E. glaucus* is a native perennial bunchgrass found throughout western North America (Dyer and O'Beck 2006). Typically found in meadows and woodlands, it grows best on moderately moist sites, but is able to survive in droughty conditions (Johnson 1999). Stems of *E. glaucus* grow from 60-180 cm tall and its inflorescences are distinctly noticeable for their single spikes which can be 5-21 cm long (Douglas et al. 2001). The seeds were likely used by the Coast Salish as a food source (Turner 1971). *E. glaucus* is noted for being deep rooted and often requiring at least 12 inches of soil to grow. It often colonizes a site after disturbance and has been reported by some sources to be short-lived– persisting only for 3-4 years without ongoing disturbance (Johnson 1999).

The main objective of this study was to document soil conditions present at two native grassland restoration sites in western Washington: American Camp at San Juan Island National Historic Park, and Ebey's Landing National Historic Reserve. Within this larger objective were two specific goals: 1) to characterize soil conditions in two native grassland communities (*F. roemeri*- and *E. glaucus*-dominated) and compare them and, 2) to look more closely at soil conditions on sites currently undergoing restoration treatments with *F.roemeri* to determine if soil conditions differed between sites where outplanted *F. roemeri* had high survival rates and where it had low survival rates

The following questions were addressed: 1) What are soil microsite conditions in areas of extant, high density native grasses (*F.roemeri* and *E. glaucus*), and how do they compare? 2) What are the soil microsite conditions present in areas where *F. roemeri* seedlings were planted and resulted in high survival (high density)? 3) What are the soil microsite conditions present in areas where *F. roemeri* seedlings were planted but (at least initially) had lower survival rates (low density)? and 4) Are soil conditions in an area of high rabbit warren density where future restoration may occur more similar to sites occupied by *F. roemeri* or *E. glaucus*?

METHODS

Site Descriptions

American Camp (AC) is part of the San Juan Island National Historic Park located on the southern end of San Juan Island in the northwestern region of Washington State (Figure 2.1). American Camp consists of 495 hectares (1223 acres), half of which is a wind-swept, open prairie habitat, while the remainder consists of both early successional Douglas-fir (*Psuedotsuga menziesii* Mirb. Franco) and mixed-conifer forests (National Park Service 2008, Rolph and Agee 1993). The majority of the prairie habitat exists on gentle slopes close to sea level. The highest point in the park, Mt. Finlayson, is 149 meters (490 feet). Located in the rain shadow of the Olympic Mountains, AC receives an average of 48 cm (19 inches) of annual precipitation (NPS 2008).

The majority of soils in the park belong to the San Juan soil series, which are developed in eolian sands over glacial outwash (NRCS 2008). The coarse texture of these soils makes them very fast-draining and low in moisture-holding capacity, though a high organic matter content helps retain moisture in the A horizon. High levels of organic matter also contribute to the dark surface color of these soils (Schlots et al. 1962). The San Juan soil series is one of the most common series associated with historical prairie sites in western Washington State (Chappell et al. 2001; Schlots et al. 1962). Plots at AC were located on soils classified as either San Juan sandy loam with

2-8% slopes or San Juan sandy loam with 5-20% slopes (Schlots et al. 1962). Seedlings of *F. roemeri* were planted at AC between 2003 and 2005.

The Prairie Overlook (PO) study site is located within Ebey's Landing National Historical Reserve on the west side of Whidbey Island, WA. Soil at the PO site is classified as San Juan coarse sandy loam with 5-15% slope, though the specific area where PO is located is quite flat, with 0-5% slope (Ness and Richins 1958). Like AC, PO receives an average of 48-51 cm (19-20 inches) of annual precipitation (NWSIT 2008). The experimental planting area had been tilled and sprayed with herbicide prior to planting. Seedlings of *F. roemeri* were then planted at various densities in 2005, and removal of non-native species occurred the following summer.

Experimental Design

This study was designed to document and compare soil microsite conditions within extant and restored native prairie patches at AC and PO. At AC, four distinct sites were chosen: 1) AC-EF: American Camp extant *Festuca*, 2) AC-EE: America Camp extant *Elymus*, 3) AC-CR: American Camp current restoration (sites where *F. roemeri* seedlings were ouplanted and resulted in lower survival, and 4) AC-FR: American Camp future restoration (an area that has been highly impacted by several decades of colonization by the non-native European rabbit (*Oryctolagus cuniculus*) and where future restoration may occur. At PO, two distinct groups were chosen: 1) PO-HDF: Prairie Overlook high-density outplanted *Festuca*, and 2) PO-LDF: Prairie Overlook low-density outplanted *Festuca*.

At AC, the location of plots within areas of extant native grasses was chosen based on visual estimates of high density. Though an exact cover amount was not determined at the time of establishment, all high-density plots had ≥ 35% cover of target species. In contrast, plot locations within current restoration sites (AC-CR) were chosen based on areas where the survival of outplanted *F. roemeri* was obviously low (e.g. dessicated seedlings present, only non-natives present, and/or higher amount of bare ground compared to other areas nearby which had been planted at the same time.

At PO, two distinct groups were chosen: areas where the survival of outplanted *F. roemeri* was high (high density of cover: PO-HDF) and where it was low (low cover density: PO-LDF). High and low *F. roemeri* density thresholds were the same as for AC, and were chosen to compare differences within this site as well as to make comparisons with *F. roemeri* sites at AC. Designations of high and low density were made at both PO sites and within AC-CR sites within 1-3 years of planting and, therefore, were an assessment of initial growth.

Field Work

In May and June of 2006, a total of 34 1-meter square plots were established: 26 at AC and 8 at PO. Percent cover of all vascular species present within the plots was recorded in May, 2006. Methodology followed that of Chappell and Caplow (2004). Cover of a species was determined as “trace” when it occurred below 0.5%. Between 0.5% and 15%, crown cover was estimated to the nearest 1%, and to the nearest 5% from 15% to 100% cover. Bryophytes (all mosses and lichens) and bare ground were also measured in this manner.

Soil moisture levels were measured over 30 cm and 12 cm depths, depending on the plot, using time domain reflectometry (TDR). TDR measures the average percent moisture over the entire length of the probe by measuring the time it takes for an electromagnetic pulse to travel to the length of the probe and back to the unit. This value is converted to a dialectic constant and finally to a percent soil moisture (Grey and Spies 1995). In each plot, 30 cm long moisture probes consisting of two stainless steel welding rods (3/8” diameter) spaced 1 cm apart were installed in June, 2006. Rods were driven into the soil perpendicular to the soil surface using a wooden guide and mallet. Three of the 26 plots at AC were too rocky for 30 cm probes and were therefore monitored only for soil moisture in the top 12 cm.

Moisture in the top 30 cm was measured using a Telektronix TDR device. These probes were left in the ground for the duration of the study, allowing for minimal disturbance to the soil. Because the Telektronix unit is only compatible with 30 cm probes, a Campbell Hydrosense® TDR moisture probe was used to measure percent moisture in the top 12 cm. This probe was inserted into the soil at each reading. Laboratory tests with soil cores of the top 30cm determined that standard calibration curves for moisture content were accurate for the A horizon of the San Juan soil series and no additional moisture content corrections were applied. Soil temperature was measured at 5 cm depth, and surface temperature at approximately 5 cm above the soil surface using a Taylor® digital thermometer.

During each site visit, soil moisture, soil temperature, and surface air temperature were recorded. Plots were monitored approximately twice a month from July through September, 2006, once a month from October 2006 through April, 2007, and then semi-monthly reading resumed and continued until the end of August 2007. Readings were taken between 1200 and 1600 hours in the afternoon. Due to technical difficulties with a TDR unit, soil moisture data over 30 cm is only reported from October 2006 until August 2007. Two additional moisture readings were not recorded also due to technical difficulties. These included the January reading (30cm) at AC, and the mid-July reading (12 cm) at PO.

Soil Analysis

Soil samples for chemical analysis were gathered in May and June of 2006, air-dried, and sieved to <2 mm. The <2mm fraction was used for all analyses. Soil was collected from the top 20 cm using a soil corer, inserted just outside each plot; A and B horizons were separated on the few occasions when B horizon was included in the sample. All chemical data are from A horizons. Soils were tested for total carbon and nitrogen, available nitrogen and phosphorous, pH, cation exchange capacity (CEC) and exchangeable cations.

Total carbon and nitrogen content were determined using a Perkin Elmer (Series II) Analyzer, model #2400. Available nitrogen (ammonium and nitrate) was extracted using a 2 M potassium chloride solution (Keeney and Nelson 1987). The weak Bray method (Bray 1) was used to measure total phosphorous (Bray and Kurtz 1945). Soil samples were prepared for pH analysis using a 1:2 (dry soil: DI water) ratio. Samples were mixed thoroughly and allowed to sit for 30 minutes, and then measured using a calomel pH probe. CEC and exchangeable cations were determined using an unbuffered 1 M ammonium chloride extraction followed by a 1 M potassium chloride rinse (Skinner et al. 2001).

Statistical Analyses

Analysis of variance was used to compare physical and chemical data of the six different vegetation groups. Physical parameters analyzed in this manner included cover type, seasonal averages of soil moisture and temperature, and minimum and maximum values of moisture and temperature. Statistical differences were further analyzed with a Tukey's HSD post-hoc multiple comparison test ($\alpha = 0.10$). Pearson's correlations were run to analyze relationships between cover type and physical and chemical data. Continuous soil moisture and temperature data were displayed graphically and analyzed for qualitative differences.

RESULTS AND DISCUSSION

Physical Properties: Cover type, Soil Temperature, and Soil Moisture

Initially, the intention was to group high and low density *F. roemeri* plots together (PO-HDF and AC-EF plots together, and PO-LDF and AC-CR plots together; see below). However, due to a statistically significant site effect, these sites were kept separate for further statistical analysis.

Cover Type

High density *F. roemeri* plots at PO and AC (PO-HDF and AC-EF), were shown to have similar cover attributes. PO-HDF and AC-EF plots both had a low mean percent cover of bare ground and high total herbaceous vegetation cover (Table 2.1). AC-EF plots exhibited a low mean percent bare ground (< 1%) due to the high cover of moss (34.0%)—a common occurrence in *Festuca*-dominated prairies in western Washington (Franklin and Dyrness 1988). This high moss cover is likely due to the fact that AC-EF plots were located in areas of extant, well-established *F. roemeri*, with no history of recent disturbance. Though PO-HDF and AC-EF plots showed the highest percent cover of *F. roemeri* at their respective sites, the mean cover of *F. roemeri* in PO-HDF plots (86.3%) was significantly higher than AC-EF plots (58.0%). Nevertheless, both groups represent areas of dense *F. roemeri* growth which imply that, on a microsite scale, they provide favorable conditions for this keystone species.

Low density fescue plots at PO and AC (PO-LDF and AC-CR) also shared similar cover attributes. Similarities among this group included mean cover of litter, moss, and total vegetation. However, PO-LDF plots were higher in *F. roemeri* cover (33.8%)

than AC-CR plots (5.2%). Though both represent locations of relative low density at their respective sites, PO-LDF plots still had a moderate cover of *F. roemeri*, while the AC-CR plots were quite low.

PO-LDF plots differed from all other groups by having the highest mean % bare ground (26.3%). In addition to outplanted fescue seedlings having lower survival in these areas, another explanation for the greater amount of bare ground in these areas is that non-native species at PO were removed several months prior to plot establishment. This manipulation most likely decreased cover of weeds and exposed more bare ground.

Measurements of percent cover did not take into account the vertical height or total biomass of plant species, which could affect microsite conditions. For example, *E. glaucus* is a tall bunchgrass (averages 1 m tall) which may create more shade than *F. roemeri* and other common weed species (e.g. *Hypochaeris radicata* L.), which are shorter or less dense in structure. Plant growth within AC-FR plots was heavily browsed by rabbits, and was rarely over 5cm high. This difference in canopy height likely affects soil microsite conditions. Vegetation with greater height and biomass would presumably create denser shade and contribute more organic matter to the soil through decomposition.

