EFFECTS OF TRAMPLING AND FIRE
ON LEPIDIUM PAPILLIFERUM
AND
SLICKSPOT HABITAT

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AUTHORIZATION TO SUBMIT THESIS

This thesis of Shaniko Nichol-Driskill, submitted for the degree of Master of Science with a major in Natural Resources and titled “EFFECTS OF TRAMPLING AND FIRE ON LEPIDIUM PAPILLIFERUM AND ITS SLICKSPOT HABITAT,” has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

Lepidium papilliferum, commonly known as slickspot peppergrass, is a rare plant found only in the sagebrush steppe of southwest Idaho. This rare plant was listed in 2009 as threatened under the Endangered Species Act due its small population numbers and the degradation of its sagebrush steppe habitat. Across the west, sagebrush steppe ecosystems are being increasingly changed by the introduction of exotic species and the resulting increase in both frequency and extent of wildfire. Historically much of the area inhabited by *L. papilliferum* has also been used for livestock grazing. Livestock grazing is a concern to this plant both because of the physical damage to the plant and soils is grows in, and because heavy livestock use is often associated with the spread of invasive species.

Within the larger sagebrush matrix, *L. papilliferum* is found almost exclusively in small microsites called slickspots. These slickspots have very specific soil characteristics that differentiate them from the surrounding sagebrush matrix and inhibit the growth of most native vegetation. In this study we looked at how livestock trampling effected the population of *L. papilliferum* within these slickspots, as well as how the trampling effected the presence of exotic species in the slickspots. During the eight years of this study, the trampling treatment was found to have no effect on either the population of *L. papilliferum,* or the numbers of exotic annuals.

In a separate, but related, study we looked at the effects of burning on the soil moisture within the slickspot habitat. Burning was found to decrease the soil moisture in the top ten cm of the soil during the spring months. This study compared slickspots within an area burned three years previously to slickspots within unburned areas of sagebrush steppe.

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Introduction

Lepidium papilliferum (slickspot peppergrass) is a rare plant occurring only in southwestern Idaho. Its range is further limited by the fact that it is only found within slickspots, areas high in clay and salts where few other plants thrive. While the total *L. papilliferum* population appears to have stabilized since 1996 (Sullivan and Nations 2009), individual populations are small and isolated from each other in a way that has warranted the listing of this plant under the Endangered Species Act. Although efforts to monitor and study this plant have increased since its initial decline and vulnerability was detected, the high amount of variability in the population has stymied efforts to identify specific drivers of the population dynamics.

Three factors consistently under scrutiny for their possible negative effects on *L. papilliferum* are livestock trampling, competition from invasive species, and fire. In the first part of this study we look at the response of the *L. papilliferum* population to a controlled level of livestock trampling over a period of five years. The effect of this trampling was also examined in regards to the prevalence of invasive species. In the second part of this study we examine how the change in plant composition and vegetation structure after a fire can affect soil moisture in slickspots, thus possibly changing the percentage of seeds that germinate and survive to set seed.

Chapter 1-Literature Review

L. papilliferum was described for the first time in 1900 by Henderson as *Lepidium montanum* var. *papilliferum*. In 1913 Nelson and McBride determined that there were enough differences between *L. montanum* and *L. papilliferum* to rename the plant *Lepidium papilliferum*. Over time there has been some confusion as to whether *L. papilliferum* and *L. montanum* var. *papilliferum* are separate species, or if one is a subspecies of another. This has caused *L. papilliferum* to be identified as *L. montanum* var. *papilliferum* in multiple publications (USFWS 2006). In 2009, phylogenetic analysis of the DNA from several varieties of Lepidium showed that *L. papilliferum* is more closely related to other, previously not considered species, than it is to *L. montanum var. papilliferum*, indicating that they are separate species (Smith et al. 2009).

L. papilliferum is generally described as being monocarpic and having two life history patterns consisting of an annual and a biennial form. The annual form germinates in early spring, flowers, and sets seed before the summer drought begins in June. The biennial form stays as a rosette the first year, overwinter, and then flowers the second year. Although the majority of rosettes do not survive the summer, and only a small percentage of plants survive to produce seed the following year, the biennial form of *L. papilliferum* produces many more seeds than the annual form and is a significant seed source. A third, even less common life history strategy has been recently identified by White and Robinson (2009). In this form the plant produces a small amount of flowers and seeds late in the first year, then flowers and sets seed again in the second year.

The seeds of *L. papilliferum* appear to most often disperse short distances simply by the function of gravity (Moseley 1994). Wind and water may also contribute to some longer-range dispersal, but the size and shape of the seeds does not appear to facilitate this (Moseley

1994). In undisturbed slickspots seeds are mainly found in the top 5 cm of soil, and it has been found the highest number of seeds germinate from depths of about 2 mm (USFWS 2006, Meyer and Allen 2005). The seeds of *L. papilliferum* remain viable in the soil for 12 or more years. When they do germinate, the population numbers are highly variable from year to year.

The “slickspots”, also known as “playettes”, in which *L. papilliferum* grows are a unique environment, which contains a set of conditions unfavorable for many native species. Slickspots can be easily picked out from the surrounding sagebrush steppe due to their sparse vegetation and smooth reflective surface. Slickspots are irregular in shape and range from 2 to 10 m in diameter. Due to the lack of vegetation, slickspots have very low levels of organic matter (Meyer and Quinney 1993). Slickspots are saline-sodic and have a relatively high clay content. Slickspots soils have been classified as the Sebree soil series (Lewis and White 1964). They are generally associated with the Chilcott soil series (Lewis and White 1964, Fischer et al. 1996), are found nested within multiple other soil series on soil survey maps. Structurally slickspots have three defined layers. The top layer is a shallow A horizon consisting of a light colored vesicular crust composed of soil which is silt or silt loam in texture (Fischer et al. 1996, personal observation). This layer can be highly variable in thickness, but in a study by Fischer et al. the average depth was found to be 3.4 cm (1996). Below the silt crust there is an abrupt increase in the amount of clay as well as the exchangeable sodium, causing a natric argillic B horizon. This combination of high clay content and high sodium forms a restrictive hardpan layer that inhibits water infiltration causing the ponding characteristic of slickspots (Fischer et al. 1996). It has been hypothesized that the lack of vegetation in slickspots is due to the anaerobic conditions caused by periodic flooding that occurs in these slickspots (Meyer et al. 2005). This hypothesis is not completely supported however due to the lack of gleying or mottling which would indicate anaerobic conditions (Fisher et al. 1996). Below the hard pan, the proportion of clay gradually declines, and salinity and sodicity increase with increasing depth (Fisher et al. 1996).

While we do not know exactly what soil characteristic causes slickspots to be favorable habitat for *L. papilliferum*, there is a positive correlation between the depth of certain soil layers and the abundance of *L. papilliferum. L. papilliferum* is more likely to be found where the silt crust is less than 3 cm thick, and where there is a thin hardpan layer (Meyers and Allen 2005).

Undisturbed slickspots are considered to be those surrounded by intact sagebrush steppe and not having any visible physical disturbance inside the slickspot. Vegetation in undisturbed slickspots is generally very sparse. Disturbed slickspots are generally surrounded by some sort of non-native grassland, or have major physical disturbance to their interiors. In disturbed slickspots, non-native species dominate with the most abundant being *Lepidium perfoliatum* (clasping-leaf pepperweed), *Ceratocephala testiculata* (bur buttercup), *Bromus tectorum* (cheatgrass), *Sisymbrium altissimum* (tall tumble mustard), and *Agropyron cristatum* (crested wheatgrass) (Colket 2006).

Slickspots occur in areas scattered around the western U.S., but *L. papilliferum* is only found in slickspots within the sagebrush steppe of southwestern Idaho. This sagebrush steppe habitat is disappearing rapidly which contributes to habitat fragmentation and geographic isolation of the remaining populations of *L. papilliferum*. Urbanization, grazing, off-road vehicle use, invasion by non-native annual grasses, fire, and historic fire rehabilitation methods are all negatively impacting *L. papilliferum* (USFWS 2006). Historically slickspots were considered undesirable due to their low productivity and efforts were made to destroy them. While their destruction in grazing or agricultural landscapes has stopped, some slickspots are destroyed due to development. The possibility of creating new slickspots has not yet been explored, but seems unlikely.

