AN ABSTRACT OF THE THESIS OF

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Richard F. Miller Jon D. Bates

On piñon-juniper encroached sites that lack the understory fuels to carry a prescribed fire, treatment options are limited to mechanical methods. Cutting with chainsaws and leaving the trees on site has been the primary treatment method for such sites, however this method creates a potential fire hazard, particularly in the first 2-3 years when needles remain suspended on downed trees. Follow-up treatments to remove juniper fuels, such as broadcast burning downed trees or moving slash into piles with machinery followed by burning are becoming more common practices on private and public lands. There is limited information on the impacts of mechanical and fire treatments on herbaceous recovery and impacts to soil nutrients and characteristics. It is important to evaluate these treatments to provide resource managers with ecological information to assist in developing appropriate fuel reduction measures. This study sampled herbaceous vegetation and soil attributes of three common mechanical treatments used to treat invasive western juniper (*Juniperus occidentalis* var. *occidentalis* Vasek) woodlands: Cut & Leave, Cut & Burn, and Pile & Burn. Sampling consisted of cover and density of herbaceous species and life forms (groups of species that function similarly), as well as total ground cover, and soil attributes including: carbon (C), nitrogen (N), carbon:nitrogen ratio (C:N), phosphorus (P), potassium (K), sulfate-sulfur (SO_4^-), calcium(Ca), magnesium (Mg), organic matter (OM~loss on ignition), cation exchange capacity (CEC), and power of hydrogen (pH). A randomized complete block experimental design (RCBD) was used with five 1-hectare blocks and three treatment plots per block (with piling plots being ½ hectare in size, and the other two treatment plots each ¼ hectare in size). Within each treatment plot, herbaceous vegetation sampling was stratified between three microsites: the slash microsite (beneath the three slash treatments; cut trees, burned trees, and burned piles), in the litter deposition microsite (litter zone around the stump) and the interspace microsite (between trees). Soil attributes were only sampled in the slash and interspace microsites, at two depths (0-4cm and 0-25cm). Each microsite within each plot was sampled by 40, $0.2m^2$ herbaceous frames and three composited soil samples from each depth. Mechanical treatments were completed in the fall of 2005 and prescribed fire treatments were completed in the fall of 2006. Treatment analysis compared pre and post treatment herbaceous data from 2005 and 2007, and soil attribute data from 2006 and 2007. Bare ground increased and litter and cover and density of most herbaceous species/life form groups declined beneath Cut & Burn

and Pile & Burn treatments compared to the Cut & Leave treatment. The largest declines in cover and density of herbaceous species/life forms were recorded beneath burned piles. The largest changes measured adjacent to slash treatment locations (in the litter deposition and interspace microsites) were in the Cut & Burn plots due to fire spreading out burned trees. In the litter deposition microsite of the Cut & Burn treatment in 2007 total herbaceous cover was 1/3 and 1/2 that measured in the Cut & Leave and Pile & Burn plots, respectively. Contrarily the interspace microsite of the Cut & Burn treatment in 2007 indicated a slight (although insignificant) increase in herbaceous cover, with annual forb cover twice that measured in either of the other treatments. Concentrations of C, N, OM, and CEC were largely unchanged from pre-treatment levels in the compared treatments, however SO_4, Mg, Ca, K, and pH all increased in response to burning compared to the Cut & Leave treatment. Implications of this research are limited to the first year post burn-treatment. However, these findings can be used as a general guide to choosing slash treatments to meet specific objectives.

Determination of which of these treatments to use is largely dependent upon management objectives and site conditions. The high degree of vegetation disturbance and nutrient release measured beneath the Pile & Burn slash treatment could pose potential problems with invasive species establishment. However, the Cut & Burn treatment had similar, although less dramatic, vegetation disturbances and nutrient releases beneath burned slash, which covered a larger proportion of area than the Pile & Burn treatment. If a similar degree of invasive species establishment occurs in both of these slash burning treatments, the Pile & Burn treatment may be a better option due to the smaller area impacted. Measurements indicated little impact to vegetation in the Cut & Leave treatment, however wildfire risk could diminish the short term benefits of this treatment. Long term monitoring of herbaceous vegetation and soil attribute response among these three slash treatments is needed to make solid inferences of the site recovery following treatments to assist in land management decisions.

