OREGON DEPARTMENT OF AGRICULTURE

NATIVE PLANT CONSERVATION PROGRAM

Astragalus peckii disturbance ecology study 2008 Final Report

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for
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Table of Contents

Introduction

Ecology. *Astragalus peckii* is a tufted, taprooted perennial endemic to the pumice and ash based soils prevalent throughout central Oregon (Figure 1). These soils have unique thermal properties such as low heat storage, a large temperature response to added heat at the soil surface, and shallow penetration of significant temperature variation. The lack of heat storage in these soils allows soil surface temperatures to rise quickly during warm days, and to become very low at night, even during the summer (Carlson 1979). These harsh temperature extremes, combined with the exceptionally good drainage and very low fertility of pumice based soils, creates an inhospitable environment for most plants. These characteristics are responsible for the barren pumice flats and frost pockets that occur throughout this region. Severe frost heaving is also characteristic of pumice soils, and the disturbance caused by this phenomenon contributes further to the lack of floral colonization of open pumice sites. However, a few plant species, such as *Botrychium pumicola* and *Astragalus peckii,* manage to survive in these extreme environments.

Throughout its range, *Astragalus peckii* is usually found in barren openings in juniper/sagebrush communities or in openings in lodgepole pine forests. Although few other plants inhabit these inhospitable microsites, *A. peckii* overcomes the limitations of the dry, exposed soils in these sites in several ways. Plants produce long fleshy tap-roots, which allow them to extract moisture from the lower reaches of deep soils and provide a reservoir from which to re-emerge following damage due to cold weather or drought. These roots also help anchor plants in place in the loose soil and prevent uprooting during frost heaves. The small, pubescent leaves prevent moisture loss and protect the plant from exposure to wind and sun. Plants also occur in the forest ecotone and occasionally beneath forest canopy; associated species include *Purshia tridentata, Artemisia tridentata, Leptodactylon pungens, Eriophyllum lanatum, Chaenactis douglasii, Festuca idahoensis, Sitanion hystrix, Phacelia hastata, Linum perenne, Bromus tectorum, Ericameria nauseosa, Gayophytum diffusum, Ericameria viscidiflora, Astragalus purshii, Mimulus nana, Agropyron spicatum, Eriogonum umbellatum, Lupinus lepidus* var. *aridus, Achillea millefolium, Gilia congesta, Madia minima, Blepharipappus scaber, Poa secunda, Layia glandulosa, Achnatherum occidentalis, Orobanche corymbosa,* and *Nama densum.*

Figure 1. Reddish stems are characteristic of large plants of *Astragalus peckii* in the Fremont-Winema Forest sites. This individual is producing both flowers and fruits. (Photo by Melissa Carr.)

Distribution. *Astragalus peckii* was thought to be extinct until rediscovered in Deschutes County near Sisters in 1980 (Meinke 1982), and is now known from approximately 40 populations ranging from Sisters south to Chiloquin. The far northern end of the species's range is represented by two historic collections northeast of Sisters that have not recently been relocated, with the majority of populations listed by the Oregon Natural Heritage Program (~30) occurring in a cluster centered southeast of Sisters near Tumalo Dam (ONHP 2001). Many of the populations in this northern group are large, covering many acres, and consisting of hundreds of thousands of plants, while others are quite small, with 10-100 plants occurring within a few square meters of habitat. These population groups probably originally made up a contiguous, interbreeding meta-population that has subsequently been fragmented by roads, agriculture and residential development.

Several scattered large populations also occur along Highway 97 near LaPine, Chemult, and

Cresent, with another un-relocated historic collection reported from a site near Odell Lake. Several new sites have been discovered during recent surveys in the Chemult area, and the potential for locating other currently unknown sites exists. The southern end of the species's range is represented by one large and two smaller populations located southeast of Chiloquin.

Threats. *Astragalus peckii* is threatened by development in privately owned sites near the fast-growing cities of Bend and Sisters, and by grazing, off-road vehicle activity, and logging on National Forest (NF) and Bureau of Land Management (BLM) lands. Despite the potential toxicity of most species of "loco-weed," cattle have been shown to extensively graze *Astragalus* spp., especially in the absence of more palatable forage (Majak et al. 1996). Although inherently of low density, pumice soils can be compacted by off-road vehicle use and logging (Allbrook 1986), and compacted soil has been shown experimentally to reduce taproot growth and drought tolerance in field grown *Astragalus* spp. (Wahiduzzaman et al. 1999).

Although exotic weeds are not currently a problem in most sites, the Chiloquin site supports a large population of *Elytrigia intermedia.* The effect of this potentially invasive grass on populations of *A. peckii* is not known. Insect herbivory and seed predation threaten other rare plants in Oregon (Gisler and Meinke 1995); the observed herbivory by lepidopteran larvae should be evaluated as a potential threat to viability of *A. peckii*. Fire suppression may also be considered a threat. Fire reduces canopy cover and competing understory vegetation in juniper, ponderosa, and lodgepole forests, and this reduced competition may benefit *Astragalus peckii*, although the long term effect of fire, or lack of fire, on this species is not yet clear. Due to these threats, *Astragalus peckii* is listed as Threatened by the Oregon Department of Agriculture and as a Species of Concern by the US Fish and Wildlife Service.

Previous research. Previous research on this species includes a demographic study focusing on the northern populations (Kagan 1992; R. Halvorson BLM, personal communication), a limited reproductive ecology study on five legume species including *A. peckii* (Gisler and Meinke 2001), and a multi-site evaluation of plant habit, bloom time, herbivory and predation, and seed production completed in 2002 (Amsberry and Meinke 2003). Data from these previous studies were used to develop a study plan for the current disturbance ecology project.

Study Objective

The objective of this multi-year study is to evaluate the effects of various types of disturbance on plant growth, reproduction, and recruitment in a series of populations of *Astragalus peckii*. Populations represent the geographic and ecological range of the species, and disturbance treatments simulate the potential effects of various management regimes.

Methods

Study sites. In 2002, after consultation with BLM and Fremont-Winema National Forest (FWNF) botanists, five sites were selected for inclusion in the project. These populations were selected based on number of plants, general vigor, and ease of access, and represent the geographic and ecological range of the species (Table 1; Appendices A-C). The Innes Market Road (IMR), Brandywine Drive (BWD), and Kohfield Road (KR) sites, all east of Sisters on Highway 20, are owned by Prineville District BLM; the IMR population was also included in the 2002 life history evaluation study. On the Fremont-Winema NF, both the Chiloquin and 86 Road populations were monitored in the 2002 study.

Table 1. Characteristics of our five study sites.

Population	Habitat Type	Ownership	Population Group
IMR	barren opening in juniper/sagebrush; associated vegetation sparse	BLM (Prineville)	northern
KR	among large, dense sagebrush; few immediately adjacent conifers	BLM (Prineville)	northern
BWD	among bitterbrush and junipers; associated vegetation sparse	BLM (Prineville)	northern
86 Road	in barren opening in lodgepole stand; associated vegetation sparse	Fremont-Winema NF	intermediate
Chiloquin	at ecotone of ponderosa forest and large meadow; associated vegetation sparse to moderately dense	Fremont-Winema NF	southern

Burning. In late June 2003, a set of ten plots (each plot one m^2 in size) at each site was delineated, identified with metal tags, and assigned to the burning treatment. To insure that all plots contained plants of *Astragalus peckii*, plot locations were selected arbitrarily, but in an unbiased manner. Ten plots approximately similar in plant composition, soils, associated vegetation, etc. were selected in a control area (which remained unburned). Each plot was staked with rebar on two corners to allow for accurate placement of the monitoring frame and was identified by a metal tag or a painted plastic stake (for unburned plots only). At all sites, plot location and placement was accomplished with input from BLM and USFS botanists and/or fire specialists. Each plot was photographed with a digital camera from a specified point; all images were downloaded and cataloged at OSU in preparation for analysis (Figure 2A).

At the Chiloquin, 86 Road, and KR sites, plots to be burned were clustered in a 1-2 acre treatment zone, with burning scheduled to occur throughout these designated areas. Control plots were clustered in an adjacent unburned area. Due to low fuel loads at the IMR and BWD sites, a large scale fire was not feasible and plots were burned individually. Extra fuel in the form of dry vegetation present in the site was added to plots that had been selected for burning; these plots were interspersed with unburned control plots. On October 23, 2003, burning was completed by Kirk Metzger and a USFS fire crew at the KR (large scale fire; Appendix D), IMR (individual plots), and BWD (individual plots) sites.

The 86 Road site (Chemult Ranger District) was burned in fall of 2004. Vandalism at the 86 Road site in late 2003 damaged plot markers; plots in this site were relocated and re-staked prior to burning. Plots at the Chemult site did not carry the fire well, with only one plot impacted ("singed on one edge"), and the rest left "unscathed". Due to the basically unchanged condition of the plots, post-fire photographs were not taken in this site (Kathy Cushman, Botanist, Chemult Ranger District, personal communication on 10/13/2004). Plots at the Chiloquin site were also burned in fall 2004, although these plots were likewise minimally contacted by the fire.

ATV disturbance treatment (BLM). At the IMR, KR, and BWD sites, all plants within ten 1 m^2 plots were disturbed by directed, but "realistic" ORV use in July 2004. Ten control plots (approximately paired with treated plots for number of plants, plant sizes, associated vegetation and soils) remained untreated. To insure that all plots contained plants of *Astragalus peckii*, plot locations were selected arbitrarily, but in an unbiased manner. Each plot was staked with plastic stakes on two corners for accurate monitoring frame placement, and was identified with a metal tag.