Soil Temperature

Soil temperatures (5 cm depth) represented the most significant difference in microsite conditions between HDF and LDF plots. These differences were more notable during the summer of 2006, when conditions were hotter and drier compared with 2007. During the summer of 2006, LDF plots at both locations had higher average soil temperatures and greater maximum temperatures between 1 July and 15 September than HDF plots (Table 2.2; $p < 0.10$). At AC specifically, AC-LDF plots had a mean maximum reading 10° higher than HDF plots (34.8°C and 24.6°C respectively). Areas of high rabbit warren density, AC-FR plots, had the highest average and maximum soil temperatures recorded (32.4°C and 35.5°C respectively) in 2006, while areas of extant *E. glaucus*, AC-EE plots, had the lowest average summer temperatures (19.9°C).

Soil temperatures followed a similar pattern during 2007. In the summer of 2007, LDF plots at AC again had higher temperatures than HDF plots. AC-EE plots again had the lowest maximum temperatures (20.0°C), while AC-FR plots had the highest (33.0 °C). LDF and AC-FR plots not only had greater average and maximum temperatures, but also exhibited greater seasonal variability (Figure 2.2a).

Several factors may explain why AC-EE plots had cooler summer soil temperatures. The higher growth form of *E. glaucus* likely creates more shade than other vegetation present in these study sites. Secondly, the location and topography of AC-EE may affect soil temperatures. Half of AC-EE plots were located in the eastern portion of the park, which is somewhat bowl-shaped with a steep hill above it (10-35% slope). This portion of the park has a slight SE aspect, making it less exposed to solar radiation during the hottest part of the day than AC-FR and AC-CR plots which have S and SW aspects respectively. The other half of AC-EE plots were also located in more protected sites: one group was located northeast of a large mounded area (the Redoubt, a human-made feature), while another plot was located just north of a large shrub thicket.

Percent bare ground and total vegetation cover were strongly correlated with soil temperatures. Plots with greater bare mineral soil exposed had higher average and maximum temperatures at 5 cm depth. This relationship was stronger during the summer of 2006 (p = .0.01) than during the summer of 2007 (p = 0.05). Conversely, plots with greater total herbaceous vegetation cover exhibited cooler soil temperatures during both years (also more strongly correlated during 2006 than 2007).

Soil Moisture

12cm Volumetric Water Content

HDF and LDF plots exhibited similar levels of volumetric water content (VWC) in the top 12 cm of soil. No differences arose between HDF and LDF plots at PO over the entire study period. At AC specifically, the only difference between these two groups was found during the summer of 2006 (July through August) when AC-EF (HDF) plots had a greater mean maximum VWC (3.8%) than AC-CR (LDF) plots (3.0%)—a difference of less than 1%. However, HDF plots at both locations have small, but consistently higher levels of VWC than their LDF counterparts (Figures 2.2 and 2.3). Though these differences are not statistically significant, they suggest that, on a microsite scale, HDF plots retain slightly more moisture than LDF plots.

As seen in Figure 2.2, it is during the winter months that there is the greatest difference in VWC between HDF and LDF plots, though differences in mean averages and maximums were not significant (Figure 2.2c and d). This trend does, however, suggest that HDF areas, and other high-density extant grass sites, retain greater moisture during winter months. Having more water storage capacity and accumulating more water over the winter months may give plants in these areas an advantage as soils dry out in spring and summer. When a Pearson Correlation was applied, percent cover of *F. roemeri* showed a positive correlation with average soil moisture over 12 cm (AC-FR plots were omitted for analysis). In 2006, plots with greater *F. roemeri* cover had greater average and maximum VWC ($p \leq 0.01$). During the following year, this relationship continued, but was weaker ($p \leq 0.05$). Though cover of *F. roemeri* was correlated with average summer moisture levels over 12 cm, total herbaceous vegetation cover was not. Total vegetation cover was correlated with winter VWC over 12 cm depth ($p \leq 0.01$).

Examining the six vegetation groups separately, the relative pattern of VWC levels in the upper 12 cm remained somewhat consistent (Figure 2.2c-f). PO plots tended to have higher VWC than most of the AC groups, except for areas of *E. glaucus*. Throughout the year, extant native grass areas at AC tended to have greater moisture compared to current and future grass restoration sites, and areas of current restoration activities (AC-CR) were consistently the driest during the summer months (Table 2.2). Overall, these differences, though consistent, are quite small. For example, during the summer of 2006 (July through September) AC-EE plots had a greater average VWC (3.4%) than AC-CR plots (2.9%) ($p < 0.10$) (Table 2.2). Microsite conditions within areas of high rabbit density were not only the hottest, but also were found to have the lowest mean minimum VWC readings during the summer of 2006 (2.3%). These very low moisture levels (combined with high temperatures) suggest that plants introduced to this area in future restoration efforts must be able to tolerate extremely droughty conditions, or that other efforts must be made to mitigate these harsh conditions.

30 cm VWC

Similar to moisture levels in the top 12 cm, no significant differences in VWC over 30 cm were found between HDF and LDF plots. However, there was a strong positive correlation between percent cover of *F. roemeri* and moisture levels over 30 cm. Average late fall/ winter VWC (Nov through March) as well as average spring/summer moisture levels (April through August) were both positively correlated with *F. roemeri* cover ($p \leq 0.01$). This suggests that greater winter recharge of soil water at microsites could affect *F. roemeri* growth. Soil properties that may contribute to greater water recharge include deeper A horizon, greater depth to a change in soil texture, a higher organic matter content, and/or a finer texture. Total herbaceous vegetation cover was also positively correlated with average winter moisture levels ($p \leq 0.01$), but not with spring/summer levels.

Relative patterns in moisture levels over 30 cm differed somewhat from 12 cm moisture patterns. For example, AC-EE plots, which had the greatest VWC in the upper 12 cm of AC sites (and were more closely related to PO sites) were more similar to AC-CR plots in 30 cm moisture levels. During the summer of 2007, AC-EE and AC-CR plots were both significantly drier than the PO-HDF plots ($p < 0.10$). From June through August of 2007, average mean moisture levels in AC-EE and AC-CR plots were 10.3% and 9.9% respectively, while PO-HDF plots had a mean average of 12.1% (Table 2.2). Similar differences were found when moisture data from April through August was compared. There was no significant difference in soil moisture over 30 cm between the four sites at AC (Figure 2.1e; $p > 0.10$), though trends suggest that AC-EF areas had the highest VWC in the top 30 cm during winter months.

Several factors may contribute to AC-EE areas being higher than other AC groups in moisture over 12 cm but lower in 30 cm moisture levels. One explanation may be that *E. glaucus*, due to its greater height and presumably deeper root system, transpires more water from deeper depths than other vegetation types. Secondly, small mammal activity may affect soil moisture capacity due to their extensive subsurface tunneling—a ubiquitous feature in *E. glaucus* patches at AC.

Chemical Properties

High and low density fescue plots showed no differences in soil chemical properties, suggesting that there are no specific nutrients or soil properties that inherently favor the survival and/or growth of *F. roemeri* at these sites. However, chemical properties were notably different between AC and PO sites. Overall, PO soils had higher nutrient content than AC sites, except for areas of extant *E. glaucus* at AC.

Like moisture levels, extant *E. glaucus* plots were more similar to PO sites in total organic C and N levels, C:N, CEC, and levels of Ca and K (Table 2.). Indeed, AC-EE plots were found to be higher in total organic carbon and nitrogen than the other 3 vegetation groups at AC ($p < 0.10$) and had higher CEC levels ($p < 0.001$).
AC-FR plots had the lowest carbon and nitrogen levels.

Since carbon is the major component of organic matter in soils (and organic matter helps to retain moisture), the higher amount of carbon in soil from the *E. glaucus*-dominated plots may help to explain why these areas have greater moisture holding capacity (in top 12 cm). Organic matter can also help to create higher CEC levels (Brady and Weil 2002). Factors that likely contribute to higher carbon content include: biomass of *E. glaucus*, small mammal activity, and topography. The larger growth form of *E. glaucus* may contribute more organic matter to the soil during decomposition of roots and above ground vegetation than other species. The deposition of manure by small mammals in these locations may also increase carbon content (Ross et al. 2007).

Management Implications

Although areas of current and future restoration of *F. roemeri* at AC were found to have the hottest and driest conditions throughout the duration of this study, it is still likely that plugs of *F. roemeri* will be able to survive in these areas if planted early enough for the root systems to become established before the onset of summer drought. Efforts to outplant *F. roemeri* at AC have had higher rates of survival when transplants have longer root systems (e.g. 20 cm), which allow for greater contact with mineral soil particles (R. Rochefort personal communication 2008). Shorter root systems are problematic in that they may not reach below the layer of thatch often present in areas where rhizomatous invasive grasses occur (Lambert 2006).

Though this study primarily focused on areas where *F. roemeri* had been outplanted as seedlings, soil moisture and temperature data from AC-FR and AC-CR areas may provide useful information for managers when considering other planting strategies, such as sowing seed. Considering the variable soil temperatures and xeric conditions found in the AC-FR area, it may be difficult to reestablish prairie vegetation through seed sowing as germination rates may be low if the top soil layers are too droughty. Some studies have found that high temperature fluctuations and soil moisture at the soil surface significantly influenced the survival of *F. idahoensis* germinants (Ahlstrand 1973). However, considering the large area of degraded prairie at AC, it may be interesting to set up a series of experimental plots to test germination success of various native grass and forb species. In this case, seed should be sown in late summer or early fall (timing could be part of the experimental design). Daubenmire (1968) speculated that *F. idahoensis* is able to survive xeric summer soil conditions because it germinates in the fall, grows through the winter months, and becomes dormant in the summer.

The addition of organic matter in the form of mulch or compost is not advised for mediation of these sites. Though it would increase the moisture holding capacity of the soil, it may also facilitate the growth of non-native species. For example, Ewing (2002) found that seedlings of *F. idahoensis*, a close relative of *F. roemeri,* had higher survival over three years in soil that was impoverished (through removal of organic matter) than soil that was mulched or fertilized—concluding that stressful environments facilitate the survival of *F. idahoensis* by giving it a competitive edge over weedy species

Though *F. roemeri* is a very adaptable species, managers may also want to include *E. glaucus* in restoration designs for greater diversity in composition and structure—and to increase wildlife habitat. This fast-growing grass should be planted in areas where soil appears to be deeper (swales), on the north side of shrubs or mounds, or other areas that are somewhat protected from extreme solar radiation. Nevertheless, the heavy browsing pressure and burrowing of European rabbits—combined with harsh soil conditions—could decrease the success of outplanting either species unless measures are taken to decrease the rabbit population at AC.

CONCLUSIONS

Differences in microsite conditions were found between areas of high and low density fescue cover. The greatest difference in soil properties between these two groups was soil temperature, which was significantly higher in areas of low density *F. roemeri* cover. Both HDF and LDF groups at PO and AC exhibited extremely droughty conditions during summer months—when moisture readings over 12 cm were commonly between 2-4%. Qualitative differences in soil moisture among the six vegetation groups were small but consistent. Soil chemical properties did not differ by microsite.

At AC, extant native grass communities tended to have lower and less variable soil temperatures as well as higher VWC, especially during winter months, compared to areas of current and future restoration. PO sites had greater cover of *F. roemeri,* higher moisture content, and generally more productive soil than AC sites. *E. glaucus*-dominated areas differed in many respects from other AC groups and were found to be similar to PO plots in moisture levels, soil temperatures, and many chemical properties such as total carbon and CEC. Locations of high rabbit density consistently exhibited the harshest microsite conditions and may require careful planning, with particular attention paid to appropriate planting times and long roots of transplants, in order for outplanted seedlings to succeed.