Vegetation and Soil Response to Tree Removal Methods in Invasive Western Juniper Woodlands

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Casey A. O'Connor, Author

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CONTRIBUTION OF AUTHORS

Dr. Jon D. Bates and Dr. Rick F. Miller contributed to the study design, and editing of chapters 2 and 3. Dr. Jon D. Bates also assisted with the statistical analysis of chapters 2 and 3.

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CHAPTER 1

Literature Review

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<u>Introduction</u>

Western juniper (*Juniperus occidentalis* var. *occidentalis* Vasek) represents the northwestern portion of the pinyon and juniper biome, occupying northeastern California, eastern Oregon, southwestern Idaho, northwestern Nevada and small portions of southern Washington (Vasek 1966) (Fig 1.1). The historic distribution and abundance of western juniper woodlands have been dramatically altered by land management practices as well as recent climatic changes (Gedney et al. 1999, Miller and Tausch 2001). Encroachment of juniper into neighboring sagebrush steppe communities has been attributed to the reduction of fire frequencies since the late 1800’s. (Burkhardt and Tisdale 1969, Miller and Rose 1995, Miller and Tausch 2001). The proportion of this shift in fire frequencies that can be attributed to natural causes versus human causes is disputed. With over nine million acres of sagebrush-steppe in various stages of conversion to western juniper woodlands concerns about the ramifications of leaving this spread unchecked have grown with public and private land managers (Miller et al. 2005). The increased dominance of juniper can result in the decline of understory species, leading to

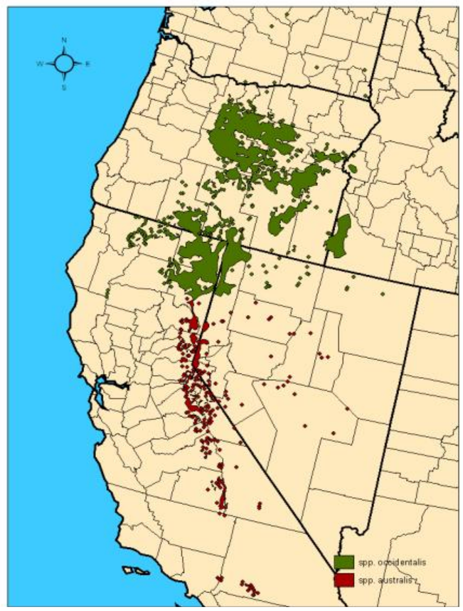

Figure 1.1. Distribution of western juniper (Miller et al. 2005)

changes in hydrologic and nutrient cycling, decreasing site productivity and species diversity, and the loss of sagebrush obligate species (Miller et al. 2005). Studies have shown that juniper removal in encroached systems can result in a rapid increase in herbaceous production and cover (Bates et al. 2000, Bates et al. 2005), increasing available forage for grazing species and improving site processes such as hydrologic and nutrient cycling (Bates et al. 2002, Pierson et al. 2007). The most common methods for removing invasive juniper are prescribed fire and cutting with chainsaws (Miller et al. 2005), with the cutting treatment often followed-up by a slash removal/redistribution treatment to decrease wildfire risks and allow large animals to move across the site. Despite a significant amount of research documenting the recent expansion of western juniper (Miller and Wigand 1994, Miller and Tausch 2001, Miller et al. 2005), the negative effects this species can have on sage-steppe communities (Miller et al. 2000, Miller et al. 2005), and the positive response these communities exhibit following reduction of juniper (Vaitkus and Eddleman 1987, Bates et al. 1998, Bates et al. 2000, Eddleman 2002, Bates et al. 2005, Miller et al. 2005, Bates et al. 2006), limited research has compared the response of plants and soils between different methods of treatment and removal of western juniper slash.