Fire is detrimental to *L. papilliferum* in several ways. Sullivan and Nations (2008) also found *L. papilliferum* to be less abundant in slickspots that have been burned, and the decline was even greater the more times the slickspot was exposed to fire. The negative impacts of fire are thought to be related to habitat fragmentation, impacts of fire suppression tactics, changes in species composition due to wildfire rehabilitation, and the changing of the fire regime due to conversion of sagebrush steppe to annual grasses (Candidate Conservation Agreement for Slickspot Peppergrass 2003). Fire is a major factor in the change from an ecosystem dominated by sagebrush steppe to one dominated by annual grasses (Wiseman, 1990). Increasing urbanization, grazing, and off-road vehicle use are also contributors to the spread of non-native species. The conversion of sagebrush steppe to a habitat dominated by non-native species is widely cited in the literature as one of the main factors of the decline of *L. papilliferum*. Sullivan and Nations (2008) studied the common patterns between the various *L. papilliferum* populations being monitored by different federal entities. The presence and quantity of *B. tectorum* was found to have a consistently negative relationship with *L. papilliferum.* Another analysis of the long-term monitoring data did not however; find a connection between weedy annuals or fire, and populations of *L. papilliferum* (Menke and Kaye 2006). If this is the case, then invasive species and fire may be an indicator for some other related factor influencing populations of *L. papilliferum.*

Livestock use is thought to have negative effects on *L. papilliferum* (U.S. Fish and Wildlife Service 2006, U.S. Department of Agriculture, Federal Register 2002). Livestock use can disturb the structure of the slickspot soil through trampling (U.S. Fish and Wildlife Service), as well as add nutrients through feces deposition that encourages colonization by exotic species (Norton et al. 2007). Trampling may also result in seeds being buried deeper than is optimal, thus reducing germination (Meyer et al. 2005). Livestock are also associated with the spread of exotic species by transporting seed inside hooves or fur (Pyke 1999). There are multiple documented examples of slickspots containing *L. papilliferum* one year, experiencing a level of livestock trampling described as severe, and then having reduced or nonexistent numbers of *L. papilliferum the* next year (Meyer et al. 2005, Moseley 2004, Popovich 2001). However, some studies have not found trampling to have a negative effect on *L. papilliferum*. All of the available *L. papilliferum* monitoring data was compiled and analyzed (Sullivan and Nations in 2008), and there was no relationship found between livestock hoofprint cover and the number of *L. papilliferum.* Livestock grazing also has the potential benefit of reducing wildfire risk (Davies et al. 2010), which could counterbalance some negative impacts.

Chapter 2- Effects of trampling on *L. papilliferum.*

Introduction

Due to observed impacts of livestock trampling, as well as the documented negative effects of overgrazing in general, livestock use in slickspot areas is under continuous scrutiny. The 2003 Candidate Conservation Agreement (CCA) for Slickspot Peppergrass set a trigger point for additional management action when greater than 10% of an element occurrence (EO) has penetrating trampling. Penetrating trampling was originally defined as trampling that is deep enough to break through the restrictive clay layer of the slickspot. Sullivan and Nation later revised this definition to include hoofprints greater than 2.54 cm. An EO is an area that is inhabited by *L. papilliferum* currently or has been in the past, and has the characteristics of known *L. papilliferum* habitat. Ten percent was chosen as a trigger point due to the fact that it represented the high end of trampling disturbance documented under current grazing practices (Colket 2005). While the CCA identified management strategies and set trigger points to reduce the impacts of livestock trampling, the exact impacts are unknown.

Much of information available in about the effects of trampling on *L. papilliferum* is anecdotal or in the form of unpublished reports. In this study we attempt to isolate the effects of livestock trampling, at levels comparable to the trigger point set in the CCA. We will look at the effects of this trampling on the *L. papilliferum* population and the non-native plant populations inside the slickspots. The following hypotheses were examined:

Hypothesis 1- The physical disturbance caused by livestock trampling will negatively affect *L. papilliferum* by increasing the depth of seed burial, damaging seeds, and compacting the soil.

Hypothesis 2- Livestock trampling will increase the numbers of exotic annuals by disturbing the soil, thus changing the nutrient availability to conditions more favorable for these species.

Predictions-

If the above hypotheses are correct, then these predictions will be true.

1. The number *L. papilliferum* plants will be lower in slickspots subjected to the trampling treatment.
2. The number of exotic annuals will be greater in the treated slickspots.

Methods

This paper is the culmination of work done by multiple people over that last 10 years. Notably the site selection and development of the methods used in this project are the work of Jacob Young and Stephen Bunting, and are also documented in Young's thesis "Effects of Livestock Trampling on *Lepidium papilliferum*, Its Habitat and Subsequent Hydrology in Southwestern Idaho" (2007).

Site Selection

The geographical range of *L. papilliferum* is limited to the western part of the Snake River plain in southwestern Idaho. This study was focused on the portion of the *L. papilliferum* population found on the Owyhee plateau. The study sites were located in the area inside and surrounding the US Air Force Juniper Butte Range (JBR) in Owyhee County, Idaho (Figure 1).

The Owyhee Plateau is at an elevation of approximately 1500 m, with very little topographic relief in the study area. This area is characterized by hot dry summers and cold winters. The average annual precipitation for Owyhee County is 26.2 cm, (Natural Resources

Conservation Service 2003). The average temperature in this area is approximately -3º C in the winter, and 18º C in the summer (U.S. Department of Agriculture, Natural Resources Conservation Service 2003).

The majority of the site selection was conducted in May 2002. Possible sites were identified based on multiple criteria. All of the *L. papilliferum* populations documented by the Idaho Department of Fish and Game, Idaho Army National Guard, and the U.S. Air Force were included as potential study sites. Initial sites were chosen based on accessibility, the size of the *L. papilliferum* population, and the ability to exclude grazing from the sites. Three sites were selected in 2002- Airbase, Holding Pen Seeded, and Holding Pen Native. In 2004 the Three Creeks site was added.

The sites were located in areas that varied in surrounding vegetation due to some being more recently burned than others. The Three Creek site had been burned the most recently in 1996, followed by Holding Pen Seeded in 1992, and then Airbase in 1980. The Holding Pen Native site has no record of being burned although it is in close proximity to the burned area of the Holding Pen seeded site.

Twenty slickspots were selected for each site. An effort was made to select slickspots of similar size, arranged within similar topographic features, and with similar vegetation inside the slickspot and in the surrounding area. Only slickspots containing *L. papilliferum plants* and/or skeletons at the time of the site selection were selected in order to confirm the initial presence of *L. papilliferum* on each slickspot.

Treatment Application

For each site, ten slickspots were selected using random number simulation to receive the trampling treatment. The treatment was performed by repeatedly leading halter-broken cattle across the slickspot until there was approximately 10% hoofprint coverage by ocular estimation. This treatment level was chosen because it represents the high end of trampling values found by Colket (2005), and is an identified trigger point in the Slickspot Conservation Agreement (2003).

Treatments were imposed in April or May of each year from 2005-2010. The same slickspots were used as the treatment and the control during each treatment application. In late May or early June the percentage each slickspot to be covered by hoofprints was estimated and recorded, as well as the average hoofprint depth, and the maximum hoofprint depth.

Vegetation measurements

In May of 2003 and 2004 baseline vegetation measurements were taken both inside the slickspots and in the surrounding area. These baseline measurements were primarily used to confirm that there were no significant differences between the treatment and control plots prior to the beginning of the treatments. A Wilcoxon rank sum test performed on the baseline data for each site indicated no significant difference ($p>0.05$) in the amount of *L. papilliferum* present between the control plots and the ones scheduled for treatment.

In 2003-2006 vegetation data were collected for the upland areas surrounding the slickspots. Shrub cover was measured using the line intercept method (Canfield 1941). One 100-m line intercept transect was randomly placed in order to measure shrub cover and then the same transect was used when estimating percent cover by species as well as ground classifications. At each meter mark, the basal and canopy cover of each vegetation species, as well as the ground cover were measured inside a 50x50-cm quadrat. The ground cover was classified according to general categories of rock, bare ground, litter, and cryptogamic crust.

During the years in which the treatment occurred, the vegetation characteristics inside the slickspots were measured in late May or early June when *L. papilliferum* was at its reproductive maturity. Inside the slickspots a single linear transect was established at the longest point. Along this transect 25x50-cm quadrats were placed every 0.5 m and the vegetation density by species recorded. The percent cover, average hoofprint depth and maximum hoofprint depth were also estimated and recorded. Ten quadrats per slickspot were sampled. If the slickspot was less than 5 m in length, then adjustments were made to the placement of the quadrats in order to allow for 10 quadrats. This was done either by using both sides of the tape or the addition of a second transect. The number of rosettes and flowering *L. papilliferum* for each quadrat as well as the entire slickspot was recorded. Due to extremely small numbers of *L. papilliferum* recorded in the quadrats, the number of *L. papilliferum* were counted for the entire slickspot and these values were used in all statistical analyses.