Sarah Schartz (Prineville BLM) implemented the disturbance treatment by riding a motorcycle through each plot. Motorcycle action was regulated, with the goal of producing a consistent impact in each plot, and was similar to the observed impact of ORV use in sites within the Prineville District. Plots were photographed immediately before treatment (Figure 3A), and immediately after (Figure 3B).

Logging disturbance treatment (FWNF). At the Chiloquin and 86 Road sites, disturbance was created by dragging a log through each plot. Again, our goal was to produce a consistent and realistic effect throughout the plots in each site. Plots were photographed before (Figure 4A) and after (Figure 4B) treatment implementation in July 2004.

Shading removal. At all sites in July 2004, the above ground vegetation of adjacent shrubs within ten 1 m^2 plots was removed with pruners at ground level to reduce shading, and plot photos were taken before and after (Figure 5, A and B). A paired set of control plots was left untreated.

Biomass removal. At each site, all *A. peckii* plants within ten 1 m^2 plots had approximately 50% of their biomass mechanically removed by clipping with pruners in July 2004. Before and after treatment photos were taken of each plot (Figure 6, A and B). Ten control plots (approximately paired with treated plots for number of plants, plant sizes, etc.) remained untreated.

Monitoring. In summer 2004, in addition to the before and after photos detailed above, photographs were taken of each of the burned plots and unburned control plots at the three BLM study sites (IMR, BWD, and KR; Figure 2B). The number of flowering plants and the total number of plants within each plot were also recorded at the IMR and BWD sites at this time. These data were obtained for comparison with the initial pre-treatment data collected in 2003 to complete a first-year analysis of the effects of the prescribed burns at these sites.

All plots at all five sites in the study were photographed again in June 2005 (C in Figures 2-6), June 2006 (D in Figures 2-6), August 2006, June 2007 (E in Figures 2-6), and June 2008 (F in Figures 2-6). Numbers of flowering plants and total numbers of plants per plot were collected for all plots in June and August 2005, June and August 2006, June 2007, and June 2008. In addition, the percentage of webbing observed on *A. peckii* plants due to lepidopteran activity was recorded in August 2005 for all treatment groups.

Photoplot analysis. A subset of photos from the disturbance treatment photoplot image series was intensively analyzed using SigmaScan Pro 5.0 image overlay features (Systat Software, Inc.). With a computer mouse tool, the program user delineated all individual *Astragalus peckii* plants, or portions of plants, excluding small seedlings, located within the plot frame for each photo examined (Figure 7). The plot area was defined in each image by tracing the inner perimeter of the plot frame. SigmaScan measurement outputs of the plot area and the area occupied by *A. peckii* plants (in terms of numbers of pixels) for each photoplot analyzed were copied to an Excel database in which percent cover values were calculated and statistical analyses of the data were performed.

Due to the time- and labor-intensive nature of *A. peckii* cover analysis using SigmaScan as detailed above, comprehensive analyses of the disturbance, shade removal, and biomass removal treatments implemented in 2004 for all sites were based on numbers of flowering plants per plot. In order to fill gaps in field-collected flowering plant data for 2004 disturbance, shade removal, and biomass removal plots at all sites, and for 2004 burn and control plots at the KR site, we opened each appropriate archived plot image in Adobe Photoshop CS (Adobe Systems Incorporated) and counted the number of flowering *Astragalus peckii* plants observed within each plot photo. Counts were combined with field-collected flowering plant data from the other study years in an Excel database for analysis.

Percent cover methods comparison (2008). In light of the difficulties encountered when using the SigmaScan Pro image analysis package to quantify *Astragalus peckii* cover within photoplots, a methods comparison was performed in 2008. Two additional methods for determining percent cover, field estimation and digital image estimation, were compared with SigmaScan cover analysis. Thirty study plots, each containing at least one flowering *A. peckii* plant, were selected from the IMR and BWD sites to use in the comparison. Each of the three methods was used to assess the percent cover (to the nearest percent) of the area of influence of *A. peckii* within each plot selected for the comparison. The area of influence was envisioned as a rough circle around each individual plant, with the perimeter of the circle touching the outermost points of the plant, such that the area of influence encompassed the entire plant and small portions of the area surrounding it.

Percent cover estimates of *A. peckii* were made in the field during the 2008 monitoring trip when plot photos were taken. As a reference, one percent of the meter-squared plot frame was found to approximately equal the area of a clenched fist. For each plot, field estimates of cover were made by the consensus of two data-collectors.

Percent cover estimates were made in the lab using Adobe Photoshop CS to view digital images of the selected plots captured in 2008. Maps of the plots that were made in the field were used as a reference for locating *A. peckii* plants in the plot images due to the difficulty in distinguishing *A. peckii* from other species that also occur within the plots. The percent cover of *A. peckii* in each plot was then estimated from the image by "eyeballing it." As with the field estimates, digital image cover estimates were made by the consensus of two data-collectors.

SigmaScan measurements of the percent of *A. peckii* cover in each of the thirty plots selected for the methods comparison were made using the same image overlay process described in the preceding *photoplot analysis* section. However, the generalized area of influence of *A. peckii* plants was delineated for the methods comparison, rather than a precise outline of the plants. As with the digital image cover estimation method, plot maps created in the field were used as an aid for distinguishing *A. peckii* plants in plot photos for the SigmaScan analysis.

A. Before 2003 burn treatment.

B. Summer 2004, first year after burn.

C. Summer 2005, second year after burn.

D. Summer 2006, third year after burn.

E. Summer 2007, fourth year after burn.

F. Summer 2008, fifth year after burn.

Figure 2. Burned Plot 5-07 photo series from 2003 (pre-treatment) to 2008 (BLM-KR site). *Lupinus lepidus* did not occur in this plot prior to burning. (Photo A and F by Melissa Carr, Photo B by Katie Mitchell, Photo C by ODA staff, Photos D and E by Elizabeth Martin.)

A. Before 2004 ATV disturbance treatment.

B. Immediately after disturbance treatment; plant fragments visible in upper right.

C. Summer 2005, one year after disturbance.

D. Summer 2006, two years after disturbance.

E. Summer 2007, three years after disturbance.

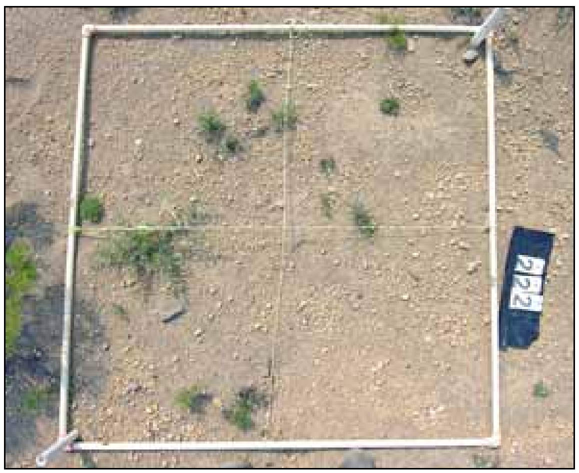
F. Summer 2008, four years after disturbance.

Figure 3. ATV Disturbance Plot 3-25 photo series from 2004 (pre-treatment) to 2008 (BLM-IMR site). (Photos A and B by Katie Mitchell, Photo C by ODA staff, Photos D and E by Elizabeth Martin, Photo F by Melissa Carr.)

A. Before 2004 logging disturbance treatment.

B. Immediately after disturbance treatment.

C. Summer 2005, one year after treatment.



D. Summer 2006, two years after treatment.

E. Summer 2007, three years after treatment.

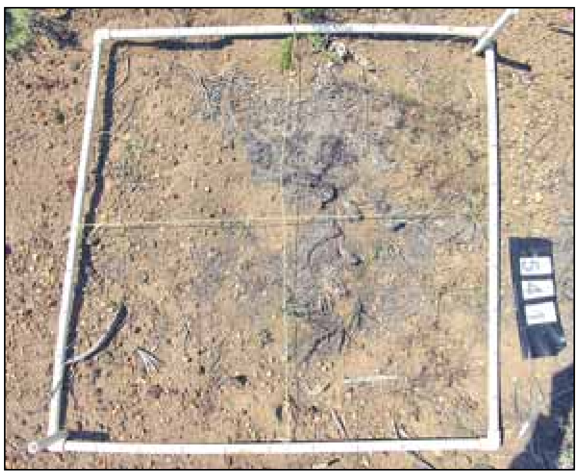
F. Summer 2008, four years after treatment.

Figure 4. Logging Disturbance Plot 2-22 photo series from 2004 (pre-treatment) to 2008 (FWNF-86 Road site). (Photos A and B by Jesse Smith, Photo C by ODA staff, Photos D and E by Elizabeth Martin, Photo F by Melissa Carr.)

A. Before 2004 shade removal treatment.

B. Immediately after treatment.

C. Summer 2005, one year after treatment.



D. Summer 2006, two years after treatment.

E. Summer 2007, three years after treatment.

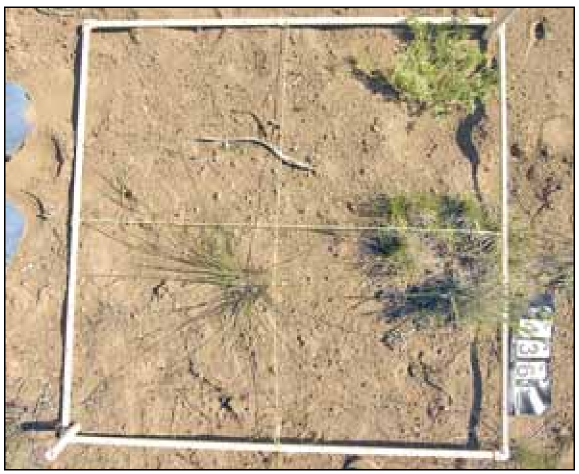
F. Summer 2008, four years after treatment.