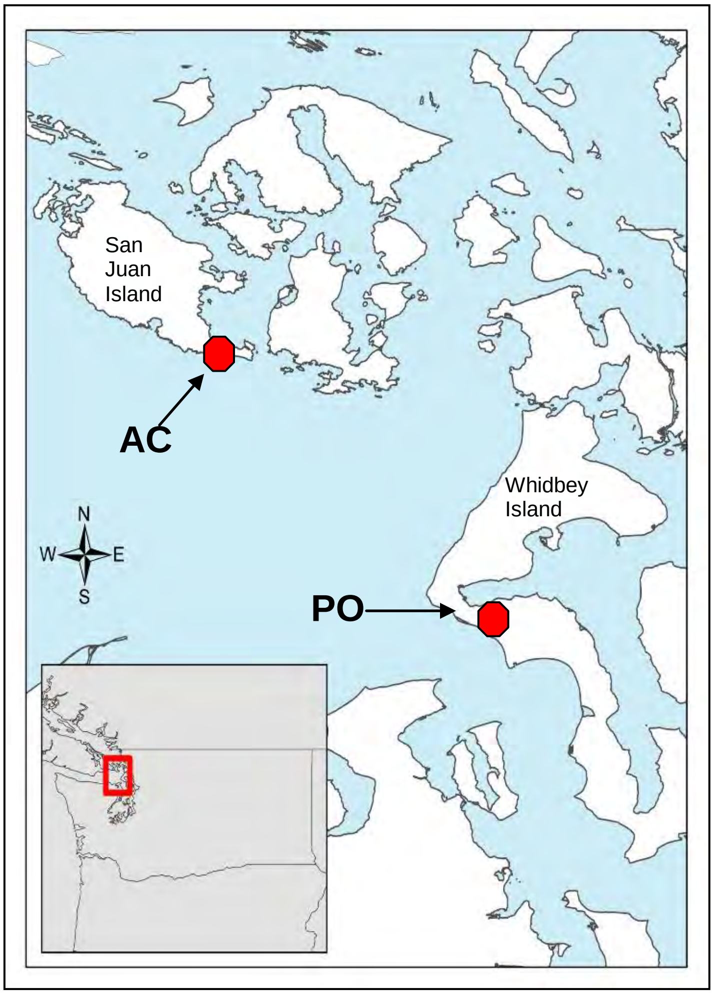

Figure 2.1. Location of American Camp (AC) and Prairie Overlook (PO) sites within Puget Sound, WA.

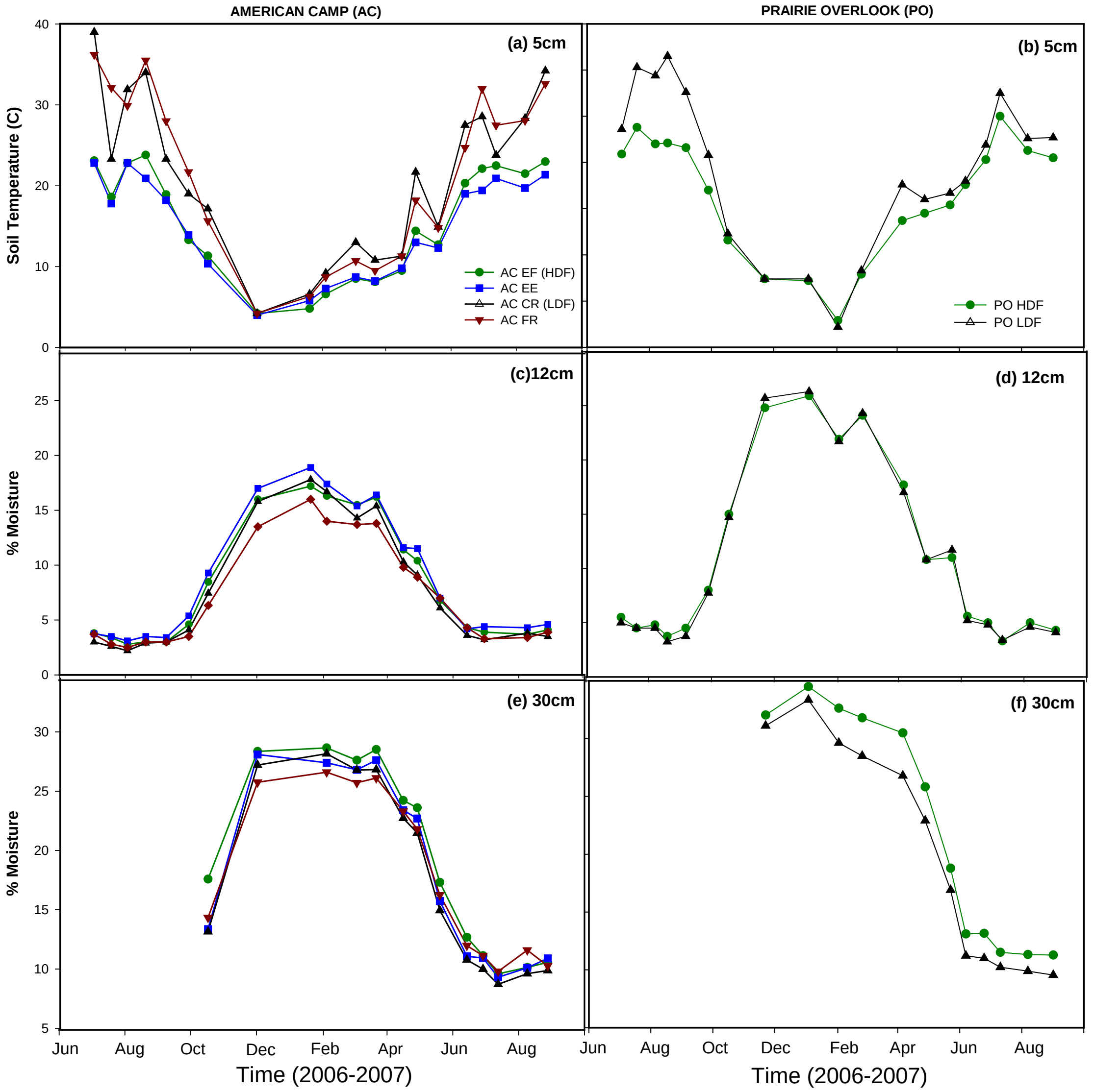

Figure 2.2. Soil physical factors (moisture and temperature) monitored at AC and PO: a and b) average soil temperature at 5 cm depth; c and d) average soil moisture in top 12 cm, and e and f) average soil moisture in top 30 cm. Lines in between data points are extrapolations and do not represent actual data points. Sites included are: AC-EF: American Camp extant *Festuca* (high density *Festuca*); AC-EE: America Camp extant *Elymus*; AC-CR: American Camp current restoration (low density *Festuca*); AC-FR: American Camp future restoration (rabbit-infested area); PO-HDF: Prairie Overlook high density *Festuca* (outplanted); PO-LDF: Prairie Overlook low density *Festuca* (outplanted).

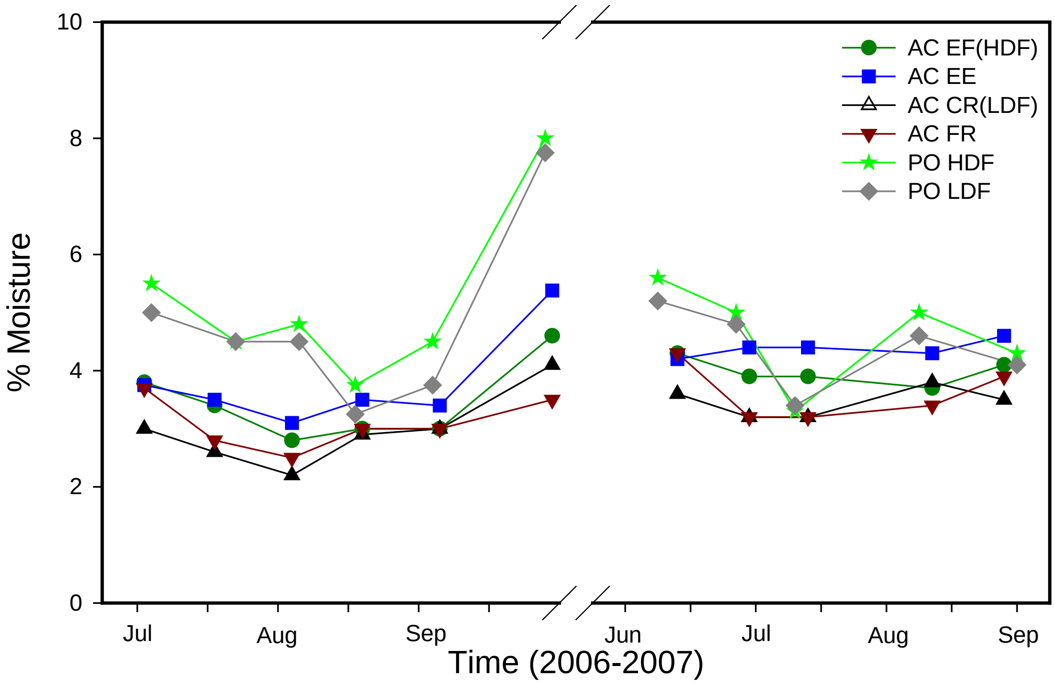

Figure 2.3. Detail of volumetric water content (% moisture) in the upper 12 cm of soil at AC and PO during xeric conditions. Sites included are: AC-EF: American Camp extant *Festuca* (high density *Festuca*); AC-EE: America Camp extant *Elymus*; AC-CR: American Camp current restoration (low density *Festuca*); AC- FR: American Camp future restoration (rabbit-infested area); PO-HDF: Prairie Overlook high density *Festuca* (outplanted); PO-LDF: Prairie Overlook low density *Festuca* (outplanted).

Table 2.1. Percent canopy cover recorded in May and June of 2006. Sites included are: AC-EF: American Camp extant *Festuca* (high density *Festuca*); AC-EE: America Camp extant *Elymus*; AC-CR: American Camp current restoration (low-density *Festuca*); AC-FR: American Camp future restoration (rabbit-infested area); PO-HDF: Prairie Overlook high-density *Festuca* (outplanted); PO-LDF: Prairie Overlook low-density *Festuca* (outplanted). Vegetation cover includes *F. roemeri*, *E. glaucus*, and all other vegetation recorded during survey in 2006.

Cover type	**PO-HDF** n = 4	**PO-LDF** n = 4	**AC- EF (HDF)** n = 5	**AC- CR (LDF)** n = 7	**AC-EE** n = 8	**AC-FR** n = 4
Bare ground	1.5^{a} (1.3)	26.3^{b} (2.5)	0.6^{a} (0.9)	11.0^{a} (11.4)	2.1^{a} (2.0)	11.5^{a} (12.3)
Litter	63.8^{ab} (11.1)	23.8^{a} (8.5)	75.0^{ab} (15.0)	62.2^{ab} (37.0)	78.1^{b} (32.2)	64.3^{ab} (42.3)
Moss	0.0^{a}	0.0^{a}	34.0^{b} (26.8)	$<0.5^{a}$ (.4)	2.1^{a} (3.4)	$<0.5^{a}$ (.3)
F. roemeri	86.3^{a} (7.5)	33.8^{b} (1.3)	58.0^{c} (22.0)	5.2^{d} (8.3)	10.4^{d} (9.2)	0.0^{d} (0.0)
E. glaucus	0.0^{a}	0.0^{a}	0.0^{a}	0.0^{a}	44.4^{b} (29.0)	0.0^{a}
Total Vegetation Cover	156.5^{ab} (16.0)	87.8^{a} (11.3)	195.7^{b} (22.2)	143.0^{ab} (45.2)	158.7^{ab} (67.5)	143.0^{ab} (38.3)

Table 2.2. Average, minimum, and maximum volumetric water content (VWC) and temperature readings. Values listed are averages with 1 standard deviation in parentheses. Values in rows not sharing a common letter are significantly different ($p \leq 0.10$). Sites included are: AC-EF: American Camp extant *Festuca* (high density *Festuca*); AC-EE: America Camp extant *Elymus*; AC-CR: American Camp current restoration (low density *Festuca*); AC-FR: American Camp future restoration (rabbit-infested area); PO-HDF: Prairie Overlook high density *Festuca* (outplanted); PO-LDF: Prairie Overlook low density *Festuca* (outplanted).