Statistical Analysis

Due to the sensitive nature of the species under observation, and the importance of identifying any possible treatment effect, extra steps were taken to reduce the likelihood of a Type II error. These included setting α at 0.10 instead of the more traditional 0.05, and running a variety of tests to confirm the results. Due to the large percentage of zero values and the huge amount of variability in *L. papilliferum* numbers, the analysis techniques most commonly associated with a data set of this kind could not be used. A repeated measured analysis of variance (ANOVA) would have allowed all of the data to be incorporated into one test, but the normality requirement of the test could not be met. As a replacement a mixed effects ANOVA was used to test the effect of the treatment on the abundance of *L. papilliferum*. The influence of the site and the interaction between the site and the treatment were treated as covariates. In order to best fulfill the normality requirements of this test, the test was done separately for each year and then for all the years combined (Tables 1 and 2). This eliminated the year-to-year variability in the population, while still incorporating the large amount of variability between plots. For the tests on individual years, the *L. papilliferum* count for each slickspot was used. These numbers were then totaled for all the years to be used in the combined test. The *L. papilliferum* counts for individual years and all the years combined were transformed by adding 0.05 and then taking the natural log. The effect of the site was treated as a random effect in the test. Due to the fact that two out of the six years tested did not fulfill the normality requirements of the test, a nonparametric Monte Carlo test was also performed for each year in order to confirm the results.

The same mixed effects ANOVA was used to determine if the trampling treatment influenced the presence of exotic annuals. The most prominent exotic and native species present in the slickspots were tested. All of the species recorded were then divided into functional groups and incorporated into the mixed effects ANOVA in order to test whether the trampling treatment influenced exotic annuals, or any other functional group as a whole. All tests were conducted using SAS 9.2 (SAS Institute, Inc., Cary, NC, USA).

Results and Discussion

Treatment application

The treatment application methods were very similar for all the years, and the goal 8-10% of the total area of the slickspot trampled was met. The evidence of this trampling as it was recorded later in the spring was much more variable, and the mean trampling for the treated plots was lower than 8-10% at 7.1% (Figure 5). This number is smaller than the actual percentage of trampling that occurred during the treatment due to the amount of siltation that occurs between the time of the treatment application (April-May) and the recording of the treatment effect (June). The variation between years is likely caused by the variation in soil moisture at the time of the treatment applications each year, and the subsequent rainfall events causing siltation. The variation between sites and within sites is due to differences between slickspots. Slickspots soils can vary greatly in how long they stay wet after a rainfall, which greatly affects the depth of hoofprints as well as how much siltation occurs.

L. papilliferum

L. papilliferum displays characteristics typical of many annual species with a large amount of variability in the population both between individual plots, sites, and years. This high degree of variability, in combination with the fact that three of the four sites have shown a dramatic decline in the numbers of *L. papilliferum* over the course of the study, made determining the presence of a treatment effect difficult. The mixed effect ANOVA which tested the effect of the treatment on *L. papilliferum numbers* for each year individually resulted in p>0.10 during every year of the study. The mixed effect ANOVA which used the total *L. papilliferum* numbers for each slickspot for the entire study period resulted in p=0.4641. The Monte Carlo 2-sided exact p-test also resulted in p>0.10 for every year of the study. Of the 495 observations recorded during the treatment period, 200 observations included zero *L. papilliferum*. These zeros were fairly evenly distributed between treated (53%) and control (47%) plots. Overall, multiple methods of data analysis indicated that the trampling treatment did not have a significant effect on *L. papilliferum* abundance. *L. papilliferum* has decreased in abundance on three of the four sites studied, but this decrease is unrelated to the trampling treatment.

An effort was made to determine if there was a relationship between the number of *L. papilliferum* and the amount of shrub cover in the surrounding vegetation. The Holding Pen Native site consistently had the highest mean number of *L. papilliferum* per slickspot, as well as having the highest shrub cover in the area adjacent to the slickspots (20% *A. tridentata*). Both of the more recently burned sites with very low sagebrush cover (≤2%), had much lower numbers of *L. papilliferum*, particularly in the last four years of the study (Figure 6). The Airbase population remained consistently low for the entire study period with a yearly mean of 4-12 plants per slickspot. This is despite a relatively long time since burning and an overall shrub cover of 14% (7% *A. tridentata,* <1% *A. canescens,* 6% *C. visidifloris*).

Due to the long time period of *L. papilliferum* population data collected in this study, the somewhat conflicting results of other studies, and the large unexplained decline in the *L. papilliferum* numbers, it seemed appropriate to revisit the relationship between *L. papilliferum* numbers and spring precipitation. A linear regression was performed between the precipitation in February and March and the numbers of *L. papilliferum* by site. Other periods of spring precipitation such as April/May, and March/April/May/June were also examined. There was not a strong correlation between *L. papilliferum* numbers and precipitation for any of the growing season periods examined ($R^2<0.03$, Table 6). The presence of a relationship may have been overridden by the large decline in *L. papilliferum* numbers during the last years of the study.

Exotic Annuals and Functional Groups

The trampling treatment was also not found to have an effect on presence of exotic annuals. The four most prominent species found in the slickspots were tested to determine if the trampling treatment was influencing their abundance. Of these four species, *B. tectorum,* *C. testiculata,* and *L. perfoliatum* were exotic annuals. *Poa secunda* (Sandberg bluegrass) was the most dominant native species in the slickspots sampled. In addition to the individual species, the effect of the trampling treatment on functional groups as whole was examined. This was done by grouping the observations for individual species based on morphologic and physiologic traits. Of particular interest in this study was whether a plant was native or introduced. This led to the following categories: invasive annual, native annual, invasive perennial, native perennial, native shrub, and native graminoid. If a plant could fit into multiple categories, it was placed into the one that was most descriptive. For instance, a plant categorized as a perennial was one that did not fit into the graminoid or shrub category as well. Invasive annuals were the most prevalent functional group, followed by native graminoids. Trampling was not found to have an effect on any of these species, exotic annuals as a functional group, or the majority of the other functional groups. The only functional group that had a significant p-value (p=0.0332) was the native annuals. Both site and year appear to be significant factors, with only a couple of exceptions, in the abundance of both the species and functional groups analyzed (Table 5).

Suggestions for further study

In an effort to explain the sudden decline in *L. papilliferum,* the relationship between its abundance and that of other functional groups were examined. It was found that the abundance of *L. papilliferum* went down as the abundance of native graminoids increased. The majority of the increase in native graminoids can be attributed to a large increase in the amount of *P. secunda* found within the slickspots during the last few years of the study. It appears that about the time the *L. papilliferum* numbers began to decline, the *P. secunda* population began to steadily increase (Figure 7), and this trend continued until the end of the study. This trend did not hold true for the one site (Holding Pen Native) where *L. papilliferum* had not declined. This may indicate that the balance of competition had moved to favor *P. secunda* over *L. papilliferum.* Similar to the results of correlations between *L. papilliferum* and precipitation, the population trends of *P. secunda* could not be explained by a relationship with spring precipitation. The large increase in numbers of *P. secunda* could be related to the reduction in grazing pressure during the study period. The increase in numbers could be a result of seeding that occurred in the past as *P. secunda* is frequently included in the seeding mixes used after a fire, but the length of time that had passed between the time of seeding and this increase in *P. secunda* makes this unlikely. *P. secunda* has been observed to be very intolerant of salinity, poor drainage, and fine textured soils. All of these characteristics occur within slickspots. It would be interesting to further explore the apparent increase of *P. secunda* during conditions normally thought to be unfavorable, as well as the relationship between the two species.

While controlling the amount of trampling that occurs within a slickspot requires the treatment to be administered in a controlled fashion, the treatment methods used in this study may not have been representative of the type of trampling which negatively impacts *L. papilliferum,* or the trampling that occurs under standard grazing practices. Evidence has been found that if the hardpan layer is not penetrated and the soil disturbance is less than ~1 cm in depth then it most likely does not have an effect on the *L. papilliferum* seed bank (U.S. Fish and Wildlife Service 2006). In this study, the depth of the hoofprints was highly variable but averaged only 1.12 cm. The trampling impact in slickspots is highly variable depending on the soil moisture at the time of trampling (Figures 2 and 3). Because the treatment was not always administered immediately following precipitation events, the surface conditions of the slickspots varied greatly from year-to-year. In addition, the amount of rainfall that occurred between the treatment application and the time of sampling resulted in varying amounts of silt filling in the hoofprints (Figure 4). Thus the depth of the hoofprints varied widely both between sites and between years. A future study might make use of a controlled artificial rainfall event, such as could be administered by a sprinkler, to ensure a more consistent treatment application.

A slickspot also has the potential to be trampled multiple times in a single season with varying degrees of hoofprint coverage under typical grazing practices. In order to truly understand the significance of this study, we need to find out how much trampling occurs under the current grazing practices. It is important to find out both the amount of slickspot coverage that occurs, as well as how many times a slickspot is typically trampled. In the future it would also, be valuable to compare the abundance of *L. papilliferum* in slickspots within areas being managed according to the currently accepted grazing practices to slickspots within an exclosure.

Chapter 3- Effects of burning and seeding on soil moisture.