Figure 5. Shade Removal Plot 5-41 photo series from 2004 (pre-treatment) to 2008 (BLM-KR site). (Photos A and B by Katie Mitchell, Photo C by ODA staff, Photos D and E by Elizabeth Martin, Photo F by Melissa Carr.)

A. Before 2004 biomass removal treatment.

B. Immediately after biomass removal.

C. Summer 2005, one year after treatment.



D. Summer 2006, two years after treatment.

E. Summer 2007, three years after treatment.

F. Summer 2008, four years after treatment.

Figure 6. Biomass Removal Plot 4-36 photo series from 2004 (pre-treatment) to 2008 (BLM-BWD site). (Photos A, B, and C by ODA staff, Photo D by Stephen Meyers, Photo E by Elizabeth Martin, Photo F by Melissa Carr.)

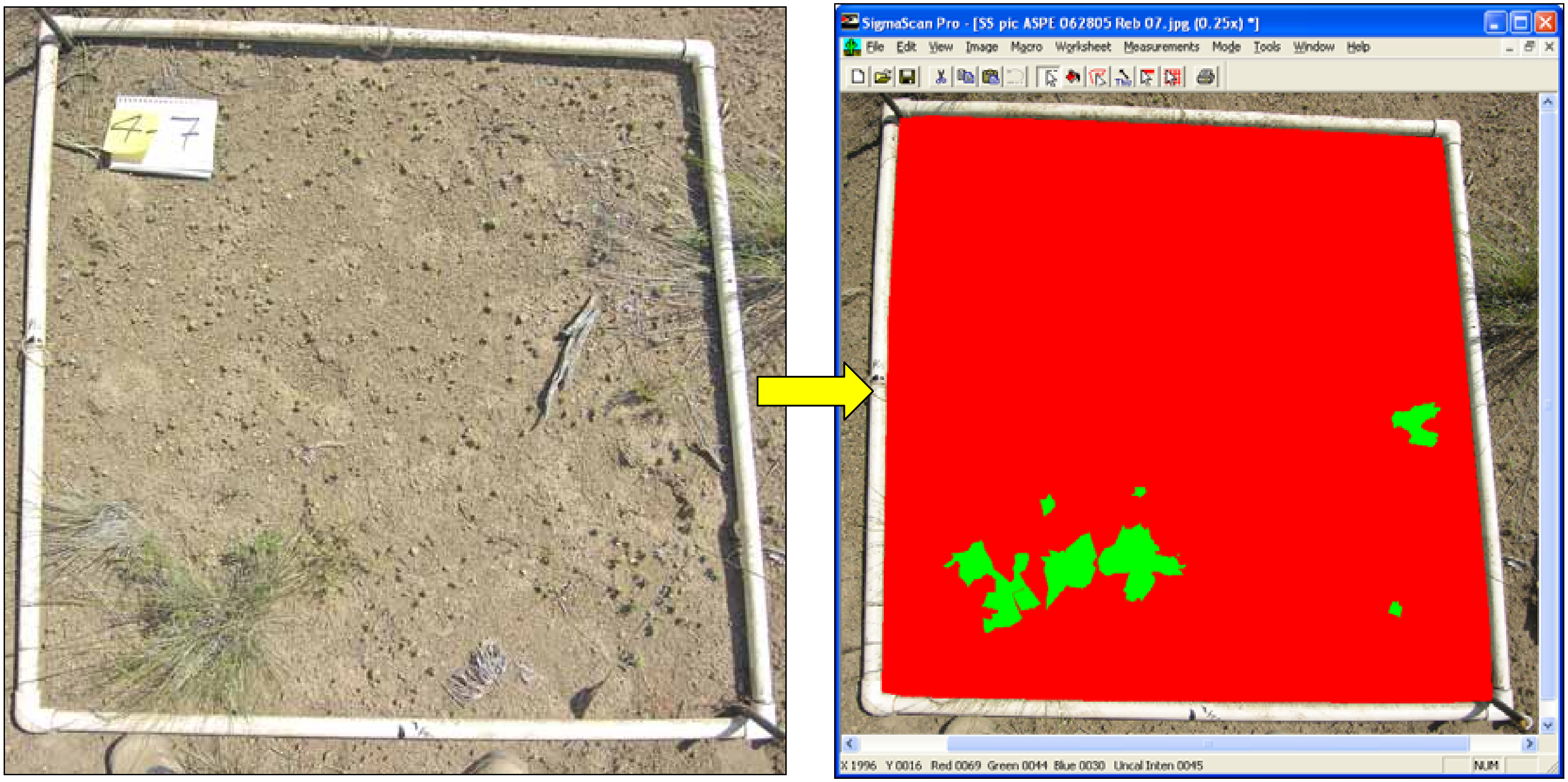


Figure 7. SigmaScan analysis of BLM-BWD Plot 4-7. The digital plot image (left) was opened in SigmaScan, where the plot area (red overlay) and the area covered by *Astragalus peckii* plants (green overlay) were delineated by the program user with a computer mouse tool (right).

Results

Burning

Burn—2004. First-year observations of the burned plots and unburned control plots at the IMR, BWD, and KR sites were made in 2004. The mean number of plants/plot at the BLM sites increased in 2004, when compared to 2003 pre-treatment data (Figure 8), and the proportion of plants flowering decreased. ANOVA analyses completed for the first-year progress report (Amsberry and Meinke 2005) indicated that burning did not significantly affect the mean number of total plants/plot or the mean number of flowering plants/plot at these sites ($p > 0.10$ in all sites). However, two-sample t-tests of the BLM study plots indicate a significant difference between burned plots and control plots at the BWD site in terms of the change in total numbers of plants/plot one year after treatment (2003-2004; $p = 0.055$; Table 2), with an average increase of 1.4 ± 1.6 plants/plot in burned plots and an average decrease of 0.9 ± 3.1 plants/plot in control plots. No such difference in mean plant density change between treatment and control groups was indicated by analysis of data from the IMR site, and 2004 plant density data was unavailable for KR. Additional two-sample t-tests indicate a significant difference in change in flowering plant numbers between burned and control plots at the KR site one year after treatment (2003-2004; $p = 0.042$; Table 2), with an average decrease of 0.9 ± 1.5 flowering plants/plot in burned plots and an average increase of 0.4 ± 1.1 flowering plants/plot in unburned plots. Similar analyses indicate no such differences in flowering plant density change at either the IMR or BWD sites ($p > 0.10$ for both sites; Table 2). Species composition changed in the burned area at KR, with a noticeable increase in the number of plants of *Lupinus lepidis* in many plots (Figure 2).

Burn—2005. Plant density data collected in 2003 (pre-burn) and 2005 were analyzed with a block design using PROC MIXED in SAS (SAS Institute). BLM and Fremont-Winema NF sites were examined separately due to the difference in burn times between these groups of sites. Results for the BLM sites indicate a greater increase in plant density in the burned plots than in the unburned control plots two years after the prescribed burns ($F_{1,2} = 40.3$, $p = 0.02$). There was an average increase of 4.3 ± 4.5 plants/plot in the burned plots and an average increase of 0.8 ± 4.5 plants/plot in the unburned control plots at these sites. There was no significant difference in plant density changes between burned plots and unburned control plots at the Fremont-Winema NF sites one year after the 2004 prescribed burns ($F_{1,1} = 0.08$, $p = 0.8$). At these two sites there was an average increase of 2.2 ± 39.5 plants/plot in the burned plots and an average increase of 1.4 ± 39.5 plants/plot in the control plots. Burned treatment groups at all five study sites experienced increases in mean plant density from 2003 to 2005, while only two of the unburned control groups (Chiloquin and KR) experienced increases in mean plant density (See Figure 8 for BLM site results).

Data from each of the three BLM sites were also analyzed individually using t-tests to assess changes in plant density from 2003 (pre-burn) to 2005 in burned plots and unburned control plots (Table 2). In addition, t-tests were used to compare changes in numbers of flowering plants per plot in burned and unburned control plots at each of these sites (Table 2). For the IMR and KR sites, results indicate there is no significant difference between burned plots and unburned plots in terms of either total plant density changes or changes in numbers of flowering plants in the two years following the prescribed burns ($p > 0.10$ for each test). However, at the BWD site, statistical analysis of the change in plant density from 2003 to 2005 indicates a significant difference between the burned plots and unburned control plots ($p = 0.041$). Burned plots at this site exhibited an increase in mean plant density (3.6 ± 4.2 plants/plot), while unburned control plots exhibited a slight decrease in mean plant density (-0.8 ± 4.8 plants/plot). As with the other two BLM sites, there was no significant difference between the burned and unburned groups in terms of changes in flowering plant numbers in the two years following the prescribed burns ($p = 0.103$). There was a small average decrease of 0.5 ± 1.1 flowering plants/plot in the burned plots and an average decrease of 1.7 ± 1.9 flowering plants/plot in the unburned control plots at this site. See Figure 9 for all BWD plot averages to date.

Similarly, data from each of the Fremont-Winema NF sites were analyzed individually using t-tests to assess changes in plant density occurring from 2004 (pre-burn) to 2005. There was no significant difference in plant density changes between burned plots and unburned control plots at either the Chiloquin or the 86 Road site in the first year after the prescribed burns ($p > 0.10$ for each).

Burn—2006. BLM sites were analyzed individually using two-sample t-tests to assess changes in plant density from 2003 (pre-burn) to 2006 in burned plots and unburned control plots, as well as to compare changes in numbers of flowering plants per plot in burned plots and unburned control plots within this period (Table 2). As in 2005, the only significant difference between burned and unburned groups in 2006 was observed at the BWD site where analysis indicates a significant difference in the change in total plant numbers per plot in burned versus unburned plots in the three years following the burn treatment ($p = 0.036$). There was an average increase of 6.3 ± 7.2 plants/plot in burned plots and an average decrease of 0.5 ± 6.2 plants/plot in unburned plots from 2003-2006 (Figure 8).