	PO-HDF	**PO-LDF**	**AC-EF (HDF)**	**AC-CR (LDF)**	**AC-EE**	**AC-FR**
	n = 4	n = 4	n = 5	n = 7	n = 8	n = 4
Avg. %VWC (12cm) 7/06-10/06	4.6^{a} (0.3)	4.2^{a} (0.4)	3.2^{bc} (0.3)	2.9^{c} (0.5)	3.4^{ab} (0.5)	3.0^{bc} (0.2)
Min. %VWC (12cm) 7/06-10/06	3.8^{a} (0.5)	3.3^{ab} (0.5)	2.6^{bc} (0.5)	2.6^{bc} (0.5)	3.1^{ab} (0.4)	2.3^{c} (0.5)
Max. %VWC (12cm) 7/06-10/06	5.5^{a} (0.6)	5.0^{a} (0.0)	3.8^{b} (0.4)	3.0^{c} (0.5)	3.9^{b} (0.6)	3.5^{bc} (0.6)
Avg. %VWC (12cm) 7/07-9/07	6.0^{a} (0)	5.5^{ab} (0.6)	5.2^{abc} (0.8)	4.6^{c} (0.9)	5.5^{ab} (0.5)	4.8^{bc} (1.0)
Avg. %VWC (30cm) 6/07-9/07	12.1^{a} (0.2)	10.5^{ab}(0.9)	10.8^{ab} (0.4)	9.9^{b} (1.5)	10.3^{b}(0.8)	11.0^{ab}(1.4)
Avg. soil temp (°C) 7/1/06-9/15/06	22.1^{a} (0.9)	28.5^{b} (3.1)	21.5^{a} (1.7)	28.2^{b} (1.6)	19.9^{a} (1.7)	32.4^{c} (0.9)
Max. soil temp (°C) 6/1/07-9/15/07	23.9^{a} (1.8)	31.7^{b} (3.7)	24.6^{a} (2.2)	34.8^{b} (3.4)	24.0^{a} (1.8)	35.5^{b} (1.3)
Avg. soil temp (°C) 6/1/07-9/15/07	20.9^{ac} (1.0)	22.6^{ac} (1.0)	21.9^{ac} (1.6)	26.5^{b} (2.2)	20.0^{a} (0.6)	29.0^{b} (1.1)
Max. soil temp (°C) 6/1/07-9/15/07	25.0^{ac} (3.2)	27.5^{a} (2.3)	23.7^{ac} (2.1)	30.4^{b} (2.5)	22.0^{c} (1.4)	33.0^{d} (1.4)

Table 2.3. Chemical properties of soil collected from American Camp (AC) and Prairie Overlook (PO) sites. Values listed are averages with 1 standard deviation in parentheses. Values in rows not sharing a common letter are significantly different ($p \leq 0.10$). PO HDF: Sites included are: AC EF: American Camp extant *Festuca* (high density *Festuca*); AC EE: America Camp extant *Elymus*; AC CR: American Camp current restoration (low density *Festuca*); AC FR: American Camp future restoration (rabbit-infested area); PO HDF: Prairie Overlook high density *Festuca* (outplanted); PO LDF: Prairie Overlook low density *Festuca* (outplanted).

Soil Property	**PO-HDF** n = 4	**PO-LDF** n = 4	**AC-EF (HDF)** n = 5	**AC-CR (LDF)** n = 7	**AC-EE** n = 8	**AC-FR** n = 4
pH	5.3^a (0.05)	5.2^a (0.3)	5.5^{ab} (0.2)	5.4^a (0.3)	5.7^b (0.2)	5.8^b (0.1)
Total %C	4.4^{ab} (1.1)	4.9^{ab} (1.5)	4.0^{ab} (0.6)	4.2^b (0.9)	5.6^a (1.1)	3.0^b (0.4)
Total %N	0.45^a(0.1)	0.4^a (0.1)	0.30^b (.05)	0.3^b (.07)	0.42^a (0.1)	0.21^b (.02)
C:N	10^a (0.5)	11^a (1.3)	14^b (0.3)	14^b (0.4)	13^a (3.2)	14^b (0.6)
CEC(cmol$_c$/kg)	12.6^a (2.3)	15.5^a (3.9)	7.2^b (3.9)	7.3^b (1.6)	16.0^a (3.2)	6. 5^b (1.4)
NO$_3$-N(mg/g)	9.9 (4.5)	9. 5 (5.0)	2.5 (1.7)	2.7 (1.4)	6.7 (7.4)	2.1 (0.9)
NH$_4$-N(mg/g)	11.5^a (1.5)	10.7^a (0.5)	5.5^b (2.0)	5.8^b (2.4)	6^b (3.5)	5.0^b (0.62)
Ca (µg/g)	1500^a (410)	1700^a (380)	640^b (91)	860^b (200)	1800^a (520)	800^b (150)
K (µg/g)	190^a (100)	190^a (40)	660^b (9)	88^b (50)	200^a (40)	58^b (19)
Mg (µg/g)	310^a (90)	360^a (100)	140^b (15)	130^b (35)	490^c (120)	100^b (17)
Na (µg/g)	27.0 (7)	33 (11)	32 (3)	37 (5)	64 (20)	39 (6)
%BS	84	78	86	79	86	79

CONCLUSIONS

In general, the survival of *C. levisecta* was more strongly associated with physical microsite conditions than chemical properties. The two factors analyzed in this study that appear to have the greatest influence on the survival of planted *C. levisecta* are 1) the presence of a host species (especially *F. roemeri*) and 2) summer soil moisture levels. Overall, a greater cover of *F. roemeri* had a positive influence on survival, though this relationship was more pronounced at Glacial Heritage in SPS and the Bluff site in NPS compared to the other sites. Minimum soil moisture levels had the strongest influence on survival. Planted *C. levisecta* fared better in areas that retained slightly more moisture in the soil during extreme droughty periods, and were less saturated during winter months.

More extreme environments (e.g. the Bluff site on Whidbey Island) may be more vulnerable to increased summer temperatures and/or decreased summer rainfall. Planting *C. levisecta* near a host plant may be particularly beneficial at such sites.

In the mounded prairies of SPS, though survival was not found to be higher in particular locations on the mounds (top, side or swale), the total cover of individuals that had survived was higher on top of the mounds. These areas were found to have higher amounts of coarse material, while the swales had the highest amount of fine material. Soil on top of the mounds may be able to retain more moisture in extreme conditions due to deeper soil, but may also be less saturated in the winter months due to the higher amount of coarse fragments. For this reason, at sites with mounded topography, it is recommended to focus planting *C. levisecta* on top of the mounds in close proximity to a known host plant or, if no host plant is present, next to a perennial plant versus an annual.

Chemical properties were not indicative of survival in NPS sites, but some differences arose between high and low survival plots in SPS. Both calcium and magnesium levels were greater in high survival plots at SPS sites—two macronutrients which tend to be found in higher levels near saltwater.

The findings of this study shed some light on the habitat variables that facilitate the survival of planted *C. levisecta,* but they raise other questions. Following is a list of questions that future research could address or thoughts about how further research could proceed:

1) Study plots included in this study were both seeded and outplanted with seedlings. It would be beneficial for similar studies in the future to monitor only one of these groups or have a large enough sample size that the two groups could be separated to differentiate between germination success and survival of seedlings.
2) Why do areas of low survival exhibit higher moisture levels during winter months at SPS sites? What are the mechanisms that cause the soil to hold more moisture (e.g. texture, organic matter), and are higher levels of moisture indeed detrimental to the survival of *C. levisecta*? For example, is *C. levisecta* sensitive to lower oxygen levels in the soil? Is there a fungal pathogen that causes mortality in more saturated soils? Is microbial activity or nutrient cycling altered in such a way that negatively affects this rare plant? Do higher moisture levels affect pH on a fine-scale which, in turn, may affect levels of aluminum (which can be toxic to some plants) in the soil?
3) Since it appears that C. *levisecta* has a greater chance of surviving near *F. roemeri*, is one explanation for this that *F. roemeri* is transpiring during winter months and therefore creates less saturated soil conditions? How do

transpiration rates of *F. roemeri* affect soil moisture in high rainfall areas such as SPS?

4) How do rainfall patterns the first year after planting, particularly during spring and summer, affect survival rates?
5) What are the requirements of calcium and magnesium for *C. levisecta* and how do these compare to soil from SPS versus NPS? Are most extant populations in close proximity to salt water because these areas contain higher amounts of these macronutrients in the soil?

The comparison of native grasses at American Camp, found that areas of extant native grasses had lower and less variable soil temperatures as well as higher moisture levels (especially during winter months) compared to areas of current and future restoration. *E. glaucus*-dominated areas differed in many respects from other AC groups and were found to be similar to PO plots in moisture levels, soil temperatures, and many chemical properties such as total carbon and CEC. PO sites had greater cover of *F. roemeri*, higher moisture content, and generally more productive soil than most AC sites.

The greatest difference in soil properties between high and low-density fescue was soil temperature, which was significantly higher in areas of low-density *F. roemeri* cover. Both HDF and LDF groups at PO and AC exhibited extremely droughty conditions during summer months—when moisture readings over 12 cm were commonly between 2-4%. Qualitative differences in soil moisture among the six vegetation groups were small, but consistent. Soil chemical properties were not different by microsite.

Locations of high rabbit density consistently exhibited the harshest microsite conditions. Despite these harsh conditions, it is likely that *F. roemeri* seedlings will have high survival rates if they are planted early enough for roots to become established, and that the root systems are deep enough and make contact with mineral soil.

Following is a list of questions which future research could address or thoughts about how further research could proceed:

1) Is *E. glaucus* an appropriate initital species to plant in the area of high rabbit warren density? If roots of seedlings are long enough, can it survive droughty summer conditions?
2) Is sowing seed a viable method for restoring prairie vegetation at AC? Could it be supplemental to outplanting of plugs?
3) Are there soil treatments (e.g. scarification, tilling, burning) that might increase germination rates of native prairie species when sown by seed?