Introduction

Research on the effects of fire and invasive species on *L. papililferum* has been inconclusive. These variables may be secondary effects, rather the direct cause of *L. papilliferum* decline. One possible explanation is that the reduction of shrub cover in burned areas may be reducing the soil moisture. It has been documented that wind movement was 63% less, and evaporation was 28% higher at the soil surface in areas cleared of *Artemisia* spp. (sagebrush) as compared to areas with sagebrush (Robertson 1947). While in some landscapes the removal of shrubs and trees results in increased soil moisture due to decreased evapotranspiration, in sagebrush steppe the opposite is true. Several studies have found that there was decreased water recharge during winter and late spring in burned areas (Davies et al. 2007, Obrist et al. 2003). This is most likely due to decreased snow deposition, and an increase in transpiration due to greater herbaceous cover in burned areas.

Several studies have found some correlation between the numbers of seedlings each year and the amount of late winter/early spring precipitation (Sullivan and Nations 2008, Menke and Kaye 2006, Palazzo et al. 2005, Meyer et al. 2005). Meyer et al. (2005) also found a relationship between increased spring precipitation and the size of plant. They found that rosettes needed to reach a minimum size in order to set seed, and there was a relationship between the size of plant and the number of seeds, with larger plants setting more seeds. On the other hand studies have not found a correlation between the number of seedlings and spring precipitation (Sullivan and Nations 2008, Unnasch 2008). These contradictory results can be partially explained by the shorter time period under examination in some of the studies, but this lack of consistency indicates that other factors besides precipitation influence the number of *L. papilliferum* seedlings each year.

The silt loam surface layers of the slickspots dry before *L. papilliferum* plant have matured and set seed (Fischer et al. 1996). In order to survive the periods of low rainfall plants must extend a taproot into the argillic horizon before the slickspot surface dries (Fisher et al. 1996). Thus any reduction in spring soil moisture, such as may occur due to the removal of sagebrush due to fire, may reduce the ability of *L. papilliferum* plants to establish the taproot they need to survive to maturity.

Burning may indirectly affect soil strength by decreasing soil moisture. It has been shown that as soil moisture decreases, soil strength increases (Vepraskas 1984). Agricultural studies on *Triticum aestivum* L. (Hard Red Spring Wheat) seedlings have shown bulk density, aggregate size and penetration resistance to have an effect on the number of seedlings and the time to seedling emergence (Nasr and Selles 1995). Root elongation has been shown to be negatively correlated to penetration resistance (Bengough and Mullins 1991).

After a fire it is common practice to seed the burned area in an effort to reduce soil movement, hasten revegetation, and deter the establishment of nonnative species (Eisworth et al. 2009). Seeding has been found to have a positive effect on the surface soil morphological properties and plant cover in the interspace between slickspots, but does not appear to change either of these characteristics in the slickspots themselves (Hilty et al. 2003).

In this study we seek to find out more specifically how the burning and seeding effects the hydrology and soil characteristics of slickspots. The following hypotheses will be examined-

Hypothesis 1- The removal of the shrub canopy and reduction in ground cover surrounding a slickspot by fire will increase moisture loss due to evaporation, transpiration, sublimation, and reduce snow capture. This will reduce the time moisture is present on the soil surface and available for infiltration and result in decreased soil moisture.

Hypothesis 2- Reduced soil moisture in the slickspot soil will result in increased penetration resistance.

Predictions-

If the above hypotheses are correct, then these predictions will be true.

1. The average measured soil moisture will be lower in the treatment plots than in the unburned plots.
2. The amount of surface moisture will decline more quickly in the treatment plots than unburned plots after a precipitation event.
3. Soil strength will be higher in treatment plots, and will reduce taproot elongation.

Methods

Site Selection

This study was carried out in the area of the *L. papilliferum* population on the Owyhee Plateau. Due to the threatened nature of *L. papilliferum* slickspots were selected which were in close proximity (<1 km) to a known population, but not being occupied by *L. papilliferum.* In this way we hoped to sample slickspots representative of suitable habitat, without risk of damaging the population. The study sites were located in the southeast corner of Owyhee County, Idaho (Figure 1).

The Owyhee Plateau is at an elevation of approximately 1500 m, with very little topographic relief within the study area. This area is characterized by hot dry summers and cold winters. The average annual precipitation for Owyhee County is 26.2 cm, (Natural Resources Conservation Service 2003). The average temperature in this area is approximately -3º C in the winter, and 18º C in the summer (U.S. Department of Agriculture, Natural Resources Conservation Service 2003).

Fifty slickspots, 25 in a burned treatment area, and 25 in the unburned control area were selected. Slickspots located within the perimeter of the 2007 Murphy Complex fire were used for the treatment plots. The control plots were slickspots located within areas of unburned sagebrush habitat. The final selection criteria required that the slickspots were in an area not scheduled to be grazed during the time of the study in order to minimize disturbance to the monitoring equipment. In order to identify areas meeting all of these criteria, GIS layers that included known populations, the perimeter of the Murphy fire, and grazing allotment boundaries were obtained. By overlaying this information, prospective locations were chosen and then visited during the week of March 15-20, 2010 to verify their suitability. Three sites were then selected (Figure 1), and named according to the pasture they were located in. Ten control plots were located in the Mosquito Butte pasture, and 15 control plots were located in the South Clover pasture. All 25 treatment plots were located in the Rock Corral pasture. Each selected slickspot location was recorded using a handheld GPS (Table 3), and photographs were taken. The three sites were within 20 km of each other, all at similar elevations, and located within a large expanse of area with very little topographic relief. At each site the slickspots were grouped around data loggers. Each data logger was connected to 4-5 moisture sensors/slickspots within a radius of ~13 m.

Vegetation Measurements

For each slickspot, the percent ground cover was categorized and measured inside and outside the slickspot. Ground cover was categorized into the following functional groups: annual, perennial, shrub, litter, moss, and other. The "other" category included any other objects that less frequently covered the ground, such as rocks, feces, and ant mounds. In addition the line intercept method was used to estimate the shrub canopy cover outside the slickspots (Elzinga et al. 1998, Wilson 2009). From the visually estimated center of each slickspot, four transects were placed at random compass directions. Each transect started at the edge of the slickspot and extended 10 m from that point. If there was another slickspot immediately adjacent to the slickspot of interest, the transect started at the far edge of the adjacent slickspot. These same transects were then used for estimating ground cover outside the slickspot. Using the same method described above to determine the beginning of the transect, ground cover was estimated using 1x1-m quadrats spaced every 2 m on alternating sides of each transect. Inside the slickspots the percent cover was measured in ten 25x50-cm quadrats. To determine the location for the quadrats, the longest intercept of the slickspot was identified, and quadrats were places on alternating sides of the intercept for the length of the slickspot. Due to the large amount of variation in size and shape for slickspots, a system of adjustment was developed. If the slickspot was small enough to where the whole slickspot was sampled with less than 10 quadrats, then only that number of quadrats was used. Ground cover of vegetation and litter was visually estimated to the nearest 1% using the same functional group categories used outside the slickspots.

An EC-5 moisture sensor probe from Decagon Devices, Inc. was installed during the week of March 15-20, in the center of each slickspot. These sensors are 8.9 cm long by 1.8 cm wide. A small hole approximately 4 cm deep and 2 cm wide was dug, and the moistures sensors were inserted in the bottom of the hole vertically. The soil from the hole was replaced, and an effort was made to replicate the original bulk density of the soil. These sensors measured the volumetric moisture content (VMC) within a 5-cm layer of soil around the surface of the probe. As the seeds of *L. papilliferum* are known to germinate from very shallow depths of less than 3 mm (Meyer and Allen 2005), these sensors were thought to provide soil moisture information about the layer of soil most critical to germination and initial seedling growth for this plant. The probes were be connected to Em5b data loggers (Decagon Devices, Inc.), set to record VMC every hour, although in order to eliminate the diurnal variation in soil moisture only the average for each day was used in the analysis. At the time of installation, 10 soil samples were taken, one from each grouping of slickspots surrounding a data logger. Five were taken from burned slickspots and five from unburned slickspots, each containing approximately 200 g of soil. These were used for the calibration of the moisture sensors and textural analysis. Three separate additional samples were also taken from each grouping of slickspots for determining the bulk density of the soil. The bulk densities obtained were used during the calibration of the moisture sensors according to the methods outlined in Cobos (2006) (Figure 8).

The majority of the moisture sensors were removed during the beginning of June, 2010. The total ground cover inside and outside the slickspots was re-measured. The canopy cover outside the slickspots was also re-measured. The same bearings were used to place transects as were used in March. For some of the plots, heavy rain made transportation to the sites impossible and the steps described above were performed in July (21, 22). In July the penetration resistance was tested using a cone penetrometer. Ten readings were taken from each slickspot at random points inside the slickspot. The only criteria used when choosing these points were that the point not be closer than 10 cm from the edge of the slickspot, and not be placed on any gravel or debris that would block penetration into the soil.