Burned treatment groups at the BWD and KR sites continued to exhibit higher mean plant densities in 2006 than in 2003 before treatment; BWD burned plots exhibited the highest average plant density on record in 2006, while KR burned plot densities were lower on average in 2006 than in 2005 and were only slightly above the pre-treatment density. In 2006, the mean plant density of the burned group at the IMR site dropped below the pre-treatment density.

Burn—2007. To evaluate changes in both total plant density and numbers of flowering plants per plot in burned and control plots from 2003 (pre-burn) to 2007, BLM sites were analyzed individually using two-sample t-tests. As in 2005 and 2006, the only statistically significant differences between burned and unburned groups occurred at the BWD site. Analysis indicates that four years after the burn treatment, there was still a possible difference in the total number of plants per plot in burned versus unburned plots, though evidence is weaker than in previous years ($p = 0.073$). There was an average increase of 2.1 ± 4.6 plants/plot in burned plots and an average decrease of 2.4 ± 5.8 plants/plot in unburned plots. Additionally, analysis indicates a weak significant difference in the number of flowering plants per plot between burned and unburned groups four years after burning ($p = 0.075$). There was a mean decrease of 0.9 ± 1.4 flowering plants/plot in the burned group and a mean decrease of 2.6 ± 2.4 flowering plants/plot in the control group from 2003 to 2007. Differences in flowering plant numbers between disturbance and control groups were not significant in previous years at the BWD site.

In 2007, as in previous years, burned treatment groups at the BWD and KR sites exhibited higher mean plant densities than in 2003 before the burn, while control groups at both of these sites exhibited lower mean plant densities in 2007 than in 2003. The 2007 mean plant densities of both the burned and unburned groups at BWD decreased from those observed in 2006, when record high mean plant density was observed for the burned group. The 2007 mean plant density of burned plots at IMR was slightly less than the pre-burn density (0.11 ± 4.8 plants/plot fewer), while mean plant density for the IMR control group in 2007 increased from pre-burn levels (2.3 ± 12.4 plants/plot greater).

Burn—2008. BLM sites were analyzed individually using two-sample t-tests to assess plant density changes from 2003 (pre-burn) to 2008 in burned plots and unburned control plots, as well as to compare changes in numbers of flowering plants per plot in burned and unburned plots within this period (Table 2). In 2008, for the fifth year in a row since the prescribed fire, the burned treatment group at the BWD site exhibited a higher mean plant density than in 2003 before burning (1.9 ± 4.7 plants/plot greater), while the control group at this site maintained a mean plant density below that observed prior to treatment (1.3 ± 6.0 plants/plot fewer). However, statistical analyses indicate no significant difference between burned and unburned plots in terms of changes in either total plant density or flowering plant numbers at either BWD or IMR ($p > 0.10$ for both analyses at both sites). This is the first year since annual post-burn monitoring was begun in 2004 that no significant difference was indicated by the change in total plant density between burned and unburned plots at BWD.

Surprisingly, the 2008 data do indicate a significant difference in total plant density between burned and unburned plots at the KR site for the first time since burning occurred ($p = 0.039$; Table 2). Note, however, that no 2004 plant density data is available for KR, so total plant density differences between plots at this site in the first year following the burn are unknown. There was an average decrease of 0.5 ± 2.2 plants/plot in burned plots at KR and an average increase of 3.1 ± 4.5 plants/plot in unburned plots from 2003-2008. In 2008, the burned group at the KR site had a mean plant density slightly lower than the pretreatment density for the first year on record, while the mean plant density of the control group increased prominently from below pre-treatment levels in 2007 to a level well above the pre-treatment plant density. The 2008 data also indicate a significant difference between burned and unburned plots at KR in terms of changes in the number of flowering plants per plot five years after the burn ($p = 0.049$; Table 2). There was an average decrease of 1.8 ± 0.79 flowering plants/plot in burned plots, and an average decrease of 0.5 ± 1.7 plants/plot in unburned plots. The only other year in which a significant difference in terms of the change in flowering plant numbers between burned and unburned plots was detected at KR was the first year following the fire.

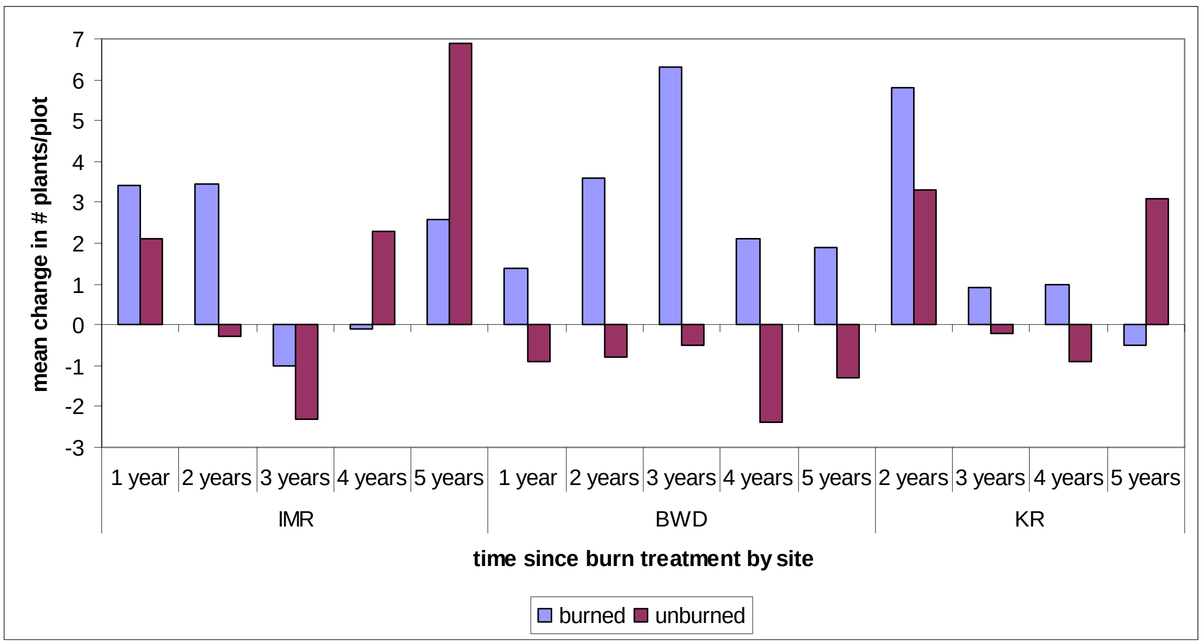


Figure 8. Mean change in plant density for burned and unburned groups at each BLM study site one, two, three, four, and five years after burning (first-year post-treatment data unavailable for KR site). ($n = 10$ plots/treatment at each site except IMR where $n = 9$ plots/treatment for the burn group from the second through fourth years after burning and where $n = 7$ plots/treatment for the burn group and $n = 9$ plots/treatment for the unburned group in the fifth year.)

Table 2. P-values for two-sample t-tests comparing the change in number of flowering plants per plot in burned and unburned control groups and the change in total plant numbers per plot in burned and control groups one year after treatment (2003-2004), two years after treatment (2003-2005), three years after treatment (2003-2006), four years after treatment (2003-2007), and five years after treatment (2003-2008) at each BLM study site. Values significant within a 90% confidence level are boldfaced. Total numbers of plants per plot were not recorded for the KR site in 2004. (n = 10 plots/treatment at each site except IMR where n = 9 plots/treatment for the burn group from the second through fourth years after burning and where n = 7 plots/treatment for the burn group and n = 9 plots/treatment for the unburned group in the fifth year.)

	1 Year After Burn		**2 Years After Burn**		**3 Years After Burn**		**4 Years After Burn**		**5 Years After Burn**	
	Δ # plants flowered/plot	**Δ total # plants/plot**	**Δ # plants flowered/plot**	**Δ total # plants/plot**	**Δ # plants flowered/plot**	**Δ total # plants/plot**	**Δ # plants flowered/plot**	**Δ total # plants/plot**	**Δ # plants flowered/plot**	**Δ total # plants/plot**
IMR (3)	0.333	0.761	0.286	0.226	0.443	0.417	0.700	0.579	0.753	0.319
BWD (4)	1.000	**0.055**	0.103	**0.041**	0.161	**0.036**	**0.075**	**0.073**	0.173	0.204
KR (5)	**0.042**	----	0.528	0.306	0.257	0.457	0.412	0.182	**0.049**	**0.039**