Past and Present Distributions of Juniper and Pinyon Species

Historical Niche of Juniper and Pinyon Species

Prior to Euro-American settlement of the western United States, the distribution of juniper and pinyon species across the sagebrush biome was typically constrained to fuel limited sites in which fire return intervals often exceeded 100's of years. Pre-settlement pinyon and juniper woodlands were largely confined to areas with shallow, lithic soils underlain by fractured bedrock or if on deeper soils the soils typically either had a texture or restrictive layer that limited the water availability to support much herbaceous production (Burkhardt and Tisdale 1969, Miller and Wigand 1994, Miller and Tausch 2001, Ramsey 2003). Limiting surface fuels on these sites permitted these long-lived but, fire-sensitive species to attain ages exceeding centuries. In neighboring more productive and contiguous plant communities, often occupying more productive Mollisols, the probability of fire occurrence was higher, and thus limited the development of pinyon-juniper woodlands. Post-settlement pinyon-juniper expansion has occurred in low sagebrush (*Artemisia arbuscula* Nutt.) communities, basin (*Artemisia tridentata* spp. *tridentata* Nutt.) and mountain big sagebrush (*Artemisia tridentata* spp. *vaseyana* Nutt.) grasslands, riparian zones, and quaking aspen (*Populus tremuloides* Michx.) woodlands (Burkhardt and Tisdale 1969, Eddleman 1987, Miller and Rose 1995, Wall et al. 2001).

Encroachment and Ecological Effects

Populations of juniper and pinyon species throughout the Intermountain West have fluctuated in distribution and density since the beginning of the Holocene (Mehringer and Wigand 1987). Historically fluctuations have been attributed to natural climatic shifts (Miller and Wigand 1994). However, one of the most pronounced increases in the distribution and density of juniper and pinyon species closely coincides with European settlement (Burkhardt and Tisdale 1976, Miller and Tausch 2001). Prior to settlement pinyon-juniper woodlands occupied <3 million ha (Miller and Tausch 2001). Currently these woodlands occupy a total area exceeding 18.9 million ha (Miller and Tausch 2001). Evidence of woodland expansion has been collected from old surveys, photographs, the distribution of relict presettlement woodlands, and tree ring chronologies (Miller et al. 2005). This expansion of woodlands has been largely attributed to a combination of the reduced role of wildfire, domestic livestock grazing, climatic shifts, and increased levels of CO_2 (Miller and Tausch 2001).

Western Juniper Expansion

Much of the Intermountain West is still in the process of woodland expansion (Betancourt et al. 1993, Miller and Tausch 2001). Western juniper found in the northern portion of the Intermountain region (eastern Oregon, Southwest Idaho, northwest Nevada, and northeast California) is representative of this ongoing expansion. The rate of expansion within the last 130 years is higher than during any other period within the Holocene Epoch (Miler and Wigand 1994). Western juniper occupies 3.6 million ha (Miller et al. 2005), and expansion and infill within current stands is continuing (Miller et al. 2008). This expansion is of concern to land managers due to the decrease in ecologic and economic value that can occur on sagebrush-steppe encroached by western juniper (Miller et al 2000, Miller et al 2005).

The stages of woodland development have been conceptually described as occurring in three transitional phases based on juniper dominance within a given plant community (Miller et al. 2005). These three phases and a wildfire inhibiting threshold that is crossed between phase II and III serve as a general outline to the effects western juniper encroachment has on the vegetation and soils of shrub steppe communities.

Phase I of juniper expansion is defined by a presence of juvenile trees on site, but shrub and herbaceous vegetation still maintain dominance of ecological processes; hydraulic, nutrient, and energy cycles. Tree canopy coverage on the site is below 10% of the maximum potential, and terminal and lateral leader growth of the trees is maximum for the site (Miller et al. 2005). This phase of expansion could be considered natural to a pre-European settlement landscape that was nearing the end of its average fire return interval. In the event of a fire across a landscape such as this, the vast majority of establishing juniper would be killed due to a strong continuity in both horizontal and vertical fuels to carry fire into the juniper canopies.