Weather data were obtained for the period of time that the moisture sensors were in the ground from the weather station at Juniper Butte Range. The plots range from 2 to 25 km from the weather station at Juniper Butte Range.

Statistical Analysis

In order to test the first hypothesis, a difference in the vegetation cover between the control and the treatment area needed to be shown. The individual functional groups did not fulfill the normality requirement of a parametric test, so a non-parametric Mann-Whitney test was used. Mann-Whitney tests were used to determine whether there was a significant difference between the treated and untreated ground cover functional groups, shrub cover, and total cover. Next, a repeated measure ANOVA was performed in order to test the effect of the treatment on VMC. The ANOVA was used to test the significance of both the treatment and the time of data collection on the total vegetation cover.

The ten penetration resistance readings were averaged for each slickspot. A Mann-Whitney test was run to detect a treatment effect. All tests were performed using SAS 9.2.

Results and Discussion

Treatment Effect on Vegetation

Burning had a highly significant effect on both the total ground cover and shrub cover in the uplands surrounding the slickspots (Table 4). The unburned control plots had higher ground cover in both in the early spring before the growing season, and in the summer after the majority of the growth had occurred. The burned areas experienced a much larger increase in ground cover during the period the sensors were in place, due to growth of both annuals and perennials (14.6% increase in the burned vs. 2.5% increase in the unburned), but still had less cover overall. The specific upland cover types that showed the most change due to the treatment were the coverages of shrubs, moss, litter, and annuals (Table 5).

Burning had a much different effect on the vegetation inside the slickspots. In the spring, the total cover in the burned plots and the unburned plots were not different (Table 6). In the summer the burned slickspots had higher total ground cover ($p<.05$) than the control slickspots, which is the opposite effect as on the vegetation outside the slickspots (Table 5). The greater summer ground cover values inside the burned slickspots were associated with growth of the annual and perennial functional groups as well as small increases in litter and the "other" category. These increases were not statistically significant ($p>.05$) on their own, but when incorporated into the overall cover. The only individual functional groups to show an effect from burning ($p<0.05$) were moss and litter.

Treatment Effect On Soil Moisture

Although slickspots themselves have no shrub cover, the shrub cover in their surroundings has a definite effect on soil moisture within the slickspots. The soil moisture in the burned plots was consistently below the soil moisture in the unburned plots ($p< 0.0001$) for the entire study period (Figure 9). The sagebrush canopy also had a moderating effect on the soil moisture, resulting in less drying between rains and a smaller spike in VMC after a rain. The unburned plots experienced less overall variability in VMC over time. This results in a greater difference between the pre-rain VMC and the post-rain VMC in the burned plots (Figure 10). This moderating effect is most likely due to moisture interception in the canopy during a rain, and less evaporation between rains in the unburned areas.

The overall reduction in VMC in the top 10 cm of soil that was observed in the burned areas can most likely be attributed to increased evaporation due to increased wind speeds. The moisture sensors in this study were installed after the bulk of the snowfall was past in this area, but if the precipitation came in the form of snow, one explanation would be that sagebrush canopies have been observed to trap more snow than burned areas (Obrist et al. 2004). The burned areas may also experience greater sublimation than the unburned areas due the increased wind exposure. In addition, the slightly higher transpiration that occurs in the burned slickspots due to the higher vegetative cover (7.8% burned, 4.3% unburned) may also contribute to the lower VMC in burned areas.

The penetration resistance was not found to be greater in the burned plots. The results of the t-test showed the penetration resistance to be significantly higher in the unburned plot (p=0.0058). It is worth noting that during the spring, livestock heavily impacted 10 of the 25 unburned slickspots. An additional t-test shows those 10 slickspots to have greater penetration resistance than the 15 un-impacted slickspots (p=0.0011), and if only the un-impacted slickspots are compared to the burned slickspots there is no difference in the penetration resistance (p=0.2675).

Suggestions for Future Study

One of the obvious and critical shortcomings of this study is that it could not be conducted in slickspots inhabited by *L. papilliferum.* The higher, more consistent levels of soil moisture found in slickspots in unburned areas may be more favorable to the germination and growth of *L. papilliferum* seedlings. This higher soil moisture may extend satisfactory growing conditions further into the spring/summer. A longer growing season may allow the rosettes to reach a larger size, which has been tied to an increased likelihood of flowering (Meyer et al. 2005). Another study that incorporated the use of the moisture sensors into inhabited slickspots would allow much more information to be gathered as the actual effect of the increased moisture levels on the plant.

Robertson (1947) found that temperatures around sagebrush were higher in the spring encouraging earlier snowmelt. He also found that the grasses in these areas started growing about two weeks earlier in the spring than grasses not interspersed with sagebrush. It would be interesting to investigate whether *L. papilliferum* is similarly delayed when growing in areas recently burned.

It would also be interesting to extend the length of time that the moisture sensors are in place. Another study of this nature (Obrist et al. 2004) found that the difference in soil moisture between burned and unburned areas disappears as the spring rains quit and the soils begin to dry. In this study the moisture sensors were removed before the soil at the depth of the probes had started to dry due to summer drought. It would be interesting to determine how long the burned areas continue to have higher VMC, and how that time period correlates to the growing season for *L. papilliferum.*

In any additional study looking at this subject, it would be good to increase the amount of variables examined. Soil nutrients and structure would also affect the growth of *L. papilliferum* and it is impossible to conclusively identify the effect of soil moisture without looking at those variables as well.

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Table 1- P-values resulting from repeated measures mixed effects ANOVA for 2005-2010 determining effect of trampling treatment on quadrat densities of prominent species and functional groups.

Species or functional group	P-value
Certocephala testiculata	0.1033
Lepidium perfoliatum	0.3086
Bromus tectorum	0.8107
Poa secunda	0.2269
Invasive annual	0.2850
Invasive perennial	0.7750
Native graminoid	0.9278
Native annual	0.0308
Native perennial forb	0.9905
Unknown	0.1491

Table 2- R^2 values from linear regression between precipitation and *L. papilliferum* numbers between 2003 and 2010.

Date	Three Creeks	Airbase	Holding Pen Native	Holding Pen Seeded
February/ March	0.0054	0.0407	0.0714	0.0777
April/May	0.0018	0.0080	0.2518	0.1753
March/April/May/June	0.0060	0.0088	0.2794	0.1312

Table 3- Site names, coordinates, and elevations for the moisture sensor sites.

Site Name	Coordinates (UTM Zone 11)		Elevation (m)
Mosquito Butte	640460	4681478	1625
South Clover	634464	4682261	1623
Rock Corral	627458	4670604	1665

Table 4- Results from ANOVA showing the effect of burning on percent shrub and total cover.

	Spring total cover	Summer total cover	Shrub cover
Burned	25.4	40.0	0.0
Control	52.5	55.3	16.8
p-value	<0.0001	<0.0001	<0.0001

Table 5- Exterior ground cover (%) by functional group and associated p-values from the ANOVA.

		Moss	**Perennial**	**Litter**	**Other**	**Annual**	**Total cover**
Spring	Burned	0.0	18.3	5.9	1.2	0.0	25.4
	Unburned	17.4	19.7	15.2	0.2	0.0	52.5
	p-value	<0.0001	0.1812	<0.0001	<0.0001		<0.0001
		Moss	**Perennial**	**Litter**	**Other**	**Annual**	**Total cover**
Summer	Burned	0	23.9	6.8	1.6	7.6	40.0
	Unburned	18.7	15.0	20.8	0.1	0.6	55.3
	p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table 6- Interior slickspot ground cover (%) by functional group and associated p-values from the ANOVA. (No annuals or forbs were recorded during spring)

		Moss	Perennial	Litter	Other	Total cover		
Spring	Burned	0.0	3.4	0.9	1.3	5.7		
	Unburned	0.58	3.8	0.4	0.5	5.2		
	p-value	<0.0001	0.1479	0.0054	0.1543	0.4762		
		Moss	**Perennial**	**Litter**	**Other**	**Annual**	**Forb**	**Total cover**
Summer	Burned	0.1	5.6	1.3	2.3	2.1	0.1	11.4
	Unburned	0.3	3.5	0.7	0.9	0.3	0.2	5.9
	p-value	0.0120	0.0567	0.0870	0.0925	0.1339	0.0599	0.0008