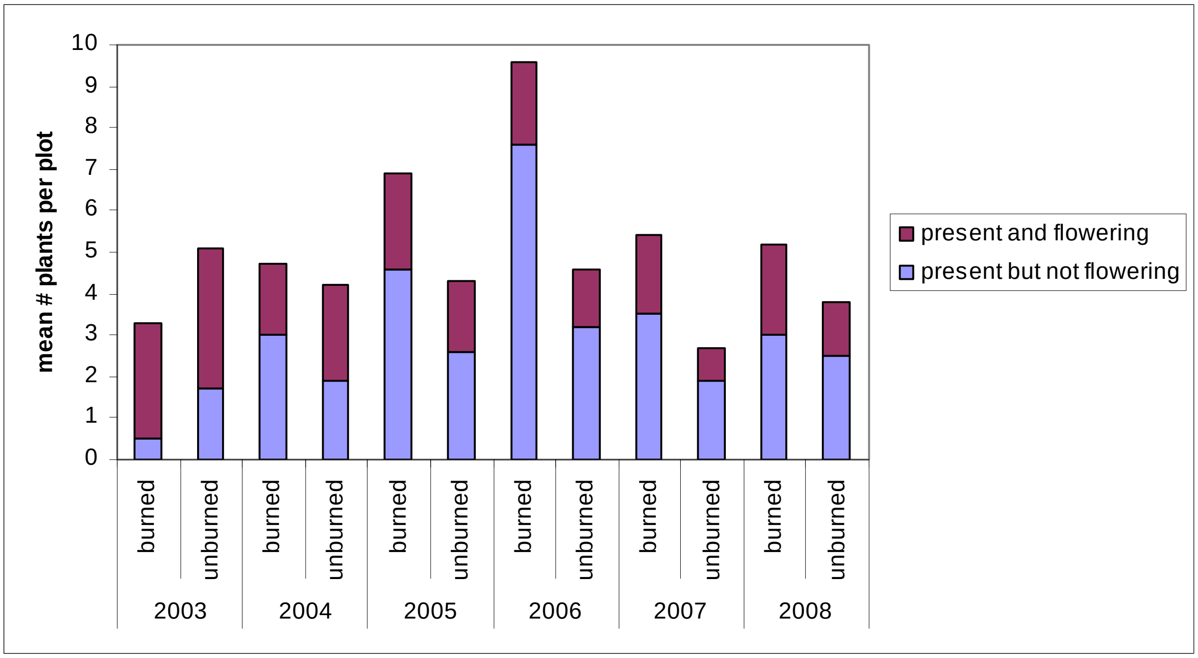


Figure 9. Mean plant densities depicting proportions of flowering and vegetative plants per plot for burned and unburned plots at the BLM BWD site from 2003 (pre-burn) to 2008. (n = 10 plots/treatment for each year.)

Disturbance. Two-sample t-tests were used to compare disturbance (ATV at BLM sites, logging at FWNF sites) and control plots at each individual study site based on the change in number of flowering plants per plot since 2004, just prior to treatment (Table 3). No difference between ATV disturbance and control groups was detected in the first year of the study ($p > 0.10$ for each site). However, 2006 data indicate a significant difference between ATV disturbance and control groups at the IMR site two years after treatment ($p = 0.037$), with a slight average decrease of 0.3 ± 1.4 flowering plants/plot in disturbance plots and a greater decrease of 1.9 ± 1.7 flowering plants/plot in control plots after two years. In 2007, differences between disturbance and control plots at the IMR site remained statistically significant ($p = 0.032$). In the three years following the disturbance treatment, there was an average decrease of 0.5 ± 1.3 flowering plants/plot in disturbance plots, and a larger decrease of 2.2 ± 1.8 flowering plants/plot in control plots at IMR. Data indicate no significant difference between ATV disturbance and control groups at the other two BLM sites in 2007 ($p > 0.10$ for both sites). In 2008, four years after treatment, no significant difference between ATV disturbance and control groups was indicated at any of the three BLM sites ($p > 0.10$ for each site).

The 86 Road site is the only site at which analysis indicates a possible difference between "logging" disturbance and control groups in 2005, one year following treatment, though the evidence is weak ($p = 0.078$). There was an average increase of 3.9 ± 3.9 flowering plants/plot in disturbed plots and a smaller increase of 0.6 ± 4.0 flowering plants/plot in control plots during the first year after treatment at 86 Road. No significant difference was discernable at either "logging" disturbance site in 2006, 2007, or 2008 ($p > 0.10$ for both sites each year).

Several types of statistical analyses based on *Astragalus* cover were performed. However, these were limited to data from the disturbance and control groups at the IMR and BWD sites for 2004 and 2005 collected as part of a feasibility study into use of SigmaScan software to obtain *Astragalus* cover measurements from digital plot photos. Based on two-sample t-tests, there was no significant difference between disturbance and control groups in terms of change in percent cover of *Astragalus* from 2004, immediately *prior* to disturbance treatment, to 2005 (IMR $p = 0.539$; BWD $p = 0.816$), nor was there a difference in terms of percent cover change from 2004, just *after* treatment, to 2005 (IMR $p = 0.284$; BWD $p = 0.116$). Likewise, there was no significant difference between disturbance and control groups in terms of change in the proportion of *Astragalus* present from 2004, immediately *prior* to disturbance treatment, to 2005 (IMR $p = 0.231$; BWD $p = 0.190$), nor was there a difference in the proportion of *Astragalus* present in plots from 2004, just *after* treatment, to 2005 (IMR $p = 0.287$; BWD $p = 0.845$). Similarly, chi-square tests indicate that no significant relationship exists between treatment type (disturbance vs. control) and change in *Astragalus* area from 2004 (post-treatment) to 2005 [$X^2(1) = 0.952$, $p = 0.329$ for IMR; $X^2(1) = 0.220$, $p = 0.639$ for BWD]. However, at the IMR site, Probit Analysis in Statgraphics Centurion XV (StatPoint, Inc.) indicates a significant relationship between the change in percent cover of *Astragalus* in disturbance plots from 2004 (post-treatment) to 2005 and the immediate change in *Astragalus* percent cover caused by the ATV disturbance treatment ($p = 0.002$). No such relationship was indicated by a similar analysis of BWD cover data ($p > 0.10$).

Shading removal. Two-sample t-tests were used to compare shading removal plots and control plots at each of the study sites based on change in the number of flowering plants/plot since treatment at one year, two years, and three years after shading removal (Table 3). No significant difference was detected between shading removal treatment and control groups at any of the sites in 2005, one year after treatment ($p > 0.10$ for all sites). There is weak evidence to suggest a difference between the shading removal treatment and control groups at the IMR site in 2006 ($p = 0.069$). Shading treatment plots at IMR exhibited an average decrease of 0.7 ± 0.8 flowering plants/plot and control groups displayed a greater average decrease of 1.9 ± 1.7 flowering plants/plot in the two years following treatment. No differences were indicated at the other study sites in 2006 ($p > 0.10$ for all other sites). In 2007 and 2008, three and four years after treatment, respectively, no significant difference between shading removal plots and control plots was exhibited at any of the five sites ($p > 0.10$ for all sites in both years).

Biomass removal. Two-sample t-tests were again used to compare treatment and control groups at each study site individually based on the change in number of flowering plants/plot since biomass removal in 2004 (Table 3). No significant difference was noted in the first year following the biomass removal treatment ($p > 0.10$ for all sites). However, there is strong evidence indicating a difference between the biomass removal and control groups at the KR site in 2006 ($p = 0.013$). At this site, there was an average increase of 2.6 ± 3.2 flowering plants/plot in biomass removal plots and an average decrease of 0.9 ± 2.4 flowering plants/plot in control plots in the two years following treatment. The difference between treatment and control groups remained significant at KR in 2007 ($p = 0.043$). There was an average increase of 0.4 ± 1.8 flowering plants/plot in biomass removal plots and an average decrease of 1.2 ± 1.5 flowering plants/plot in control plots three years after treatment. No significant difference between biomass removal treatment and control groups was noted at any of the other sites three years following treatment ($p > 0.10$ for all other sites in 2007). In 2008, four years after treatment, there was no significant difference between biomass removal and control groups at any of the study sites ($p > 0.10$ for all sites).

Table 3. P-values for two-sample t-tests comparing the change in number of flowering plants per plot in treatment and control groups one year after treatment (2004-2005), two years after treatment (2004-2006), three years after treatment (2004-2007), and four years after treatment (2004-2008) at each study site. Treatments include disturbance (**D**; logging disturbance at Sites 1 & 2, ATV disturbance at Sites 3-5), shading removal (**SR**), and biomass removal (**BR**). Values significant within a 90% confidence level are boldfaced. For the Chiloquin site, treatment groups are compared with control group data from 2003. For control groups at each site, n = 10 plots throughout the course of the study except at IMR in year 4, where n = 9. Due to plot marker damage/removal, several plots within the different treatment groups have been removed from the study over time. For affected treatment groups, reduced sample sizes are reported below the P-value. For all other groups, n = 10 plots/treatment.

	1 Year After Treatment			2 Years After Treatment			3 Years After Treatment			4 Years After Treatment		
	D	SR	BR	D	SR	BR	D	SR	BR	D	SR	BR
Chil (1)	0.691	0.613 (n = 9)	0.445	0.282	0.319 (n = 9)	0.154 (n = 8)	0.248 (n = 6)	0.589 (n = 9)	0.176 (n = 3)	0.626 (n = 6)	0.728 (n = 9)	0.126 (n = 3)
86 Rd (2)	**0.078**	0.541	0.857	0.707	0.372	0.132	0.834	0.551	0.219	0.160	0.305	0.145
IMR (3)	0.505	0.391	0.884 (n = 8)	**0.037**	**0.069**	0.339 (n = 7)	**0.032** (n = 8)	0.106	0.406 (n = 7)	0.698 (n = 8)	0.516 (n = 9)	0.874 (n = 7)
BWD (4)	0.377	0.559	0.175	1.000	0.767	0.517	0.322	0.298	0.144 (n = 9)	0.835	0.607	0.500 (n = 9)
KR (5)	0.624	0.321	0.387	0.824	1.000	**0.013**	0.866	0.298	**0.043**	0.874	0.755	0.655

D = Disturbance **SR** = Shade Removal **BR** = Biomass Removal

Percent cover methods comparison (2008). Field estimates, digital plot image estimates, and SigmaScan measurements of *A. peckii* percent cover for each of the thirty photoplots selected for the methods review were compared using matched pairs t-tests. Results of the matched pairs testing indicate a significant difference between each of these methods for quantifying *Astragalus* cover: there is a significant difference between field estimates and SigmaScan measurements ($p = 0.036$), between digital image estimates and SigmaScan measurements ($p < 0.01$), and between field estimates and digital image estimates ($p < 0.01$). It is interesting to note, however, that a standard two-sample t-test indicates no significant difference between sample *means* for field estimates and SigmaScan measurements of *Astragalus* cover for the 30 plots studied ($p = 0.628$). (Because both over- and under-estimates characterize field data, a test of *mean* differences does not identify the between-method differences shown by the matched pairs test.) Field estimates of *Astragalus* cover ranged from 0-7 percent, exhibiting the lowest mean of the three methods studied (2.33 percent, Figure 10). SigmaScan cover measurements ranged from 0-8 percent, with a slightly higher mean of 2.47 percent. Digital image estimates of cover ranged from 1-11 percent, and exhibited the highest mean (4.13 percent). Digital image estimates were greater than the cover estimates obtained from the other two quantification methods for 83 percent of the plots analyzed, and image estimates were never lower than cover estimates made using either of the other methods.