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APPENDIX A. Location of *C. levisecta* research plots in south Puget Sound Sites:

Figure A.1a. Research plots at Glacial Heritage Natural Preserve

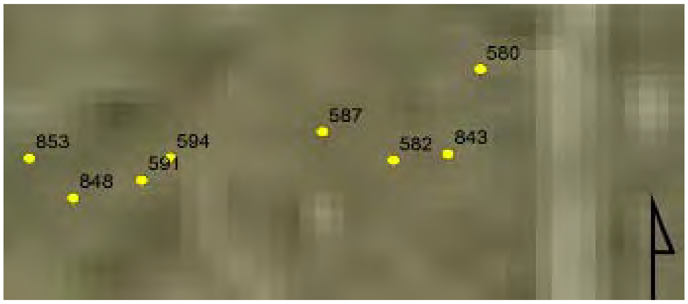


Figure A.1b. Detail of Glacial Heritage southern plots

Figure A.1c. Detail of Glacial Heritage northern plots

Figure A.1d. Research plots at Mima Mounds Natural Area Preserve

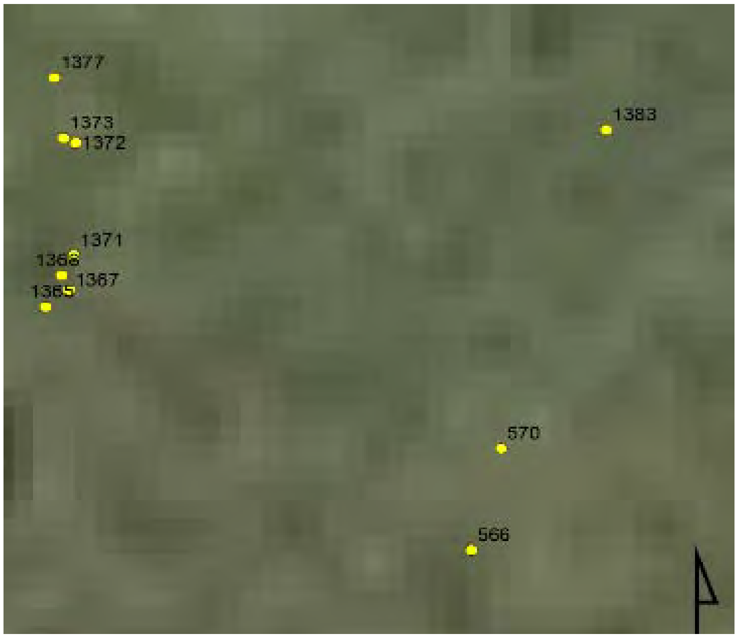


Figure A.1e. Detail of Mima Mounds southern plots

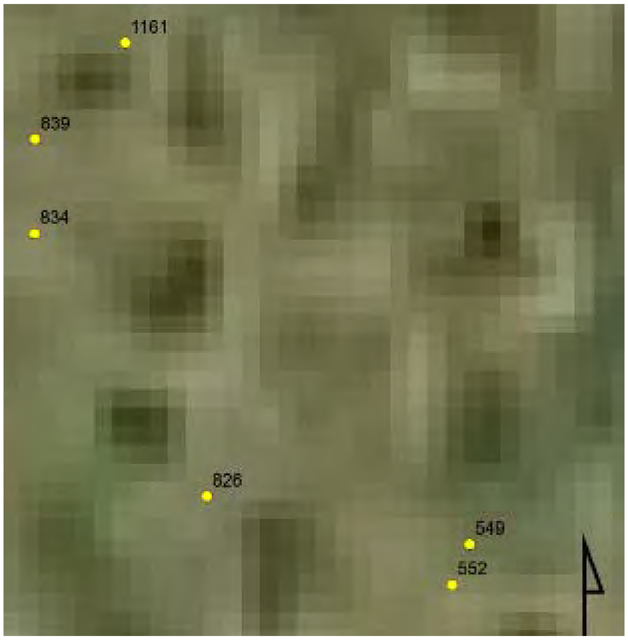


Figure A.1f. Detail of Mima Mounds northern plots

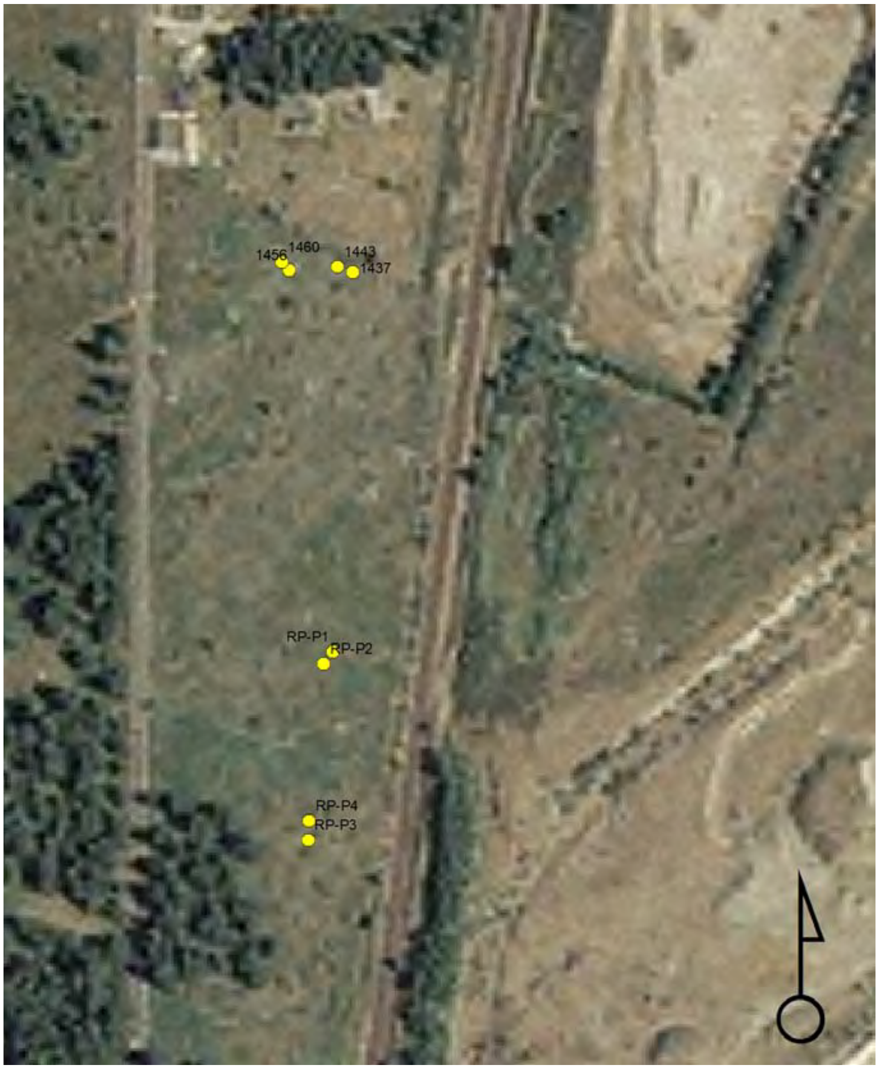


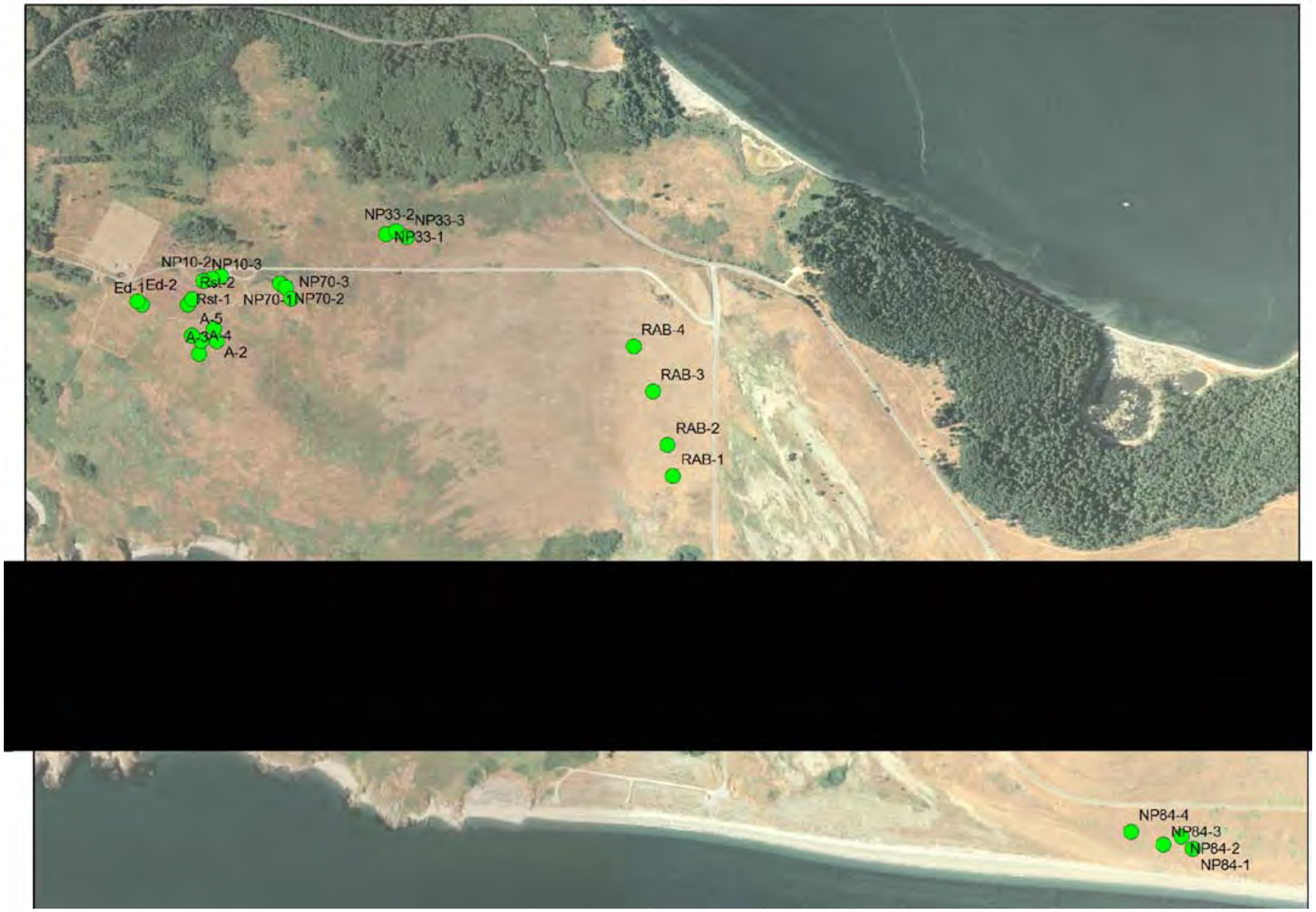
Figure A.1g. Research plots at Rocky Prairie Natural Preserve

Table A.1. GPS Coordinates for SPS *C. levisecta* sites.
(Coordinate system: UTM (NAD 83) Zone 10N)

	Plot ID	**Easting**	**Northing**
Glacial Heritage			
	549	496248.632	5194679.785
	552	496246.121	5194675.391
	566	496070.922	5192817.531
	570	496074.443	5192828.974
	580	496072.351	5190682.423
	582	496060.288	5190668.941
	587	496051.063	5190673.199
	591	496025.518	5190666.812
	594	496029.775	5190670.36
	702	496420.764	5191052.124
	706	496428.57	5191052.834
	713	496419.345	5191075.541
	826	496219.757	5194685.121
	834	496200.925	5194713.054
	839	496201.239	5194723.098
	843	496066.674	5190669.651
Mima Mounds			
	848	496016.293	5190663.264
	853	496011.326	5190670.36
	1161	496210.655	5194733.455
	1365	496031.114	5192845.115
	1367	496033.389	5192846.964
	1368	496032.394	5192848.528
	1371	496033.816	5192850.519
	1372	496033.958	5192863.036
	1373	496032.678	5192863.462
	1377	496031.825	5192870.147
	1383	496085.303	5192864.316
	1391	496396.62	5191047.758
	1399	496404.295	5191054.337
	1404	496410.875	5191055.434
	1416	496437.191	5191085.039
	1422	496452.542	5191091.619
Rocky	1437	510801.359	5196475.326

Prairie			
	1443	510789.297	5196478.341
	1456	510758.138	5196475.326
	1460	510751.102	5196482.362
	RP-P1	510787.287	5196222.031
	RP-P2	510782.261	5196213.99
	RP-P3	510769.857	5196098.349
	RP-P4	510772.21	5196112.471

APPENDIX B. Map of plot locations at American Camp, San Juan Island



[redacted]

Table B.1. GPS Coordinates for American Camp plots. (Coordinate system: UTM (NAD 83) Zone 10N)