Phase II of juniper expansion are sites in which trees are established on site and contribute an equal influence on ecological processes along with shrub and herbaceous species. Tree densities in this phase of expansion have typically reached full stocking on the site, have well established root systems, and are at the stage when trees are acquiring a much higher proportion of soil resources than trees in phase I. Tree canopy continues to expand from 10 to 30% of maximum site potential, and leader growth rates remain high. Although trees in this phase of expansion are still typically susceptible to high levels of mortality in the event of a wildfire, as expansion reaches the end of this phase the fire threshold is crossed. This threshold is defined by a significant reduction in surface fuels resulting in a change of the fire regime. A decline of shrubs is the most documented shift in understory vegetation following western juniper encroachment. Mountain big sage sites show 20-25% declines in shrub cover in response to trees reaching 50% of the maximum site potential (Miler et al 2000). A decline of the herbaceous layer in the understory of juniper encroached sites has been shown to vary significantly between different plant associations and soils. Sites with herbaceous species sensitive to western juniper encroachment, such as Thurber needlegrass (*Achnatherum thurberianum* (Piper) Barkworth) associations, can be expected to cross this 'fire safe' threshold at a quicker rate then on sites with deeper more productive soils where tree dominance occurs at greater densities and canopy cover. (Miller et al. 2005)

Phase III of juniper expansion is the final stage by which trees have established dominance on the site and are the primary plant group influencing ecological processes (Miller et al. 2005). At this point the shrub steppe community has been almost completely converted to a woodland with greater than 75% of the pre-invasion shrub layer eliminated. Tree canopy on the site exceeds 30% of the sites maximum capacity leading to reduced rates of lateral leader growth. In early Phase III terminal leader growth rates remain high but lateral leader growth diminishes as trees begin to compete more with each other for resources. Trees begin to cut off resource supply to lower level branches, resulting in a dramatic decrease of vertical fuels needed to carry a fire into the canopy. This 'crown lifting' significantly enhances the trees ability to survive a fire event, and the 'fire safe' threshold is further solidified. Once a juniper encroached site crosses into this last stage of expansion, understory vegetation and soils of the site are significantly impacted. Besides the significant reduction of the shrub layer, certain grass and forb species typically decline on the site as well. Understory cover, particularly on sites where soil depth or restrictive layers are <50cm deep, is drastically reduced, leading to higher levels of bare ground and the subsequent increase in soil erosion and redistribution of soil and litter nutrients (Doescher et al. 1987, Klemmedson and Tiedman 2000, Bates et al. 2000, Bates et al. 2002, Pierson et al. 2007). Levels of degradation on a phase III encroached site can vary drastically due to an array of factors such as; soils, topography, understory species, climate, and time. (Miller et al. 2005)

Common Western Juniper Removal/Reduction Treatments

Prescribed Fire

Due to the ecologic and economic ramifications of juniper encroachment on a site, an array of treatments have been developed to reduce or remove trees from shrub-steppe communities. The most intuitive approach is the reintroduction of fire upon the landscape. The introduction of prescribed fire is a commonly utilized treatment to reduce fuel loadings on sites across the spectrum of the three phases of juniper expansion outlined by Miller et al. (2005). However, treatments solely based upon introduction of a prescribed fire (broadcast burns[1]) are typically only effective on sites where expansion has not progressed beyond the middle of phase II. The ability to use prescribed fire on sites is largely dependent on the structure and abundance of understory surface fuels. Prescribed burning late phase II and phase III woodlands require some form of prior vegetation manipulation by cutting all or a percentage of the trees. On sites that have crossed this ecological threshold, mechanical or a combination of mechanical and prescribed fire treatments are required to restore the site to shrub-steppe.

Mechanical

Initially, mechanical treatments of juniper and pinyon encroached landscapes were driven by a surplus of heavy machinery and manpower following

[1] When fire is applied to key areas and then fuel, weather and topography drive fire's spread across the landscape. Very similar to how wildfire functions, except usually done in weather and fuel conditions that enable more control over fire spreading.

World War II, with dozing and chaining being the most common methods (Gottfried and Severson 1994). Over time these methods have been largely abandoned on western juniper woodlands, especially by government agencies, as a negative perception of the disturbance of these treatments was developed by the public (Miller et al. 2005).

Use of chainsaws to treat western juniper encroachment on public lands has increased substantially from its inception on the Prineville BLM District in the late 1970's (Miller et al. 2005). In recent years, chainsaws have been adopted as the most common mechanical treatment method utilized to control western juniper, however a reemergence of heavy machinery based methods is currently being evaluated. Cutting and/or removal of trees by feller-bunchers, pullers, mechanical shears, and excavators are commonly utilized techniques on public and private land restoration projects in pinyon and juniper woodlands in the Intermountain West.