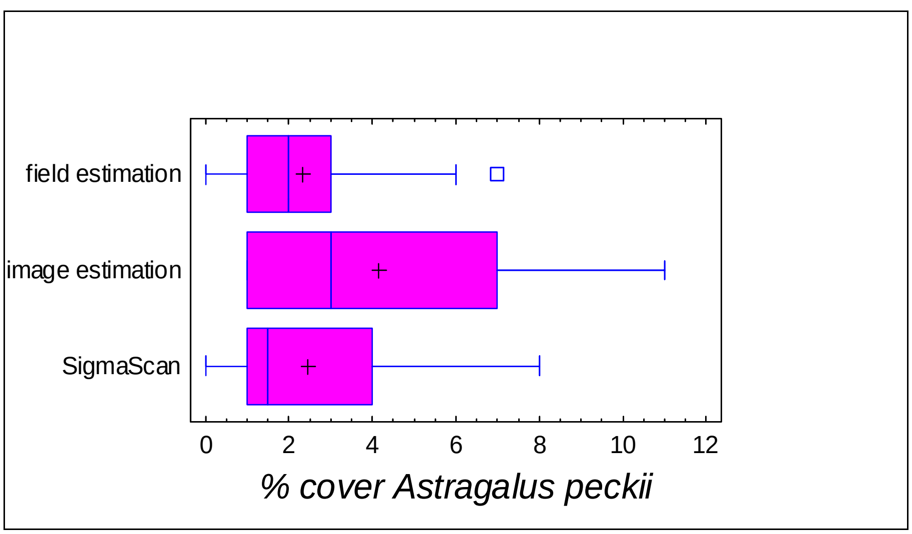


Figure 10. Boxplots of *Astragalus peckii* percent cover measurements for methods comparison plots (n = 30 plots) obtained from field estimation, digital image estimation, and SigmaScan image analysis.

Discussion

Due to the patchy nature of the prescribed fires at the 86 Road and Chiloquin sites, which essentially left plots in the burn group at these sites untreated, the Fremont-Winema NF study sites are considered inappropriate for analyses of the effects of fire on *Astragalus peckii*. Therefore, efforts focus on the three BLM study sites for the fire ecology component of this study.

Although ANOVA results indicate that no significant difference in the change in plant numbers existed between burned groups and unburned control groups in the first growing season following prescribed burns at the BLM study sites, t-tests do indicate a significant difference between treatment and control groups in terms of change in total numbers of plants/plot in the first year following the burn at the BWD site. Similar analyses indicate a statistically significant difference in plant density changes between burned and unburned plots after two, three, and four post-burn growing seasons at this site alone. However, statistical support is weaker for the fourth year (2007), and the difference between burned and unburned plots was not statistically significant in the fifth year (2008). Since burning, mean *Astragalus* plant density for the burned treatment group at BWD increased each year through 2006, while plant density in the unburned control group remained below pre-treatment levels. Mean plant density in both the burned and unburned BWD plots dropped considerably in 2007. In 2008, mean plant density declined slightly in the BWD burned group and increased in the unburned group, although it has remained above pre-treatment density in the burned group and below pre-treatment density in the unburned control group at BWD throughout the course of the study.

The 2008 data indicate a significant difference between burned and control groups at the KR site five years after the prescribed fire, with a decrease in the mean plant density in the burned group and an increase in mean plant density in the unburned group, the opposite of what was observed at BWD. However, data from the KR site has been inconsistent in the five year period following the prescribed fire (see Figure 8 and Table 2), and 2008 was the first year that a significant difference in total mean plant density between treatment and control groups was detected. A significant difference between burned and unburned groups in terms of flowering plant numbers was also noted at the KR site for the first year following the fire and then again for the fifth year. One year following the burn, the average number of flowering plants decreased in the burned group and slightly increased in the unburned group. Five years following the burn, the number of flowering plants decreased in both groups, although the amount of the decrease was significantly greater in the burned group.

Despite differences between the burned and unburned treatment groups indicated by a few of the analyses performed on the data collected in the course of this study, it is impossible to formulate any broad conclusions regarding the effects of fire on *A. peckii*. Results should be treated cautiously due to the observed variability in the data collected to date and the necessity of analyzing the five ecologically different sites individually. Block design analysis indicates a significant difference in plant density changes from 2003 to 2005 between burned and unburned plots considering the three BLM sites collectively. However, t-tests considering data from each site individually indicate that mean plant density differences between burned and unburned plots were only significant at the BLM BWD site.

Analyses of disturbance treatment data (change in number of flowering plants/plot) collected in the first, second, third, and fourth years following disturbance have not yielded any overarching patterns. Results, though weak, suggest a significant difference between "logging" disturbance and control plots at 86 Road in the first year after treatment. The number of flowering plants/plot increased in both groups, with a larger increase in the disturbance group. However, no difference was indicated in the second, third, or fourth years following treatment. Although data indicate no significant difference between ATV disturbance and control groups at the IMR site just one year after treatment, there is strong statistical evidence indicating a difference between these groups at the IMR site in the second and third years following disturbance. The average number of flowering plants decreased in both groups, with a larger decrease in the control group. However, differences between the disturbance and control groups were no longer statistically significant in the fourth year following treatment. No other significant differences between disturbance and control groups were indicated by analyses of flowering plant data. Analyses of *Astragalus* cover data indicate a significant relationship between the severity of the disturbance (in terms of immediate percent cover change in *Astragalus*) and the percent cover change in *Astragalus* in the first year following disturbance (2004 post-treatment to 2005) at the IMR site, but not at BWD.

Analyses of changes in flowering plant numbers indicate no significant difference between shading removal and control groups at any of the study sites just one year after treatment. However, in 2006, after two years, changes in flowering plant numbers indicate a significant difference between shading removal and control groups at the IMR site only, though supporting evidence is weak. Flowering plant numbers decreased in both groups, with a greater decrease in the control group. There was no difference between treatment and control groups in 2007 or 2008.

Analyses of flowering plant data indicate no significant difference between biomass removal and control groups at any of the study sites one year after treatment, but indicate a significant difference between these groups at only one of the sites, KR, after two years, with strong supporting evidence. Similar analyses of 2007 data indicate a significant difference between biomass removal and control groups, again at the KR site only, three years following treatment. Mean flowering plant numbers increased in biomass removal plots and decreased in control plots at KR in both these years. There was no significant difference between treatments in 2008.

Observed differences in treatment effects could in part reflect the substantial variability in mean plant density changes in control groups at the different sites over the course of this study. It is clear that there are a number of spacio-temporal variables influencing *A. peckii* within the study sites, making it difficult to isolate treatment effects on the plants. Results are further complicated by variability in the treatment applications within individual plots and between plots, particularly for the burn and disturbance treatments. Due to the patchy nature of the prescribed burns at the FWNF sites, most of the research plots within the burn treatment group were not directly contacted by the fire at these two sites. Disturbance (ATV/logging) treatments directly impacted some plants within individual plots, while leaving others apparently unscathed, simulating the irregular disturbance created by recreational ATV use.

Efforts to use SigmaScan to calculate the percent cover of *Astragalus* within research plots from digital plot photos have been hampered by automation difficulties with the software. Due to the low contrast of *Astragalus* plants against the pumice and ash substrate, and size and color similarities between *A. peckii* and other species co-occurring in study plots, manual plotting of our target plants was necessary to obtain the most accurate SigmaScan cover measurements. Although the SigmaScan manual plotting feature has been successfully used to measure the percent cover of *Kalmiopsis fragrans* within study plots using digital images taken in the field (see Amsberry et al. 2007), this method has proven to be prohibitively time-consuming for comprehensive cover analysis of *Astragalus peckii* cover. Hand-plotting to determine *A. peckii* cover is a time- and labor-intensive procedure that is challenged by the same low color contrast and low image resolution problems that hampered automated SigmaScan measurement for this species. Even with manual plotting, small seedlings cannot be confidently discerned from photos.

Of the three techniques for determining *A. peckii* cover examined in the comparative methods analysis (SigmaScan analysis, field estimation, and digital image estimation), estimating cover in the field while collecting other plot data is the fastest means for determining percent cover. In addition, it provides the best opportunity for discerning *A. peckii* plants from look-alike species that may also occur within plots, likely making it the most effective method for ensuring that all *A. peckii* plants (and only *A. peckii* plants) are included in the cover measurement. Field-drawn maps delineating the locations of individual *A. peckii* plants within each study plot were needed to accurately discern *A. peckii* plants in digital images of study plots for both SigmaScan analysis and digital image estimation of cover (by "eyeballing"). Although SigmaScan analysis is an effective method for measuring the area of cover of a plant species that contrasts sharply with its environment, we recommend against further use of SigmaScan with *A. peckii*.