	Plot ID	**Easting**	**Northing**
American Camp			
	NP84-1	500,980.41	5,366,935.00
	NP84-2	500,959.91	5,366,964.62
	NP84-3	500,916.61	5,366,946.39
	NP84-4	500,843.70	5,366,969.17
	RAB-1	499,791.04	5,367,363.35
	RAB-2	499,777.36	5,367,433.99
	RAB-3	499,738.63	5,367,559.31
	RAB-4	499,697.62	5,367,666.39
	NP33-3	499,162.17	5,367,921.59
	NP33-2	499,139.38	5,367,935.26
	NP33-1	499,116.60	5,367,919.31
	NP70-1	498,863.69	5,367,812.22
	NP70-2	498,881.91	5,367,803.10
	NP70-3	498,879.63	5,367,803.10
	NP10-1	498,729.69	5,367,828.72
	NP10-2	498,710.08	5,367,821.80
	NP10-3	498,688.75	5,367,815.45
	Rst-1	498,652.42	5,367,760.67
	Rst-2	498,662.22	5,367,773.36
	Ed-1	498,544.58	5,367,761.25
	Ed-2	498,533.63	5,367,768.17
	A-1	498,713.54	5,367,703.58
	A-2	498,719.89	5,367,674.75
	A-3	498,677.21	5,367,644.76
	A-4	498,682.98	5,367,674.75
	A-5	498,661.07	5,367,687.44

APPENDIX C. *C. levisecta* Summary Data

Table C.1. Soil temperature data from *C. levisecta* study

			% COVER		SOIL TEMPERATURE, 5cm (°C)						
SITE	PLOT	SURVIVAL	FERO	CALE	Max. summer soil temp 2006	Avg. soil temp (7/1-9/6) 2006	Avg. soil temp (6/1-9/1) 2006	Min. winter soil temp 2006-07	Max. summer soil temp 2007	Avg. soil temp (6/1-9/1) 2007	Avg. soil temp (3/1-7/1) 2007
Glacial Heritage	582	high	2	2	32.5	27.4	27.9	2.8	26.6	19.5	18.8
	587	high	20	2	29.7	24.6	25.7	3.5	25.8	22.0	18.7
	594	high	30	3	28	23.8	24.5	3.5	24.9	20.9	17.4
	702	high	35	2	31.9	26.8	26.1	3.5	24.1	22.1	18.8
	843	high	6	3	29.3	24.8	25.5	3.5	25.9	21.9	17.8
	1391	high	25	2	30.6	26.2	27.5	3.5	25.9	22.8	19.1
	1404	high	30	2	29.4	25.0	26.0	3.9	24.9	21.3	17.9
	1422	high	40	2	30.4	25.6	26.3	4	23.1	21.3	18.2
	580	low	15	0	29.1	24.5	25.4	3.1	24.4	21.4	17.5
	591	low	5	0	27.7	24.2	24.8	2.4	23.6	20.7	17.5
	706	low	0	0	34.2	28.2	28.3	3.1	24.3	22.7	19.9
	713	low	15	0	34.1	26.5	27.6	3.1	24.1	22.1	18.7
	848	low	2	0	27.5	23.8	24.5	2.8	24.1	20.1	16.7
	853	low	6	0	32	26.1	26.8	2.4	23.8	21.2	17.7
	1399	low	3	0	34.5	28.0	28.5	2.7	24.6	22.1	18.8
	1416	low	30	0	29.8	25.1	25.9	4	23.2	21.4	18.0

Table C.1 (continued)

			% COVER		SOIL TEMPERATURE, 5cm (°C)						
SITE	PLOT	SURVIVAL	FERO	CALE	Max. summer soil temp 2006	Avg. soil temp (7/1-9/6) 2006	Avg. soil temp (6/1-9/1) 2006	Min. winter soil temp 2006-07	Max. summer soil temp 2007	Avg. soil temp (6/1-9/1) 2007	Avg. soil temp (3/1-7/1) 2007
Mima Mounds	550	high	20	3	29.8	24.9	24.6	2.1	27.5	20.8	17.1
	570	high	13	2	30.9	25.5	25.0	3.8	25.3	23.4	17.3
	839	high	2	6	26	22.0	22.6	2.7	27.4	20.7	16.3
	1161	high	45	6	25.6	21.8	22.2	2.7	24	20.3	16.2
	1368	high	5	3	30.2	26.6	26.1	4.2	26.4	21.8	18.1
	1373	high	15	2	32.8	28.3	27.7	4.3	29.7	23.2	19.3
	1377	high	20	3	28.8	25.3	25.1	3.5	26.3	21.5	18.0
	1383	high	0	2	31.5	28.0	28.0	3.9	27.9	23.4	19.8
	552	low	35	0	26.1	22.6	22.4	2.7	25	20.3	15.9
	566	low	0	0	34.8	28.9	27.6	3.9	25.3	22.7	19.4
	826	low	25	0	28.5	24.4	24.1	2.4	24.8	20.1	16.8
	834	low	20	0	30.5	24.6	23.9	2.7	24.9	22.2	16.9
	1365	low	5	0	32.3	29.2	28.0	4.2	24.8	21.9	18.9
	1367	low	6	0.5	31.4	28.6	28.0	4.3	27.8	22.2	18.6
	1371	low	2	0.5	33.3	27.5	28.1	3.4	26.5	22.1	19.0
	1372	low	2	0	34.6	29.3	28.9	3.9	29	22.7	19.8
Rocky Prairie	P1	extant	20	3	29.3	24.0	23.9	4.2	28.6	22.5	18.9
	P2	extant	5	2	30.3	24.0	23.8	4.4	24.7	21.6	18.5
	P3	extant	5	3	27.2	24.2	23.9	5	23.4	21.2	18.3
	P4	extant	9	3	25.1	22.1	22.2	4	25	21.1	18.0
	N-1437	low	2	0	33.8	27.0	25.8	5.1	24.2	22.5	19.7
	N-1443	low	0.5	0	32.1	25.3	25.0	5.9	24.3	22.7	19.3
	N-1460	low	10	0	28	24.3	23.5	4.2	23.3	21.5	18.7
	N-1456	low	35	0	28.1	23.9	22.9	2.8	22.5	21.4	18.8

Table C.1. (continued)

			% COVER		SOIL TEMPERATURE, 5cm (°C)						
SITE	PLOT	SURVIVAL	FERO	CALE	Max. summer soil temp 2006	Avg. soil temp (7/1-9/6) 2006	Avg. soil temp (6/1-9/1) 2006	Min. winter soil temp 2006-07	Max. summer soil temp 2007	Avg. soil temp (6/1-9/1) 2007	Avg. soil temp (3/1-7/1) 2007
Sherman	SHE-P1	high	10	0.5	23.7	23.2	22.4	4.9	26.1	20.2	15.9
	SHE-P2	high	20	1	25.6	23.9	23.9	4.8	25.4	20.4	15.7
	SHE-P3	high	25	1	29.5	24.8	24.8	4.9	27	20.5	15.9
	SHE-P4	high	15	4	25.4	23.5	23.5	5.1	29.2	21.2	16.4
	SHE-P5	high	30	2	29.6	25.7	25.7	5.5	26.7	21.3	16.7
	SHE-P6	high	10	5	27.2	24.4	24.4	4.9	29.3	21.5	17.5
	SHE-P7	high	15	0.5	29.9	25.3	25.3	5.5	26.9	21.0	16.3
	SHE-P8	high	18	1	24.4	22.9	22.9	5.2	25.5	19.8	15.9
	SHE-N1	low	15	0	31.7	28.8	28.8	5.4	23.5	20.9	16.9
	SHE-N2	low	12	0	23.6	22.4	22.4	4.4	26.8	20.6	15.3
	SHE-N3	low	7	0	26.9	24.2	24.2	5.3	27.9	21.0	16.5
	SHE-N4	low	15	0	27.4	24.8	24.8	5.0	25.8	20.4	15.9
	SHE-N5	low	8	0	29.4	25.7	25.7	5.5	27.2	20.4	16.2
	SHE-N6	low	30	0	25.9	23.6	23.6	5.5	25.3	20.0	16.6
	SHE-N7	low	10	0	25.6	23.3	23.3	4.9	23.4	19.1	15.2
	SHE-N8	low	8	0	28.4	25.1	25.1	5.3	28	21.0	18.1
Bluff	BLF-P1	high	1	3	35.5	31.6	31.6	8.4	36.5	27.7	27.2
	BLF-P2	high	25	2	38.7	34.2	34.2	8	32.3	27.6	28.6
	BLF-P3	high	10	5	37.2	31.5	31.5	8.2	33.2	27.1	25.6
	BLF-P4	high	10	1	34.4	29.7	29.7	8.4	34	24.7	28.8
	BLF-N1	low	0.5	0	38.4	33.5	33.5	8.7	35.8	24.8	22.1
	BLF-N2	low	0	0	38.2	32.2	32.2	8.5	34.6	25.1	20.6
	BLF-N3	low	0	0	37.2	29.7	29.7	8.2	34.3	29.1	21.5
	BLF-N4	low	0	0	39.3	29.8	29.8	8.8	39.7	29.8	26.9

Table C.2. Soil moisture data from *C. levisecta* study (12 cm)

% SOIL MOISTURE (Volumetric Water Content), 12 cm

SITE	PLOT	Min. summr moist. (6/1-9/1) 2006	Max summr moist (6/1-9/1) 2006	Avg. moisture (6/15-9/15) 2006	Avg. moist. (6/1-9/1) 2006	Min. summr moist. 2007	Max summr moist. 2007	Avg. moist (3/1-7/1) 2007	Avg. moist. (4/1-9/1) 2007	Avg. moist. (6/1-9/1) 2007	Avg winter moist. 11/15-4/15 '06-07	Max winter moist. 2006-07
Glacial Heritage	582	2	6	3.5	3.8	4	9.3	10.3	8.2	6.7	18.4	20.0
	587	3	6	4.3	4.6	5	9.3	9.4	7.8	6.8	12.6	16.5
	594	3	6	4.0	4.2	4	9.7	10.2	8.0	6.2	20.4	24.0
	702	2	5	3.3	3.6	4	11	9.7	8.4	7.3	14.4	16.5
	843	3	4	3.3	3.4	4	9.7	9.3	7.3	6.6	14.9	15.7
	1391	2	5	3.3	3.4	3	10.7	9.2	7.2	5.9	16.6	20.5
	1404	3	7	4.0	4.2	5	11.7	12.5	9.8	8.1	22.9	26.0
	1422	3	5	3.9	3.9	5	11	10.8	8.7	7.6	18.5	19.5
	580	3	6	3.8	4	3	9.3	9.1	7.0	6.1	14.3	15.7
	591	2	4	3.2	3.2	4	11	13.7	10.0	7.4	27.2	29.0
	706	2	4	2.7	2.8	3	10.7	11.5	8.8	6.8	19.1	21.3
	713	2	4	3.2	3.2	4	8	7.0	6.3	5.7	11.4	12.0
	848	2	3	2.8	3	4	11.3	14.7	10.3	7.2	28.6	30.0
	853	3	5	3.5	3.6	4	12	11.2	8.4	6.9	26.7	30.0
	1399	2	4	2.5	2.6	3	10.7	10.1	7.3	6.2	17.9	20.0
	1416	2	4	2.7	2.8	4	12.3	10.5	8.7	6.8	17.6	21.0

Table C.2 (continued)