Prescribed fire and chainsaws are the most common methods used to treat invasive western juniper in eastern Oregon. The utilization of heavy equipment has increased and enabled more controlled treatment of phase II and III sites. Heavy equipment provides easier and timely movement of slash materials to break up fuel load continuities. Typical treatment of late phase II and phase III encroached sites had previously been performed by cutting with chainsaws, and then either letting the slash naturally break down on site, or by introducing prescribed fire after the cut trees had dried enough for good fuel consumption. Prescribed fire on such sites would typically be in the form of either a winter jackpot[2] prescribed burn, or fall or spring broadcast burn. The main problem with leaving cut slash on the ground is that a wildfire ignition during the extreme wildfire conditions of summer would likely evolve into a large, hot wildfire that would be difficult and dangerous to suppress due to the unnaturally high and continuous dead fuel loading on the site. It has also been shown leaving cut trees on site can result in the removal of desirable grass species and encourage weed invasion (Bates et al. 2007). A wildfire event such as this would also be of concern to land managers due to the possible detrimental effects on physical soil properties, native plants, and seed banks. Piling of downed slash has been adopted by many land mangers (especially in the ponderosa pine [*Pinus ponderosa* C. Lawson] ecotone) to reduce the risks associated with summer wildfire starts. Piling of slash breaks up the horizontal continuity of the slash on the ground which inhibits fire spread and enables suppression equipment safer travel within a juniper cut unit; thus improving the probability of suppression.

Another added benefit to piling and burning of slash on the site is the limited logistics needed to carry out fire treatments. Compared to multiple prescription requirements and logistical needs that must be met in order to undertake a broadcast burn, burning of piles typically only needs a trace moisture (>0.10”) and a few personal with drip torches to be carried out. Risk of fire escape

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[2] Separately igniting areas of high fuel accumulation (“jackpots”); typically done when fuel/weather conditions inhibit fire spreading potential.

from the very controlled conditions in the fall or spring during which piles are typically burned is low compared to broadcast burns.

Research of Mechanical and Fire Based Treatments

Mechanical Cutting

Mechanical cutting of invasive western juniper woodlands can result in a rapid increase in herbaceous production and cover (Bates et al. 1998, Bates et al. 2000), increasing available forage for grazing species and improving site processes such as hydrologic and nutrient cycling (Blackburn 1983, Bates et al. 2002, Bates et al. 2007, Pierson et al. 2007). The response of understory vegetation following mechanical cutting of western juniper with chainsaws is quite comprehensive, however research of soil responses specific to this treatment is quite limited.

Vegetation Response

Short term response of vegetation following western juniper removal by cutting with chainsaws has shown increased understory production and diversity, improved perennial cover and density, and also a varied zonal response with respect to juniper biomass inputs. Vaitkus and Eddleman (1987) found that cutting and leaving of juniper in low sagebrush (shallow soil) site yielded a nearly 300 percent increase in herbaceous biomass two years after treatment, however they noted that annual plants contributed most to this increase. Rose and Eddleman (1994) found that cutting and leaving of western juniper in ponderosa pine / Idaho fescue

(*Festuca idahoensis* Elmer) communities increased understory production by 50 percent 2 years post treatment. In a basin big sagebrush / Thurbers needlegrass-bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Love) site that had overstory juniper cut, biomass increased nine-fold 2 years post treatment, and perennial plant basal cover increased by a factor of 3 (Bates et al. 2000). In research that separated understory response into three zones (interspace, duff, and debris) it was found that cover and density increased in all of the zones, but at disproportionate levels between species (Bates et al. 1998). Cover and density of Sandberg bluegrass (*Poa secunda* J. Presl) and squirreltail (*Elymus elymoides* [Raf.] Swezey) were the greatest in the duff zone, while cover and density of the other perennial grasses and densities of perennial and annual forbs were highest in the interspace zone (Bates et al. 1998).