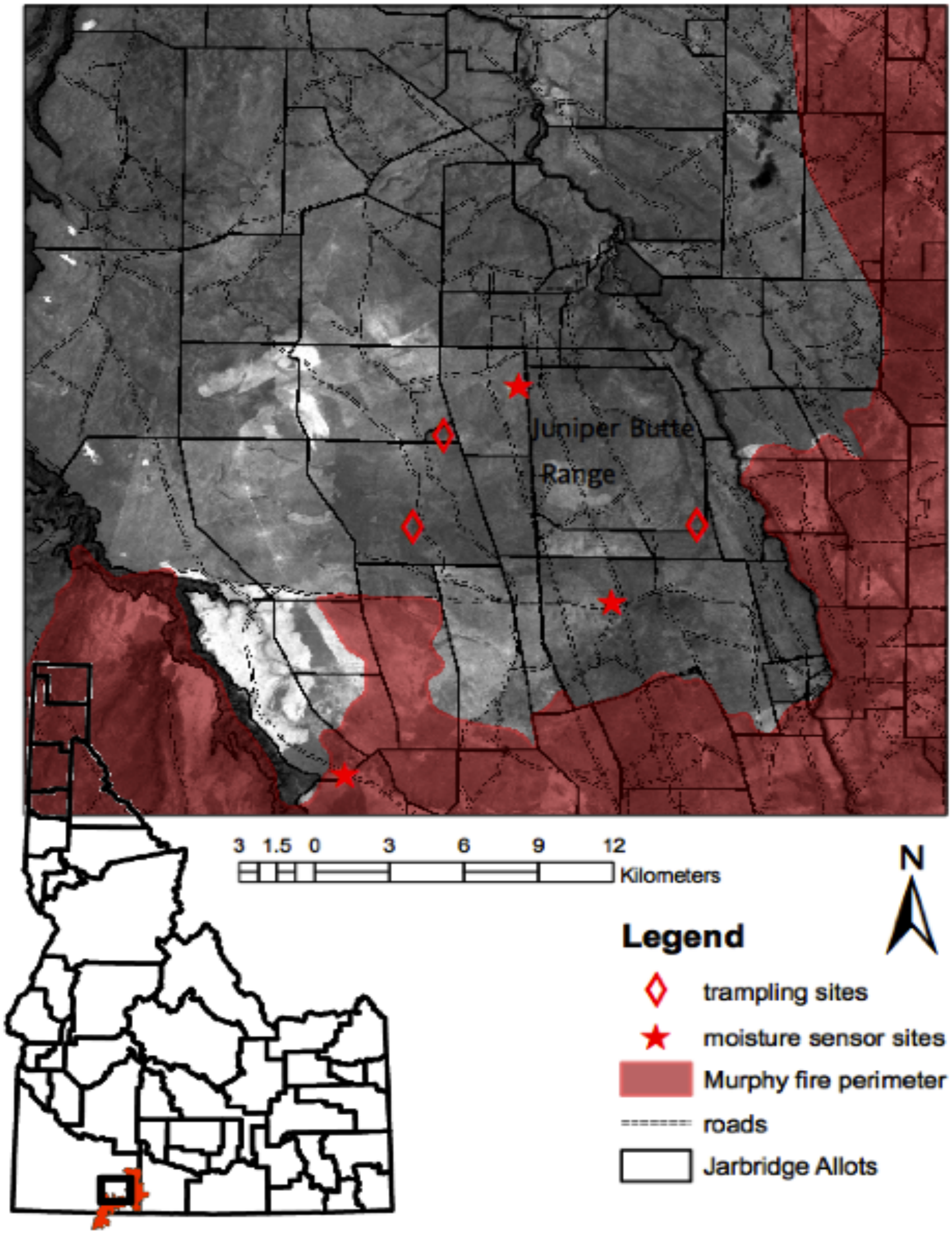

Figure 1-Location of the study area and sites in the southeastern corner of Owyhee County, Idaho.

Figure 2- Photo taken at the time of treatment application. Example of hoofprint depth that can occur when moisture is low in a slickspot. (Photograph courtesy of Jacob Young)

Figure 3- Photo taken at the time of treatment application. Example of hoofprint depth that occurs when moisture is present in the slickspot. (Photograph courtesy of Jacob Young)

Figure 4- This is the same view as in Figure 3 at the time of sampling. Precipitation between the time of the treatment and sampling caused the hoofprints to be almost completely silted in. (Photograph courtesy of Jacob Young)

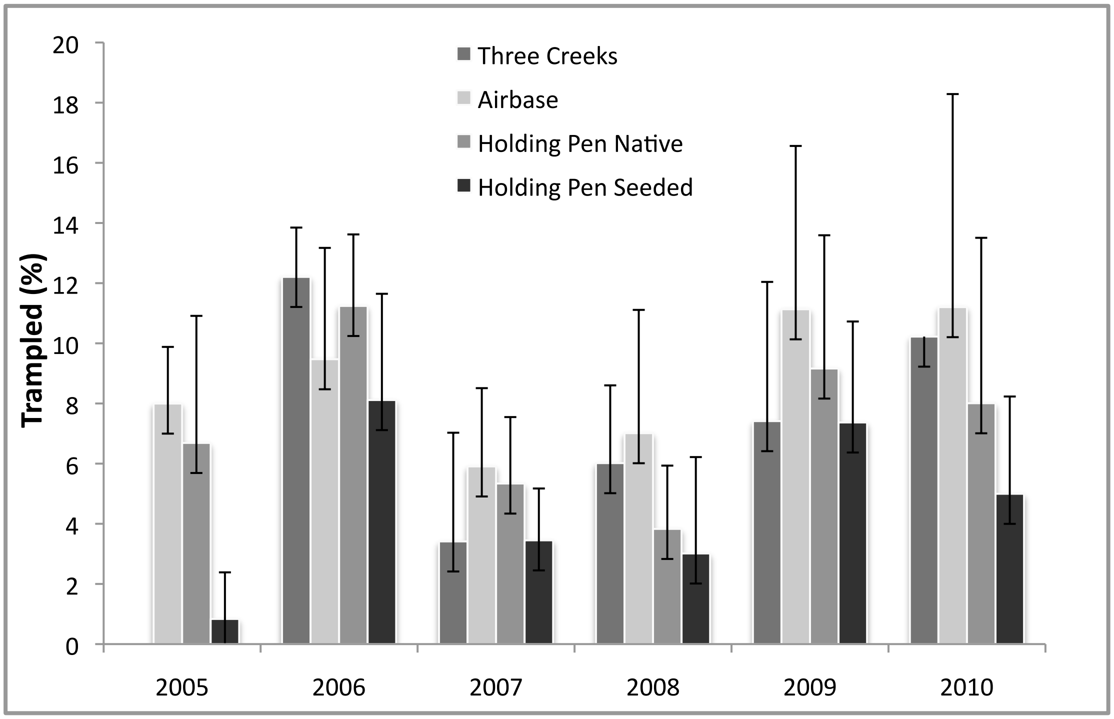

Figure 5- Percent coverage of trampling evidence and standard deviation as recorded in late May/early June.