Given the challenges encountered in the course this study, future use of square-meter photoplots to analyze treatment effects for this particular species is discouraged. Efforts to study *Astragalus peckii* should focus either on treatment and continued monitoring of individual plants (to ensure that treatments are administered equally) or on larger-scale sampling of populations. Despite drawbacks in the experimental design, our study did enable us to garner noteworthy insight into *A. peckii* phenology that may have otherwise gone undetected. Photoplot monitoring data for

June and August of 2005 and 2006 reveal that *A. peckii* seedlings continue to germinate throughout the summer months, leading us to speculate that most of the seedling mortality in this species occurs during the freezing winter months, rather than the hot, dry summer months as previously assumed.

Overall, study results indicate that *Astragalus peckii* is relatively resistant to one-time disturbance events, with no clear, overarching differences noted between treatment and control groups for any of the modes of disturbance investigated. A study by Wrobleski and Kauffman (2003) suggests that occasional fires may benefit other *Astragalus* species that also occur in big sagebrush (*Artemisia tridentata*) communities. Their data indicate higher reproductive and vegetative growth in *Astragalus malachus* plots than in control plots in the first growing season following prescribed fire, although no significant difference between burned and control plots was noted for *A. purshii*. Burning did not appear to affect the frequency, density, or relative abundance of either of the *Astragalus* species studied, although burning did appear to extend the active growth and succulence period, as well as the period during which flowers were available for reproduction in both species.

It is likely that the long taproot and prostrate growth form of *A. peckii* that enable it to withstand the harsh environmental conditions of its native habitat also contribute to the species's resistance to occasional anthropogenic disturbance. However, the cumulative effects of repeated disturbance on *A. peckii* are unknown. This study focused on single-incident disturbances only, and results should not be applied to cases of repeated disturbance events. Researchers have documented deleterious effects of repeated disturbance on other species in the genus *Astragalus*. Groom et al. (2007) provide evidence suggesting that repeated exposure to off-highway vehicle traffic has resulted in significant density depression in a dune-endemic *Astragalus* species, and that direct OHV impact decreases the survival probability of the plants. Maschinski et al. (1997) provide evidence that repeated trampling by foot traffic was detrimental to an endangered *Astragalus* species at Grand Canyon National Park. These studies, coupled with the lack of definitive results in our own research, suggest the prudence of a cautious approach when considering actions that will disturb *A. peckii* populations.

Management Recommendations

- Limit the duration and severity of *Astragalus peckii* exposure to repeated disturbance from logging, ATV use, and livestock grazing. If disturbance occurs, establish a monitoring program to assess its long-term impacts on affected *A. peckii* populations.

- As burning does not produce a definitive positive or negative impact to survival, growth, and reproduction of *A. peckii*, sites supporting this species can be included in controlled burns. Monitoring of populations before and after burning would provide additional information on the effect of fire on this species.

- Because seedlings emerge throughout the spring and early summer and exhibit low mortality during the summer months, proposed disturbances (such as logging) should be limited to the winter months to avoid excessive impacts to seedling recruitment.

- During our study visits we noticed increasing weed infestations (knapweed, cheatgrass) in disturbed areas near Sisters. Monitoring of *A. peckii* populations for encroaching weeds, with treatment if needed, may be required to protect this species from the threats posed by exotic species competition.

- Future monitoring of *A. peckii* populations should focus on large scale transect sampling methods to assess overall trends in plant density and reproduction, coupled with the tracking of individual plants to garner demographic information. We recommend against continued use of square-meter photoplots for this species.

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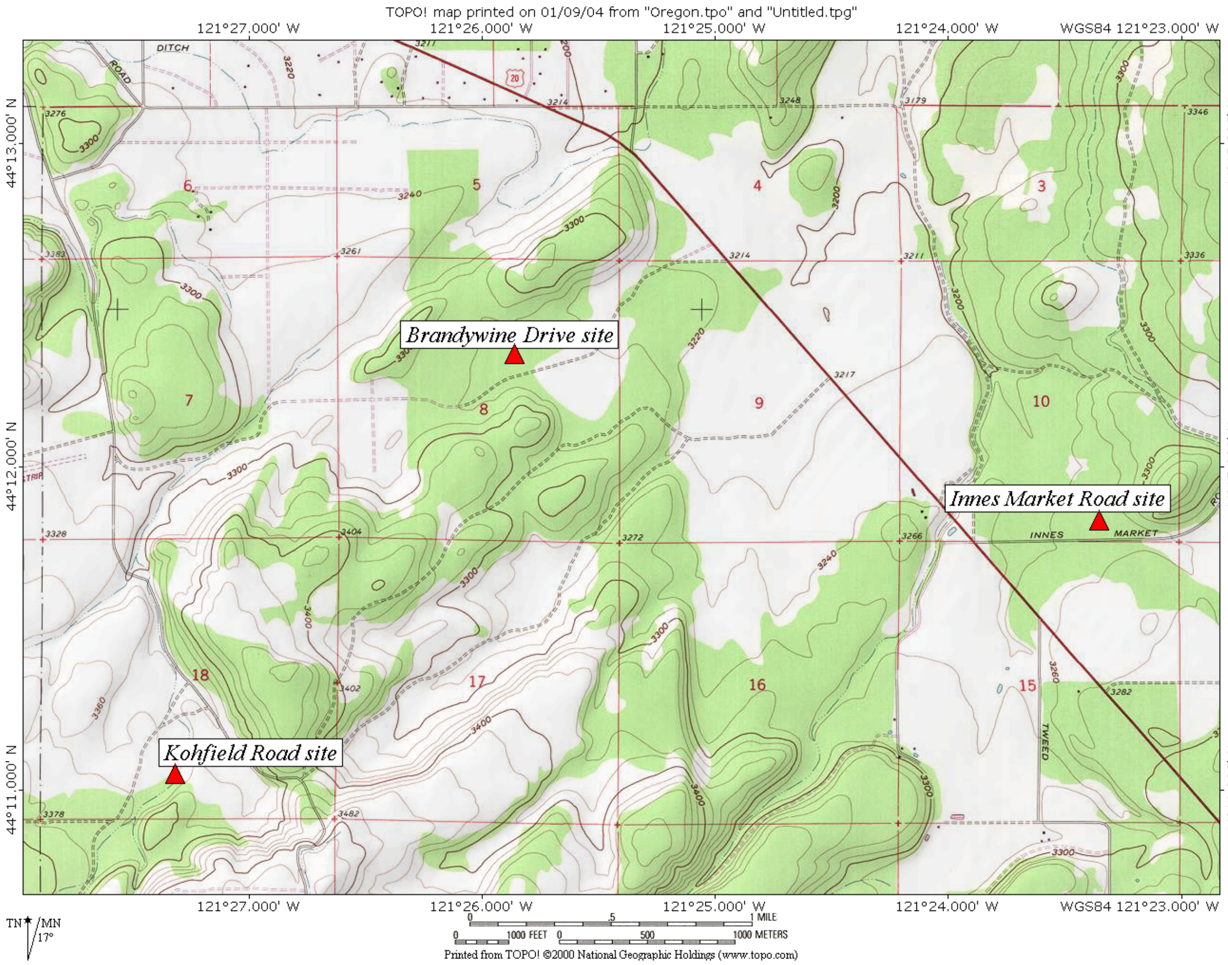
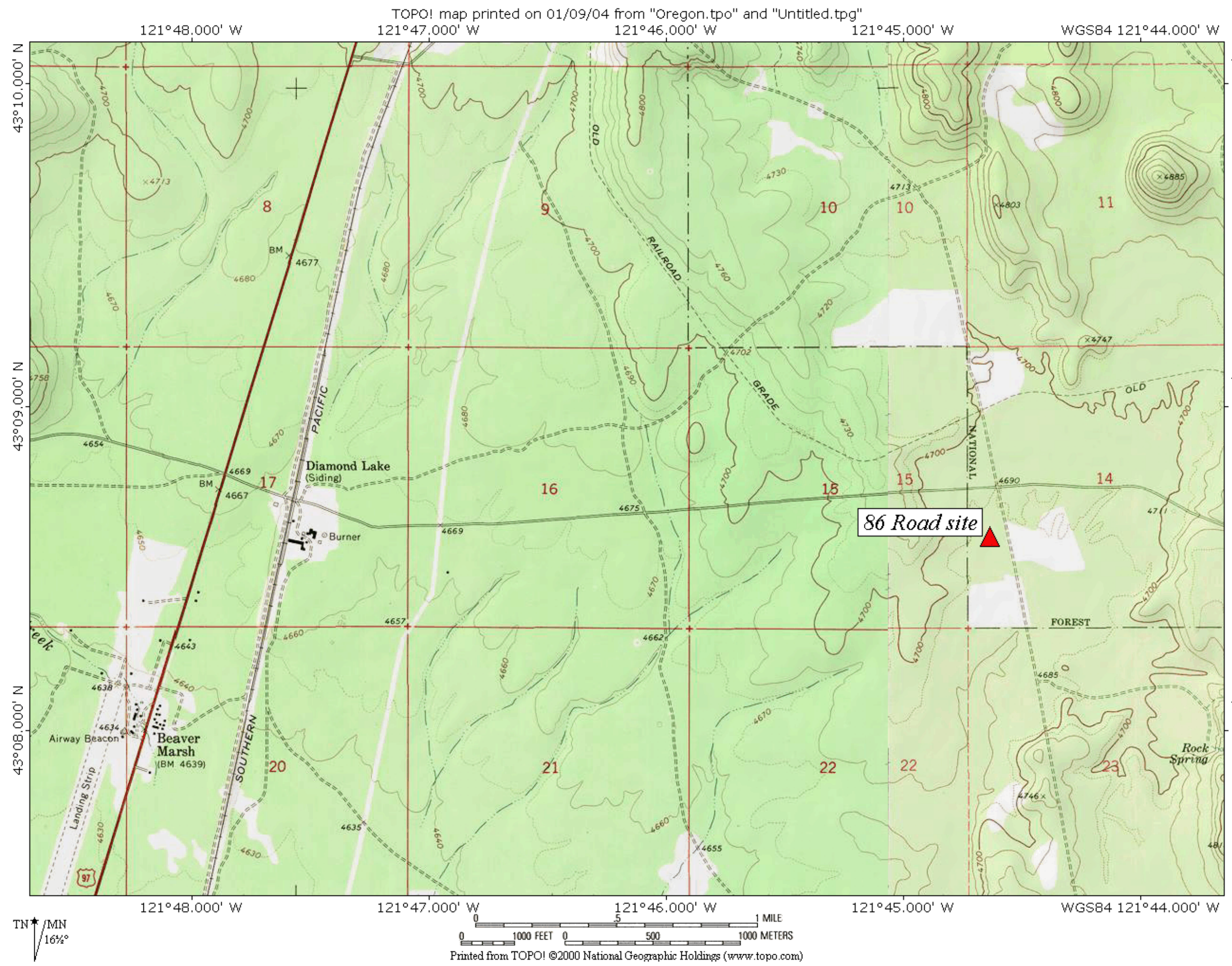
Appendices