Research of long term understory response following juniper cutting is more limited than research of short term response (≤2 years). Research by Eddleman (2002) over an 18 year period, and by Bates et al. (2005) sampling over a 13 year period, are the best indicators of the long term understory vegetation responses to be expected post cutting of juniper woodlands. Eddleman's research utilized three plots that increased in elevation, precipitation and soil depth; 1110-1210 m, 335-371 mm, and 35.5-68.5 cm, respectively. His research compared uncut juniper woodlands to both cutting and removal of slash from the site over an 18 year period, as well as cutting and scattering of slash over a 13 year period. Results indicated that uncut woodlands changed little, with a slow decline of shrub cover the most notable change. Both cutting treatments experienced major increases in shrub cover and densities, as well as increased perennial grass cover, with the cut and scatter treatment showing greater increases in squirreltail than the cut and remove treatment. Cheatgrass (*Bromus tectorum* L.) cover varied widely from year to year. Bates et al. (2005 & 2007) compared cutting of juniper and leaving slash in place to adjacent uncut woodlands. Thirteen years following treatment, herbaceous standing crop biomass was 10 times greater in the cut treatment compared to the uncut control. Perennial grass density was also 2-3 times greater in the cut treatment compared to the uncut control. Perennial grass (excluding Sandberg bluegrass) cover and densities did not change after the 5th year post cutting, implying that all open establishment sites had been filled by this time. Also by the 5th year, cheatgrass had replaced Sandberg bluegrass as the codominant with the other perennial grasses; however in the following years of this study, cheatgrass declined significantly in cover and biomass as perennial grasses replaced this species.

Soils Response

Soil nutrient response following cutting of western juniper is primarily limited to studies analyzing the treatment effect on nitrogen and carbon response. Research of nitrogen response has shown that extractable forms of this nutrient vary highly with respect to year and season.

In research spanning a 2 year period post cutting significant increases of extractable N (NH_4^+ and NO_3^-) were found in the first year (a dry year) in intercanopy zones of the cutting treatment when compared to all other zones (others being canopy and debris) in the treated and control plots (Bates et al. 2002). No differences of extractable N were found the second year (a wet year) when comparison between treatments and zones was made. Researchers inferred the contrasting year effect (a dry year compared to a wet year) overpowered treatment effect of N response parameters sampled. Researchers suggested that the wet year effect didn't lead to leaching of N, but rather it allowed uptake of extractable N by microorganisms. This theory was supported by sampled nitrification and N mineralization rates being higher in the interspace zones (in comparison to debris zones) of the treated plots, and equal to or higher in the interspace zones (in comparison to canopy zones) of the control. It was also noted that a resource island effect for available N was not present in canopy soils of the uncut woodland (Bates et al. 2002).

Stubbs and Pyke (2002) compared three treatments (cut and removal of all woody material, prescribed burn, and a control) across a moisture gradient of increasing precipitation (324-447 mm of precipitation) to the response of extractable N from canopy and interspace zones. No significant differences in extractable N were found between the canopy removal treatment and the control, although all treatments (including the control) indicated a resource island effect with regards to higher levels of extractable N in the canopy zones. The study also noted a soil moisture effect on the available N with wetter sites showing smaller differences between compared treatments and zones.

Miwa (2007) evaluated the persistence of nutrient islands beneath the tree canopy zone on western juniper cutting sites that were 1, 8, and 15 years old, as well as a control woodland site. His protocol was based on randomly selecting juniper stumps within these cutting units, and collecting 3 composited, 5 cm-in-depth soil core samples, from distances of 50, 100, 150, and 300 cm out from stumps. Acquired samples were then analyzed for total C and N, soluble P, K, Ca, Fe, Si, Al, and Na, inorganic NH_4^+ and NO_3^-, pH and gravimetric water content. Findings from this research indicated that many of the analyzed soil variables (notably NO_3^-, P, K, Ca, and total C and N) persisted at elevated levels up to 15 years in the tree-canopy zones when compared to intercanopy areas. However, Mg and Na concentrations appeared to be elevated in the canopy zone for a short period (≤1 year), but showed no difference between the canopy and intercanopy zones of older cut units. Soil moisture, Al, and Fe generally increased with distance away from the canopy zones, while pH decreased with distance away from the canopy zones. This research indicated that the canopy zone of western juniper creates resource islands with respect to some soil resources, and also can create resource deserts with respect to other soil resources. The disproportionate levels of resources between the canopy and intercanopy zones was also shown to vary by the nutrient, time, and distance from the canopy zone.