% SOIL MOISTURE (Volumetric Water Content), 12 cm

SITE	PLOT	Min. summr moist. (6/1-9/1) 2006	Max summr moist (6/1-9/1) 2006	Avg. moisture (6/15-9/15) 2006	Avg. moist. (6/1-9/1) 2006	Min. summr moist. 2007	Max summr moist. 2007	Avg. moist (3/1-7/1) 2007	Avg. moist. (4/1-9/1) 2007	Avg. moist. (6/1-9/1) 2007	Avg winter moist. 11/15-4/15 '06-07	Max winter moist. 2006-07
Mima Mounds	550	4	7	5.3	5.6	5	11.3	9.8	8.0	6.1	15.1	17.0
	570	4	6	4.8	5	5	13.7	9.9	8.9	7.0	15.4	16.5
	839	3	6	4.5	4.8	4.7	9.3	9.3	7.6	6.9	16.3	17.0
	1161	3	12	6.2	6.8	5	9.3	9.3	7.6	6.6	16.6	18.5
	1368	3	6	3.7	3.8	5	10.3	12.7	9.3	7.0	26.2	29.0
	1373	3	8	4.7	5	5.3	9.3	9.1	7.4	6.8	16.6	18.0
	1377	3	8	4.7	5	5	11.3	11.6	8.8	7.8	16.8	19.3
	1383	3	6	4.0	4.2	4	7.7	9.3	7.1	5.8	16.8	20.0
	552	3	6	5.0	5.4	5.7	12	9.9	8.5	7.8	15.5	16.0
	566	2	5	3.0	3.2	5	11	12.1	9.2	7.4	21.3	26.0
	826	3	7	4.5	4.8	6.7	10.3	12.6	10.0	8.4	23.4	26.5
	834	3	9	5.3	5.8	4	12	12.0	8.4	7.0	20.8	24.3
	1365	2	4	3.2	3.2	4.7	14	11.8	9.5	7.8	25.2	28.0
	1367	3	4	3.3	3.4	5	11.7	12.8	9.5	6.4	27.6	31.0
	1371	3	6	3.7	3.8	5.3	11.3	11.7	8.9	7.6	23.3	26.0
	1372	2	7	3.8	4.2	5.3	12.7	11.5	9.4	8.2	22.3	25.0
Rocky Prairie	P1	2	3	2.8	2.8	5.3	13	11.1	8.6	7.6	16.6	20.0
	P2	2	4	3.0	3.3	3.3	11	7.9	7.0	6.7	13.0	15.0
	P3	3	4	3.4	3.5	3.7	8.3	8.1	6.5	5.7	13.6	14.7
	P4	3	4	3.8	3.8	3	7.7	8.9	7.0	6.1	18.0	20.0
	N-1437	3	5	3.4	3.5	3.7	8.7	10.4	7.3	5.4	17.6	19.7
	N-1443	2	4	3.0	3.3	3.3	6.3	8.3	6.1	4.4	13.3	14.0
	N-1460	3	4	3.4	3.5	4	10	8.5	7.0	5.6	14.4	16.0
	N-1456	2	4	3.0	3.3	4	8	8.4	6.5	5.3	14.6	15.0

Table C.2 (continued)

% SOIL MOISTURE (Volumetric Water Content) 12 cm

SITE	PLOT	Min. summr moist. (6/1-9/1) 2006	Max summr moist (6/1-9/1) 2006	Avg. moisture (6/15-9/15) 2006	Avg. moist. (6/1-9/1) 2006	Min. summr moist. 2007	Max summr moist. 2007	Avg. moist (3/1-7/1) 2007	Avg. moist. (4/1-9/1) 2007	Avg. moist. (6/1-9/1) 2007	Avg winter moist. 11/15-4/15 '06-07	Max winter moist. 2006-07
Sherman	SHE-P1	3	8	4.2	4.4	3	5	6.4	5.0	4.3	14.4	19.0
	SHE-P2	3	10	4.3	4.6	3	5	5.9	4.4	3.9	14.2	19.0
	SHE-P3	3	9	4.2	4.4	3	4	5.2	4.1	3.5	12.7	16.0
	SHE-P4	3	8	4.2	4.4	3	4	5.2	4.1	3.4	13.0	18.0
	SHE-P5	3	9	4.2	4.4	2	4	5.6	4.4	3.5	12.3	16.0
	SHE-P6	3	10	4.5	4.8	2	4	5.6	4.3	3.5	12.4	15.0
	SHE-P7	3	9	4.3	4.6	3	4	5.4	4.2	3.4	11.9	16.0
	SHE-P8	3	10	4.5	4.8	3	6	6.2	4.7	3.9	13.3	18.0
	SHE-N1	2	9	4.0	4.2	2	4	5.5	4.1	3.3	11.8	15.0
	SHE-N2	2	13	4.7	5.2	3	4	6.2	5.1	3.9	12.6	16.0
	SHE-N3	2	8	3.8	4.2	3	4	5.1	4.2	3.7	12.1	16.0
	SHE-N4	3	9	4.8	4.4	2	5	5.6	4.5	3.8	13.9	20.0
	SHE-N5	3	9	4.3	4.6	2	4	5.5	4.1	3.2	11.7	17.0
	SHE-N6	3	10	4.5	4.8	2	4	5.2	4.1	3.5	12.9	19.0
	SHE-N7	3	9	4.3	4.6	3	4	6.1	5.1	4.0	14.1	19.0
	SHE-N8	2	8	3.5	3.8	2	4	5.2	3.6	3.3	12.9	17.0
Bluff	BLF-P1	2	8	4.0	4.2	3	4	5.5	3.9	3.7	13.8	19.0
	BLF-P2	3	7	3.8	4.0	3	4	5.6	4.0	3.5	13.4	16.7
	BLF-P3	3	7	4.0	4.2	3	5	6.2	4.3	3.8	13.1	14.7
	BLF-P4	3	7	4.0	4.0	3	4	6.0	3.9	3.8	14.1	17.0
	BLF-N1	2	6	3.5	3.6	3	5	6.5	4.3	3.6	14.7	18.3
	BLF-N2	3	7	3.8	4.0	3	4	5.3	4.1	3.5	13.3	16.3
	BLF-N3	3	7	3.8	4.0	3	5	5.9	4.2	3.7	15.1	19.0
	BLF-N4	3	8	4.3	4.6	3	4	5.9	4.3	3.7	14.9	19.3

Table C.3. Soil moisture data for *C. levisecta* study (30 cm)

SITE	PLOT	% SOIL MOISTURE (Volumetric Water Content), 30 cm Min. summer moisture 30 cm 2007	Max summer moisture 30 cm 2007	Avg. moisture 30 cm (Apr-Aug) 2007	Avg. moisture 30 cm (June-Aug) 2007
Sherman	SHE-P1	10.0	11.9	12.8	10.91
	SHE-P2	9.3	10.4	11.8	9.92
	SHE-P3	9.4	11.3	12.3	10.28
	SHE-P4	9.7	11.3	13.6	10.38
	SHE-P5	9.1	11.3	12.1	10.25
	SHE-P6	9.4	10.5	12.0	9.80
	SHE-P7	9.7	11	11.7	10.24
	SHE-P8	10.09	12.3	13.2	11.11
	SHE-N1	9.6	11	11.7	10.12
	SHE-N2	9.1	11.3	12.1	10.17
	SHE-N3	9.7	11.4	12.3	10.41
	SHE-N4	8.7	10.8	11.6	9.86
	SHE-N5	9.9	12.5	13.4	11.15
	SHE-N6	9.7	12.5	13.3	10.99
	SHE-N7	9.9	12.9	13.9	11.17
	SHE-N8	9.6	11	11.7	10.25

APPENDIX D. Summary Data for native grass study

Table D.1. Soil temperature data from native grass study

		SOIL TEMPERATURE (C) 5cm depth					
SITE	PLOT	Max. summer soil temp 2006	Max. summer soil temp 2007	Min. winter soil temp 2006-07	Avg. soil temp (PO:7/1-9/1) 2006	Avg. soil temp (6/7-9/1) 2007	Avg. soil temp (April-Aug) 2007
Prairie	POH-1	26.0	24.6	3.1	23.2	21.5	18.6
Overlook	POH-2	24.7	23.8	2.5	22.3	20.4	18.2
	POH-3	22.4	29.4	2.8	21.7	22.0	19.2
Ebey's	POH-4	22.3	22.0	3.1	21.1	19.7	18.1
Land.	POL-1	34.2	28.7	3.4	31.1	22.7	20.2
	POL-2	34.2	30.2	2.6	30.6	23.7	21.4
	POL-3	31.8	25.4	2.5	27.8	22.3	20.0
	POL-4	26.4	25.8	3.7	24.4	21.5	19.9
American	NP10-1	22.3	21.5	4.5	20.3	19.9	16.8
Camp	NP10-2	23.9	21.7	4.1	20.4	20.4	17.3
	NP10-3	26.9	24.9	4.5	23.9	23.1	19.3
San	NP33-1	22.9	24.1	3.4	20.0	22.6	18.7
Juan	NP33-2	26.8	26.5	3.7	22.7	23.3	19.2
	NP84-1	23.4	20.9	3.8	16.6	19.4	17.3
	NP84-2	27.3	22.3	4.6	21.5	20.2	17.7
	NP84-3	24.4	21.7	4.5	21.1	20.1	17.0
	NP84-4	25.1	22.9	4.7	21.4	20.4	17.4
	NP33-3	23.8	24.0	3.2	20.0	21.2	17.6
	NP70-1	20.9	19.4	3.9	18.1	19.2	16.2
	NP70-2	22.9	22.2	4.1	20.1	20.0	16.8
	NP70-3	24.5	22.2	3.5	20.0	21.0	18.1
	A-1	31.6	32.8	4.3	26.0	24.3	20.2
	A-2	32.3	27.8	4.2	26.6	24.4	20.3
	A-3	30.5	25.9	4.2	26.9	24.8	20.4
	A-4	35.1	32.5		27.6	28.4	22.4
	A-5	35.7	30.1	3.7	28.3	24.6	19.8
	E-1	34.1	32.0	3.2	28.5	28.5	23.1
	E-2	35.2	28.4	3.2	28.9	25.6	21.4
	R-1	41.6	31.9	5.1	31.4	30.1	24.7
	R-2	37.5	32.3	5.3	29.3	27.8	23.3
	RAB-1	35.6	34.9	4.1	33.3	29.9	24.4
	RAB-2	37.2	32.3	4.1	32.9	29.9	24.3
	RAB-3	34.1	31.6	3.9	31.9	27.6	22.7
	RAB-4	35.1	33.2	4.6	31.3	28.5	23.2

Table D.2. Soil moisture data for native grass study (12cm)

SOIL MOISTURE 12 cm depth

PLOT	Min. summr moist. (7/1-9/1) 2006	Max summr moist. (7/1-9/1) 2006	Avg. moist. (7/1-9/1) 2006	Min. summr moist. 2007	Max summr moist. 2007	Avg. moist.(6/7-9/1) 2007	Avg spring moist. (3/1/-6/30) 2007	Avg winter moist.(11/06-4/07)
POH-1	3	5	4.2	3	6	4.6	12.4	22.9
POH-2	4	6	4.6	3	6	4.5	12.1	21.4
POH-3	4	5	4.8	3	6	4.5	12.4	23.1
POH-4	4	6	4.8	4	6	4.9	12.5	24.1
POL-1	3	5	4	3	5	4.0	11.6	22.5
POL-2	3	5	3.8	3	5	4.3	12.3	23.3
POL-3	3	5	4.4	3	6	4.6	11.9	21.3
POL-4	4	5	4.6	3	6	4.7	13.3	24.8
NP10-1	3	4	3.4	4	4	4.0	10.4	17.4
NP10-2	3	4	3.4	3	5	4.3	10.5	17.6
NP10-3	2	3	2.8	3	6	3.8	8.9	15.2
NP33-1	3	4	3.4	3	6	4.3	10.2	15.9
NP33-2	2	4	3	3	5	3.7	9.0	15.1
NP84-1	4	5	4.5	3	6	4.5	10.4	15.0
NP84-2	3	4	4.25	4	5	4.7	9.3	16.5
NP84-3	3	4	3.25	4	6	4.4	10.0	15.8
NP84-4	3	3	3	4	6	5.1	10.0	16.1
NP33-3	3	4	3.2	3	5	3.8	9.1	14.5
NP70-1	3	4	3.6	2	6	4.3	11.4	19.5
NP70-2	3	3	3	3	5	4.0	9.6	17.1
NP70-3	3	4	3.2	3	5	4.0	10.0	17.5
A-1	3	3	3	3	5	3.6	8.6	14.3
A-2	3	3	3.2	3	6	3.6	9.3	14.9
A-3	2	3	2.8	2	5	3.6	8.7	15.3
A-4	2	3	2.6	3	4	3.4	8.7	15.2
A-5	3	3	3	3	4	3.3	8.5	14.5
E-1	3	3	3	3	5	4.0	9.5	18.8
E-2	3	4	3.8	3	5	4.0	10.4	19.5
R-1	2	2	2	3	3	3.0	8.2	16.3
R-2	2	3	2.4	3	4	3.1	7.7	14.9
RAB-1	2	3	2.8	3	5	3.6	9.1	14.9
RAB-2	2	3	2.8	3	4	3.8	9.2	15.0
RAB-3	2	4	3	3	6	4.3	8.9	14.2
RAB-4	3	4	3.2	3	4	3.4	7.6	12.7