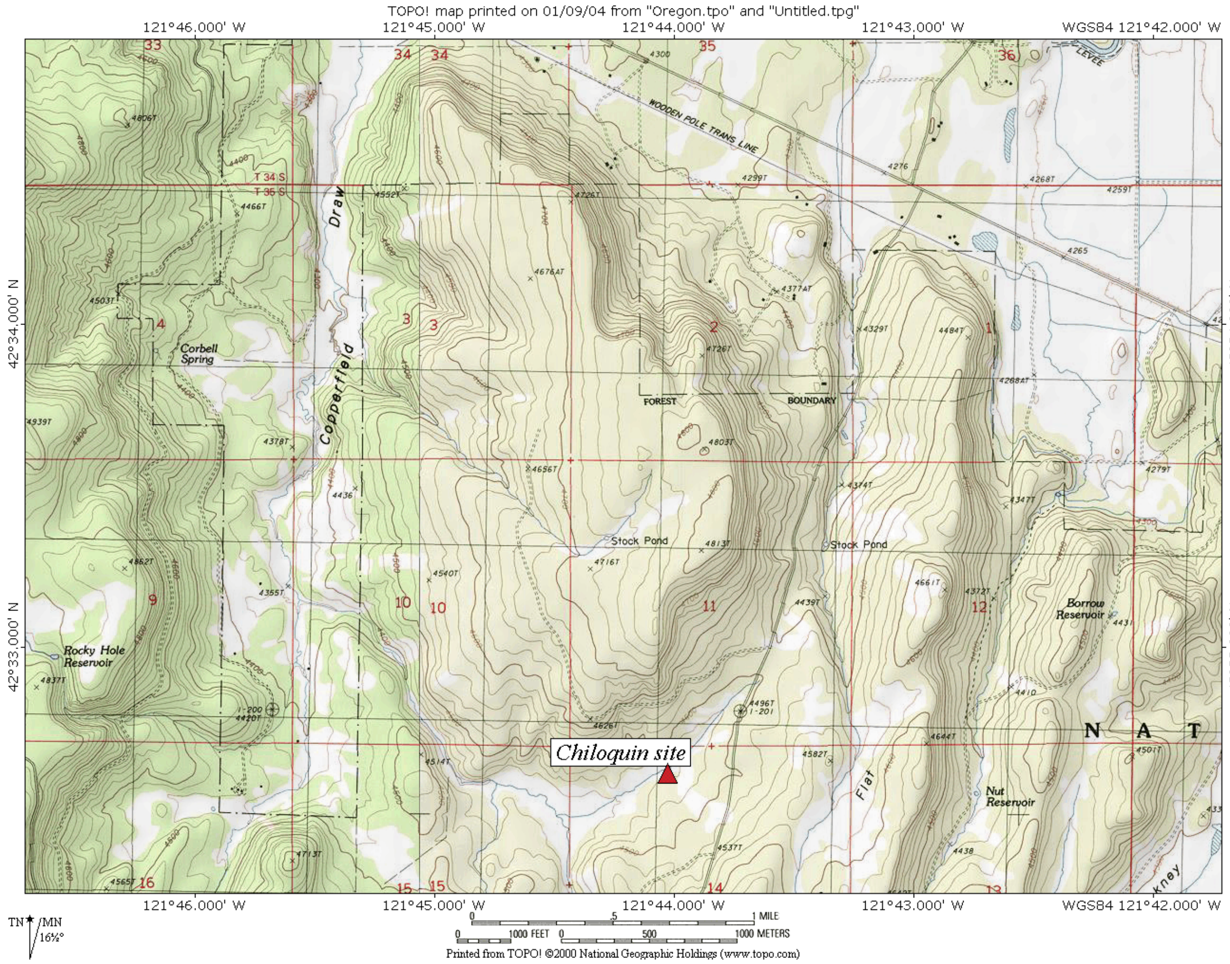


Population	Location
IMR	T16S/R11E/S10 NW1/4 of SE1/4
KR	T16S/R11E/S18 SE1/4 of SW1/4
BWD	T16S/R11E/S8 SW1/4 of NE1/4

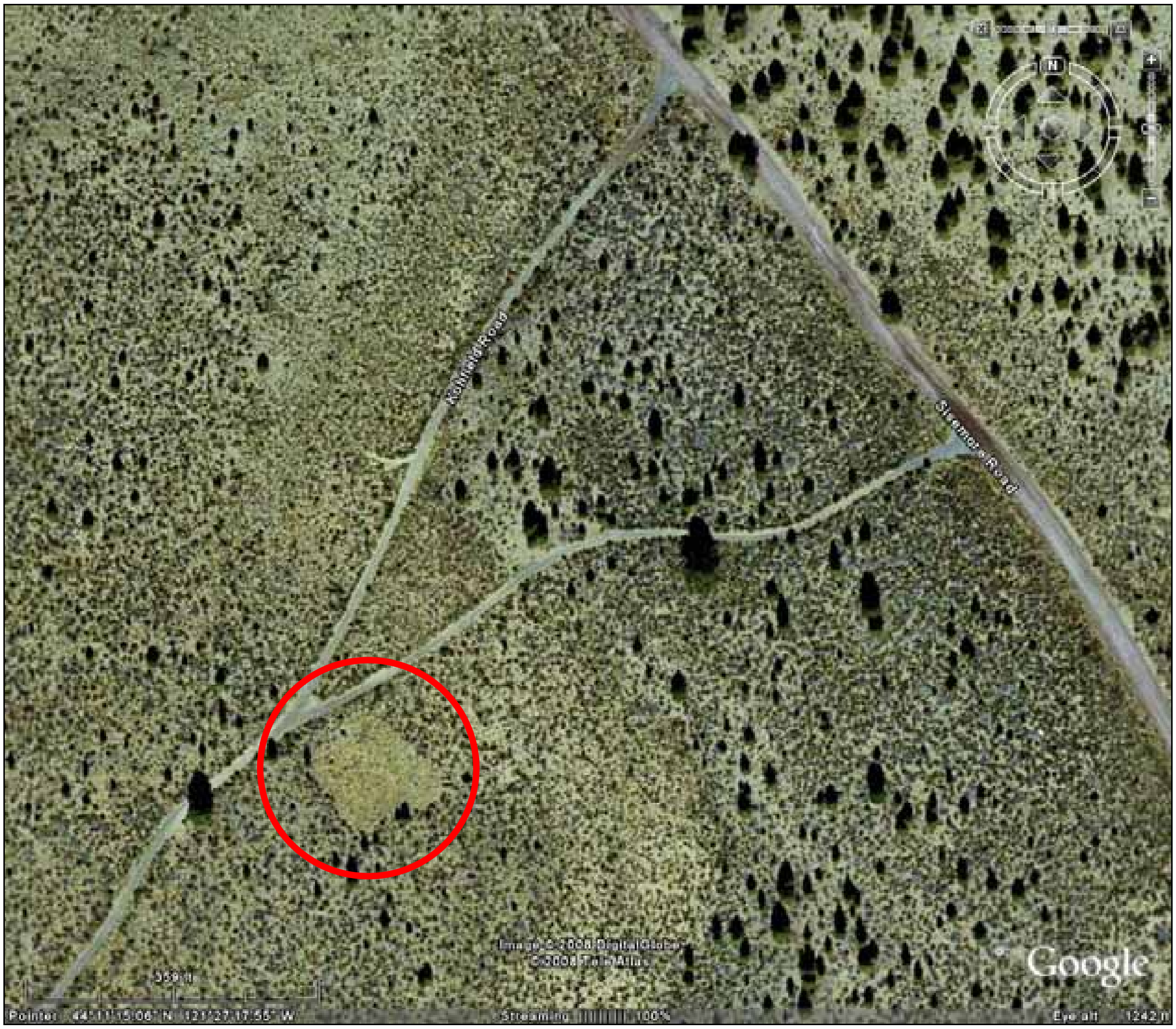
Appendix A. Location of BLM study sites east of Sisters in Deschutes County.



Appendix B. Location of the 86 Road site on the Fremont-Winema NF (T28S/R8E/S14 NW1/4 of SW1/4).



Appendix C. Location of the Chiloquin site, east of Chiloquin and south of the Sprague River Road (T35S/R8E/S14NW1/4 of NW1/4).



Appendix D. Burned area (circled) at BLM-KR site captured on satellite imagery in September 2006.