In research that utilized sampling of above ground parameters linked to soil resources (Bates et al 2000), it was indicated that juniper cutting can result in more available N and water for understory herbaceous species. Two years after treatment, total understory biomass and N uptake was 9 times greater in the cut treatment than in the control. Analysis of western juniper leaf water potentials indicated greater available soil water in cut compared to uncut treatments. Greater available soil water in the cut treatments was also supported by volumetric soil water content and soil water potential measured in the interspace zones of both treated and control plots.

Mechanical Cutting and Burning

Implementation of a prescribed burn treatment following the cutting of western juniper is becoming a more common practice because winter burning lowers the wildfire risk associated with large loadings of down-dead material, enables better movement of wildlife and livestock across the site, and has been suggested to increase desirable herbaceous response (Bates and Svejcar 2009). Typically burn treatments are implemented outside of the natural fire season, since burning juniper slash in hot dry conditions can result in a decline of native perennial grasses and an increase of invasive annuals (Miller et al. 2005). Research of western juniper cuttings that have been prescribe burned is quite limited, although inferences from similar vegetation communities and/or treatments can be made for areas lacking in research. It is worth noting that even when research of similar prescribed fire treatments are compared, much variation can arise due to the complexity of conditions that can significantly impact this treatment. A good example of this can be seen in research by Bates et al. (2006), which found very different herbaceous responses resulting from fall and winter burning treatments.

Vegetation Response

Research that compared long term (10 years post treatment) effects of two winter prescribed burn treatments (burning of 1 year old and 2 year old juniper cuttings) to a cutting that wasn't burned, found remarkable herbaceous succession responses (Bates and Svejcar 2009). Ten years after the burning treatment in the two cuttings, total herbaceous and perennial cover were 1.5 and 2 times higher, respectively, in the cut and burn treatments in comparison to the cut and leave treatment. It was also found that cheatgrass cover was twice as high in the cut and leave treatment in comparison to the burning treatments. (Bates and Svejcar 2009)

A partial cutting/prescribed burning-study with burns taking place in early fall or early spring in western juniper encroached aspen stands demonstrated variable plant response after fire (Bates et al. 2006). One third of mature invasive junipers were cut and allowed to dry prior to fire application to increase surface fuel loads. The early fall burn, which occurred in drier conditions than the spring burn and was aerially ignited to create a head fire, experienced significantly higher fire severity, as was indicated by a 100% mortality of uncut junipers and a significant reduction of herbaceous understory cover and diversity. This reduction in the native perennial herbaceous layer was replaced by weeds and annual forbs. This treatment also resulted in the highest recruitment of aspen suckers, averaging 12,000 suckers/hectare. The early spring treatment occurred in wetter conditions, and was hand lit with drip-torches. Mortalities of uncut juniper following this treatment were 80% for mature trees, and 50% for juniper seedlings. Measurement of aspen recruitment indicated this treatment was significantly less than the early fall burn treatment with an average of 4,000 suckers/hectare. The notable upside to the early spring burn was that the understory remained intact, and native herbaceous plant cover and diversity increased, and there was no weed encroachment. (Bates and Miller 2004)

Soils Response

To date no research specific to soil response following prescribed burning of western juniper cuttings has been done. Only generalized inferences can be made with regards to soil response following fire in addition to results from research of pinyon-juniper slash burning. Research has shown burning heavy fuel loadings, like those found in timber slash, results in soils surface temperatures in the range of 500-700ºC (Neary et al. 1999). Soil surface temperatures in shrub-land vegetation are typically lower, but can range between 250-700ºC (Neary et al. 1999). Burning durations are also an important factor to consider, as ignited slash can burn for over a day, whereas shrub-lands only burn for a matter of minutes with some scattered larger fuels burning for several hours. Burning juniper slash on the ground will likely result in surface temperatures and durations between these given for logging slash and shrublands. Subsurface temperatures typically drop off significantly with soil depth, but are heavily influenced by soil moisture content and burn duration. As soil temperatures and burn durations rise, first living biological components are killed, then organic matter begins to be consumed, and lastly soil nutrients are volatilized. Mortality of living biological components occurs at ground temperatures ranging from 48ºC and 94ºC, with plant roots being the most sensitive and Vesicular Arbuscular Mycorrhizal (VAM) least sensitive within this temperature range (Neary et al. 1999). Nutrients begin to volatilize with N at 200º, K > 760º, P > 774º, S > 800º, Na > 880º, Mg >1107º, and Ca > 1240ºC (Weast 1988). Temperatures high enough to volatilize nutrients other than N are rarely achieved (especially subsurface), and typically only seen for short durations during wildfires or during prescribed burning of slash (Neary et al. 1999).