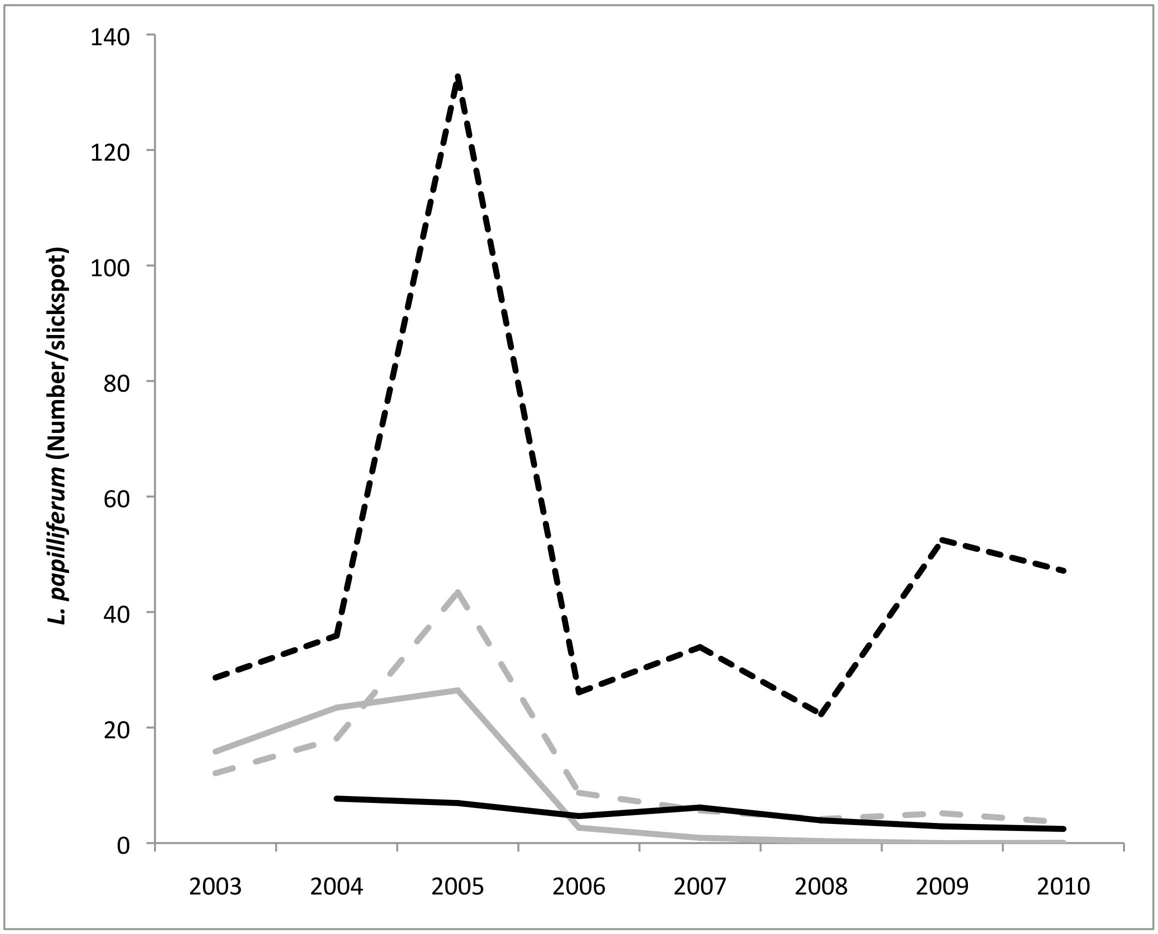

Figure 6- Mean *L. papilliferum* numbers per slickspot. H.P. Seeded (black dashes), H.P. Native (grey dashes), Three Creeks (grey line), and Airbase (black line).

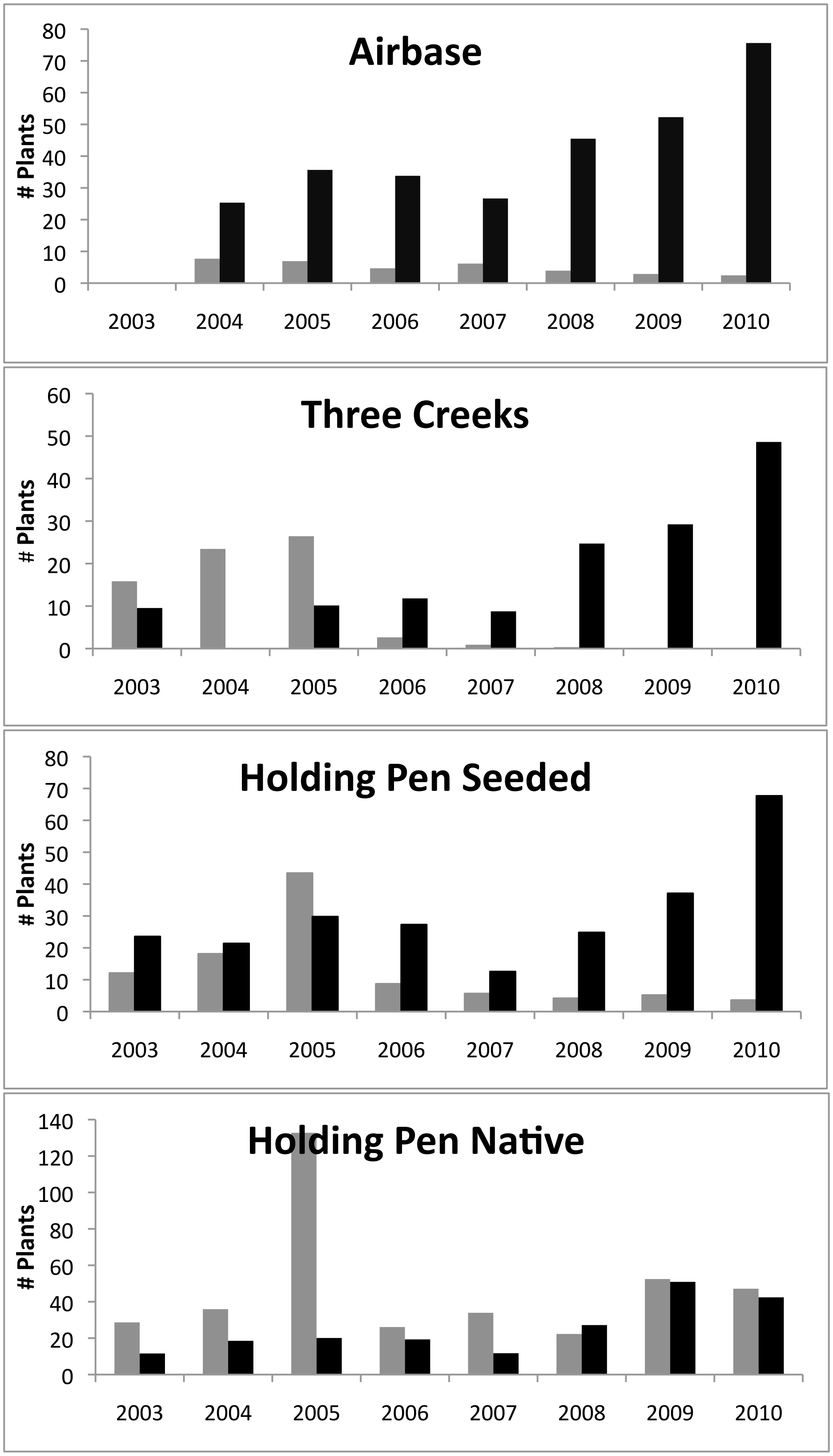

Figure 7- Mean slickspot numbers of *L. papilliferum* (grey) and *P. secunda* (black) by year.

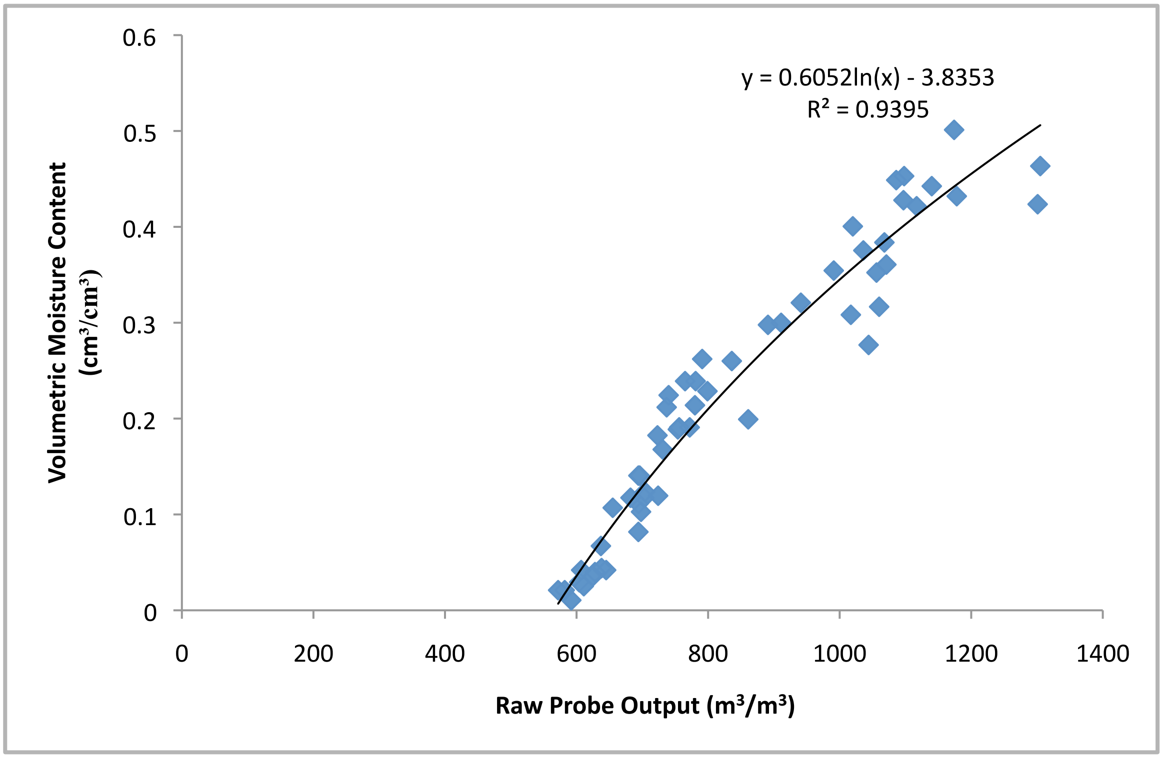

Figure 8- The raw probe outputs plotted against the known VMC in order to obtain a soil specific calibration function.