Table D.3. Soil moisture data for native grass study (30 cm)

SOIL MOISTURE 30 cm depth

PLOT	Min. summr moist. 2007	Max summr moist. 2007	Max winter moist.12 cm	Avg. moist. (June-Aug) 2007	Avg. moist. (April-Aug) 2007	Avg moist. (Nov-April)	Avg moist. (11/1-4/1))	Max winter moist. 2006-07
POH-1	10.9	12.8	27.7	11.8	16.1	28.2	29.7	31.3
POH-2	11.1	13.3	24.7	12.1	16.9	31.4	32.8	35.2
POH-3	11.2	13.2	26.7	12.1	17.2	31.9	33.2	35.7
POH-4	11.3	13.3	29.3	12.3	17.5	32.1	33.2	35.7
POL-1	8.5	9.9	26.3	9.2	13.2	26.3	27.8	30.7
POL-2	10.2	11.8	28.7	11.0	16.0	31.4	33.0	36.7
POL-3	9.9	11.4	23.7	11.0	15.2	27.8		31.7
POL-4	10.0	11.9	25.3	10.7	13.6	30.0	32.3	34.3
NP10-1	9.7	11.4	18.3	11.3	15.4	30.0	30.1	30.5
NP10-2	9.6	11.4	19.0	10.9	15.0	27.7	27.7	28.1
NP10-3	9.2	10.5	18.0	10.2	14.1	28.6	28.7	29.7
NP33-1	10.0	11.5	16.7	11.1	15.3	27.2	27.2	28.8
NP33-2	9.4	11.0	15.7	10.7	15.2	27.6	27.6	29.6
NP84-1	9.2	12.2	18.3	10.5	12.8	26.2	26.2	30.0
NP84-2	9.5	12.7	18.0	11.3	12.1	30.1	30.1	30.4
NP84-3	9.7	11.7	17.3	10.5	15.1	27.5	27.5	28.3
NP84-4	9.4	11.5	16.7	10.6	14.7	30.0	30.0	30.5
NP33-3	9.3	11.8	15.3	10.0	14.2	26.9	26.9	27.7
NP70-2	7.3	10.1	18.3	9.1	14.4	24.9	24.9	25.5
NP70-3	8.7	10.9	18.7	9.3	12.7	26.7	26.7	27.5
A-1	9.2	11.0	17.3	10.2	12.7	25.8	25.8	26.8
A-2	10.8	14.0	17.3	12.0	16.5	29.2	29.2	30.9
A-3	9.4	11.2	17.3	10.2	14.2	28.1	28.1	29.6
A-4	10.1	11.5	17.0	10.7	17.1	29.2	29.2	29.5
A-5	10.0	10.7	16.0	10.3	14.3	27.3	27.3	28.0
R-1	6.5	9.1	17.3	8.0	10.9	27.4	27.4	27.8
R-2	7.5	8.6	16.3	7.9	10.9	23.0	23.0	23.9
RAB-1	9.7	11.6	16.7	10.6	14.8	27.5	27.5	27.7
RAB-2	9.2	11.9	16.0	10.8	14.8	27.9	27.9	27.9
RAB-3	11.5	14.8	15.3	13.0	17.0	27.3	27.3	29.5
RAB-4	8.7	10.4	16.0	9.8	12.7	21.4	21.4	21.9

Table D.4. Explanations of plot IDs for native grass study

CODES:	POH	Prairie Overlook HIGH-density Festuca (Ebey's Landing, Whidbey Island)
	POL	Prairie Overlook LOW-density Festuca (Ebey's Landing, Whidbey Island)
	NP10	Native plant polygon identified by NPS/ Festuca-dominated
	NP33	Native plant polygon identified by NPS/ Festuca-dominated
	NP84	Native plant polygon identified by NPS/ Elymus-dominated
	NP70	Native plant polygon identified by NPS/ Elymus-dominated
	A	Amy Lambert's research plots, outplanted *F. roemeri* (low survival
	E	Educational plots, outplanted *F. roemeri* (low survival
	RAB	Plots located within high-denisty rabbit warren area

APPENDIX E. Summary of chemical data from *C. levisecta* study

Table E.1. Chemical data from *C. levisecta* study

							Available nitrogen						
SITE	**PLOT**	**pH**	**total %C**	**total %N**	**C:N**	**CEC**	**NO_3-N**	**NH_4-N**	**P**	**Ca**	**K**	**Mg**	**Na**
						cmol_c/kg	mg/g	mg/g	mg/kg	ug/g	ug/g	ug/g	ug/g
Sherman	SHE-P4	6.18	1.85	0.15	12.40	12.4	4.1	0.69	7.01	600	155	449	23.18
	SHE-P6	6.16	1.67	0.14	12.30	12.3	5.2	0.48	5.52	582	142	417	22.40
	SHE-P7	6.13	1.09	0.18	6.16	6.2	2.5	0.24	2.95	530	36	366	28.75
	SHE-P8	6.02	1.33	0.10	13.04	13.0	4.1	0.44	5.06	529	106	378	25.48
	SHE-N1	6.17	1.39	0.12	11.88	11.9	4.3	0.53	6.58	507	171	365	21.85
	SHE-N2	6.31	1.66	0.19	8.62	8.6	1.1	0.41	5.88	597	100	436	27.4
	SHE-N7	6.15	1.84	0.15	12.02	12.0	5.6	0.71	6.75	681	149	510	27.2
	SHE-N8	6.3	1.85	0.15	12.65	12.7	6.7	0.75	5.55	574	182	457	24.5
Bluff	BLF-P1	6.03	1.667	0.22	7.72	7.7	6.8	0.51	3.79	760	57	379	45.5
	BLF-P2	5.83	1.948	0.24	8.25	8.3	3.8	0.27	2.83	755	69	342	49.1
	BLF-P3	6.13	2.164	0.27	8.07	8.1	2.5	0.32	3.87	735	127	329	60.8
	BLF-P4	6.2	2.105	0.18	11.96	12.0		8.87	4.19	745	87	423	55.7
	BLF-N1	6.33	1.809	0.26	7.09	7.1	1.9	0.26	3.26	870	74	436	66.6
	BLF-N2	6.2	1.927	0.27	7.24	7.2	3.7	0.51	2.96	767	79	362	48.5
	BLF-N3	6.07	2.313	0.2	11.68	11.7	6.5	17.4	4.22	770	90	386	53.2
	BLF-N4	6.4	2.927	0.25	11.85	11.9		23.1	3.52	730	85	390	61.3

APPENDIX F. Summary of chemical data from *C. levisecta* study

Table F.1 Chemical data from native grass study

SITE	PLOT	pH	total %C	total %N	C:N	CEC	NO_3-N	NH_4-N	P	Ca	K	Mg	Na
						$cmol_c$/kg	mg/g	mg/g	mg/kg	ug/g	ug/g	ug/g	ug/g
Prairie	POH-1	5.2	3.03	0.33	9	9.3	4	9.6	30.5	906	127	193	18
Overlook	POH-2	5.3	4.75	0.49	10	13.8	12	12.1	25.5	1621	357	369	26
	POH-3	5.3	4.34	0.44	10	12.8	9.2	11.2	20.1	1628	135	296	30
Ebey's	POH-4	5.3	5.59	0.54	10	14.4	14.4	13.2	18.8	1852	159	394	35
Landing	POL-1	5.0	4.41	0.44	10	12.4	9	11.3	22.3	1451	189	306	28
	POL-2	5.2	2.97	0.32	9	11.9	6.1	10.2	25.6	1310	233	240	23
	POL-3	5.1	6.04	0.57	11	18.3	6.1	11	15.5	2017	159	460	50
	POL-4	5.6	6.09	0.50	12	19.4	16.6	10.4	15.4	2194	232	480	28
American	NP10-1	5.6	3.82	0.26	15	5.2	1.7	3.1	14.9	756	67	158	32
Camp	NP10-2	5.3	3.68	0.26	14	4.2	2.8	5.6	13.8	511	68	123	33
	NP10-3	5.2	3.82	0.27	14	13.9	4	6.5	21.8	620	56	145	35
San Juan	NP33-1	5.7	3.96	0.28	14	5.3	4	8.3	6.8	690	62	127	28
Island	NP33-2	5.8	5.13	0.38	14	7.2	1	41	9.8	638	80	141	31
	NP84-1	6.0	4.70	0.35	13	18.5	15	38	12.1	1715	249	679	97
	NP84-2	5.8	5.28	0.40	13	16.7	16	37	10.6	1615	183	540	66
	NP84-3	5.8	4.29	0.31	14	13.6	14	39	8.9	1347	133	528	73
	NP84-4	5.8	5.09	0.37	14	15.6	19	40	12.3	1636	188	575	77
	NP33-3	5.9	4.73	0.34	14	9.4	5	32	7.8	996	130	212	25
	NP70-1	5.4	6.73	0.53	13	18.5	12.3	9.8	23.2	2137	236	416	46
	NP70-2	5.4	7.22	0.57	13	18.8	17.3	12.5	19.9	2676	238	507	68
	NP70-3	5.5	6.71	0.49	14	16.4	16.7	7.9	19.6	1834	179	515	54
	A-1	5.5	4.44	0.31	14	7.0	2.1	5.5	25.3	819	89	130	31
	A-2	5.9	2.98	0.20	15	6.0	1.7	3.5	9.4	743	41	116	42
	A-3	5.5	4.96	0.34	15	6.7	1.1	2.8	27.5	751	84	105	34
	A-4	5.4	3.22	0.22	15	7.8	3.1	10.1	31.3	944	73	131	43

Table F.1 (Continued)

SITE	PLOT	pH	total %C	total %N	C:N	CEC cmol$_c$/kg	NO$_3$-N mg/g	NH$_4$-N mg/g	P mg/kg	Ca ug/g	K ug/g	Mg ug/g	Na ug/g
	E-1	5.0	5.62	0.41	14	6.2	4.7	6.9	29.9	621	74	95	33
	R-1	4.9	4.83	0.34	14	10.7	4.2	7.2	42.4	1234	184	192	39
	R-2	5.2	3.66	0.26	14	6.7	2.8	7	11.5	931	72	169	36
	RAB-1	5.7	3.28	0.23	14	6.2	1	5.7	24.8	849	75	105	34
	RAB-2	5.8	3.21	0.22	15	7.9	1.8	5.4	26.0	867	37	113	46
	RAB-3	5.8	3.16	0.22	15	7.2	3.1	4.5	29.0	889	46	111	41
	RAB-4	6.0	2.48	0.18	14	4.5	2.5	4.5	8.2	575	72	76	33