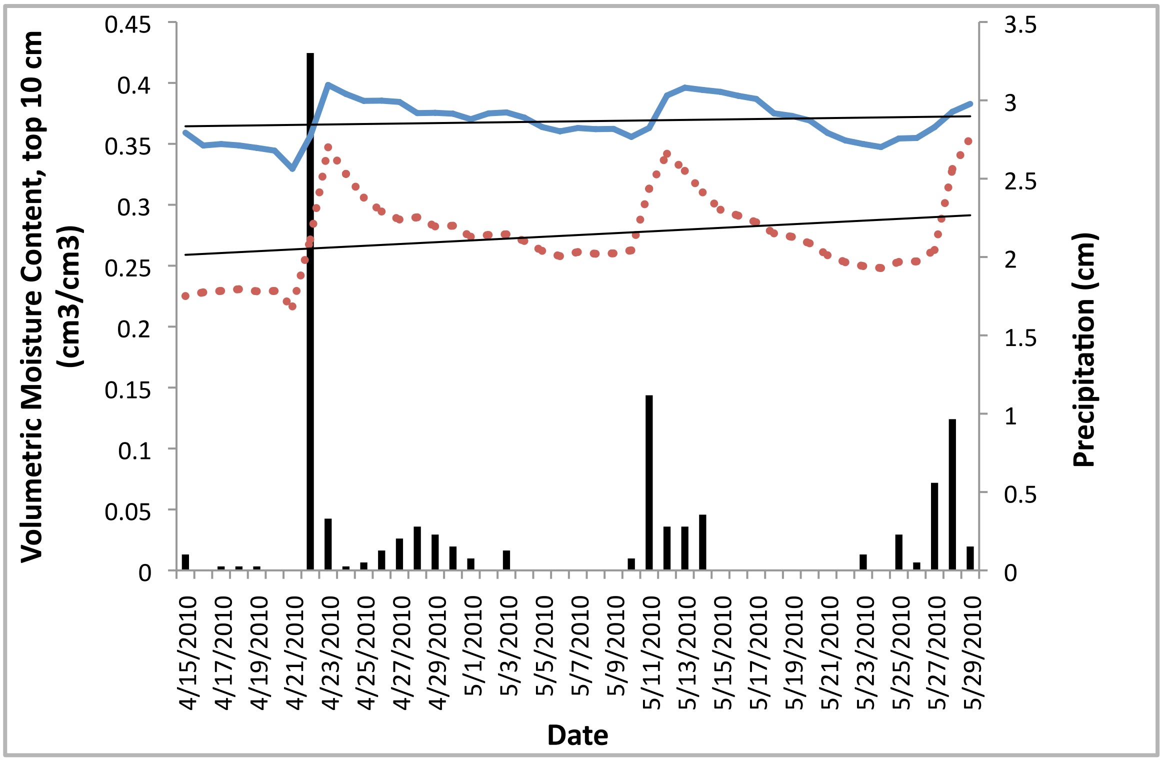

Figure 9- Mean soil moisture per day (blue line=unburned, red dotted line=burned), plotted with total precipitation per day (black bars) obtained from the JBR weather station.

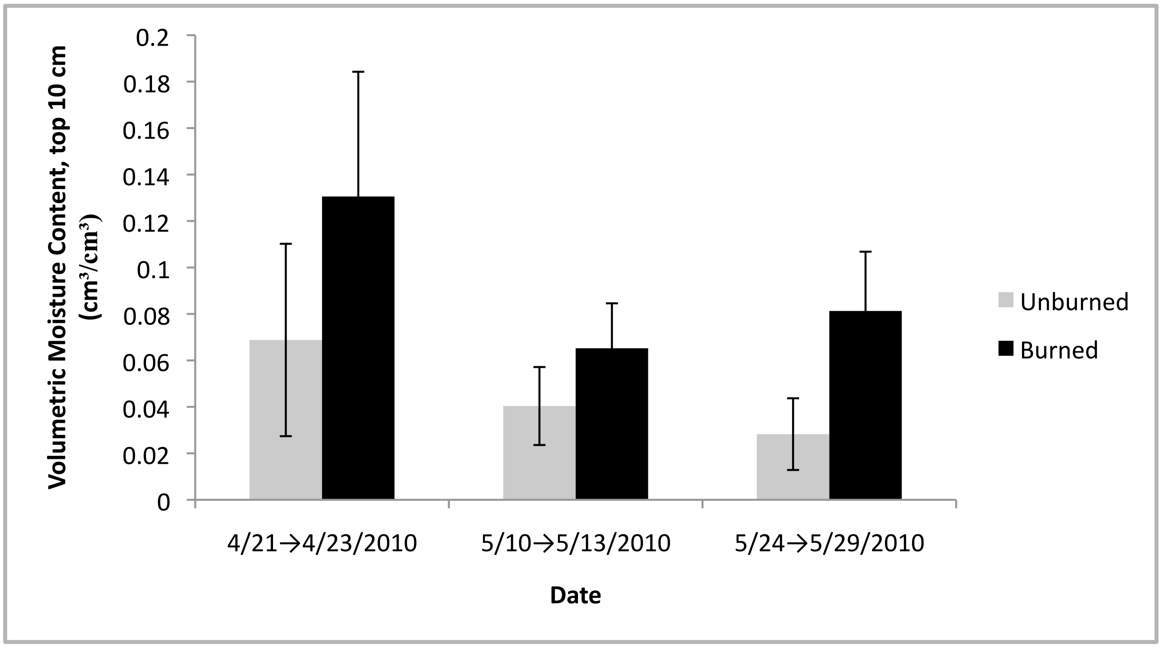

Figure 10- Mean change between the VMC before precipitation and after precipitation in the burned (black) and unburned (grey) areas for three specific precipitation events. The change in VMC was significantly different ($p<.05$) between the burned and unburned sites for all three rain events.

Appendix A: List of plants found on the sites sampled.

Symbol	Common name	Scientific name
ACHY	Indian ricegrass	*Achnatherum hymenoides*
AGCR	Crested wheatgrass	*Agropyron cristatum*
AGDA	Thickspike wheatgrass	*Elymus lanceolatus*
AGDE	Desert wheatgrass	*Agropyron desertorum*
AGIN	Intermediate wheatgrass	*Agropyron intermedium*
AGOSE	False-dandelion	*Agoseris* spp.
ALLIU	Onion	*Alliums* spp.
ANRA	Raceme pussytoes	*Antennaria racemosa*
ANRO	Rose angelica	*Angelica roseana*
ANTEN	Pussytoes	*Antennaria* spp.
ARTR	Wyoming big sagebrush	*Artemisia tridentata* ssp. *wyomingensis*
ASCR	Pallid milkweed	*Asclepias cryptoceras,*
ASPU	Milkvetch	*Astralagus puniceus,*
ATCA	Fourwing saltbush	*Atriplex canescens*
ATSP	Spinescale saltbush	*Atriplex spinifera,*
BRTE	Cheatgrass	*Bromus tectorum*
CACH	Desert paintbrush	*Castelleja chromosa*
CETE	Bur buttercup	*Certocephala testiculata*
CHNA	Rubber rabbitbrush	*Ericameria nauseosus,*
CHVI	Yellow rabbitbrush	*Chrysothamnus viscidflorus,*
COPA	Maiden blue eyed Mary	*Collinsia parviflora*
CRAC	Tapertip hawksbeard	*Crepis acuminata*
CRYPT	Cryptantha	*Cryptantha* spp.
DELPH	Larkspur	*Delphinium* spp.
DEPI	Tansymustard	*Descurainia paradisa*
DRVE	Spring draba	*Draba verna,*
EPCI	Willow-weed	*Epilobium ciliatum*
HAGL	Saltlover	*Halogeton glomeratus,*
HECO	Needle-and-thread	*Hesperostipa comata*
LASE	Prickly lettuce	*Lactuca serriola,*
LEPE	Clasping leaf pepperweed	*Lepidium perfoliatum*
LILE	Blue flax	*Linum lewisii*
LOGR	King desert-parsley	*Lomatium graveolens*
LOMAT	Desert-parsley	*Lomatium,* nonnative
MATE	Tansy aster	*Machaeranthera tanacetifolia*
MEDIC	alfalfa	*Medicago* spp.
PENST	Penstemon	*Penstemon* spp.
PHHO	Spiny phlox	*Phlox hoodii*
PHLO	Llongleaf phlox	*Phlox longifolia*
POSE	Sandberg bluegrass	*Poa secunda*
PSSP	Bluebunch wheatgrass	*Pseudoroegneria spicata*
SATR	Prickly Russian thistle	*Salsola tragus*
SCAN	Nose skullcap	*Scutelleria antirrhinoides*
ELEL	Squirreltail	*Elymus elymoides*
STCI	Chicoryleaf wirelettuce	*Stephanomeria chichoriacea*
SIAL	Tall tumble mustard	*Sisymbrium altissimum*
STELL	Starwort	Stellaria spp.
STTH	Thurber’s wirelettuce	*Stephanomeria thurberi,*
TOWN	Townsend daisy	*Townsendia* sp.
VUOC	Sixweeks fescue	*Vulpia octoflora*