In 1981 Gifford published research that sampled fire temperatures and soil properties (pH, electrical conductivity [EC], P, K, and percent N and organic C) from the prescribed burn of a 7 year old pinyon-juniper chaining. In this research, peak temperatures were measured using heat sensitive Tempil paints located 10 cm above ground as well as 2.5 cm below ground. Measurements were recorded from interspace and debris piles (ranging from 1 to > 6 trees). Above and belowground temperatures, respectively, were 187ºC and < 55ºC for the interspace area, and > 777ºC and 288ºC beneath the debris piles. Sampling of the soil properties one year post treatment, indicated that EC, P, K, and percent N and organic C had increased significantly at all sampled soil depths (0-10 cm). Sampling of the soil properties two years post treatment indicated that EC and K were the only sampled soil properties still significantly higher in the burned sites than in the unburned sites.

Nutrient specific research of fire effects in vegetation communities that evolved with fire regimes is the most comprehensive with respect to N due its low temperature of volatilization and important role within living organisms (Neary et al. 1999). Typically, burning results in a large loss of total N from the site, usually in organic forms that were unavailable to plants prior to burning (Pyne et al. 1996). After burn temps reach the 200˚C point, total N begins to be lost, and some of this is converted to the inorganic forms usable by plants, such as ammonium (NH_4^+) and nitrates (NO_3^-) (Pyne et al. 1996). When burn temperatures reach between 300 and 400˚C, these volatilized forms of N reach their peaks in the soil, and begin to decline at higher temperatures as these volatilized forms of N are lost to the atmosphere (Pyne et al. 1996). Stubbs and Pyke (2005) found that after broadcast burning western juniper-sagebrush sites, available N (NH_4^+ and NO_3^-) was higher under burned juniper canopy zones in comparison to unburned juniper canopy zones. Although N is commonly attributed to be the most limiting nutrient in pinyon-juniper ecosystems, K and P have also been implied to be possible limiting nutrients (DeBano and Klopatek 1988).

In research specific to P compounds response following burning, DeBano and Klopatek found that soil moisture played a crucial role on phosphatase activity following simulated burning of Utah juniper (*Juniperus osteosperma* [Torr.] Little) soils (DeBano and Klopatek 1988). Comparing burning over wet (50% field capacity) and dry (both treatment surface temperatures of ~475ºC), it was found that the wet burn resulted in a significant increase in phosphatase activity 45-90 days post burn, whereas the dry burn resulted in a continual decline of phosphatase activity over this 90 day period. Only 54% of the total P could be accounted for in the ash residue remaining after the burning treatment, and the authors hypothesized that the loss could be attributed to P being volatilized.

Mechanical Cutting, Piling and Burning

Both cutting and burning and piling and burning methods have been applied in other woody vegetation types as fuel treatments to reduce the risk of wildfires. Through the application of FARSITE modeling in a Sierra Nevada mixed-conifer forest, Stephens (1998) indicated that in the occurrence of a wildfire, both cutting and burning and cutting and piling fuel reduction methods significantly reduced potential fireline intensities, heat per unit area, rate of spread, area burned, and scorch heights, in comparison to no treatment or leaving slash in place. An additional advantage piling and burning has over cutting and burning is the minimized impact of fire on non-target shrub and tree species during prescribed burn implementation; a value recognized in silviculture fuel treatments of other woody species (Jerman 2004).

Published research specific to western juniper sites that have been cut, piled and burned is not available, although there are several noteworthy publications that have looked at this fuel treatment method in pinyon-juniper woodlands as well as in ponderosa pine sites. One of the biggest differences between this treatment and the others previously addressed is that heavy machinery is used to make piles. Although hand and machine piling is often done in commercial forests, piling on juniper sites is typically done with machinery by either pushing material together with a cat, or by utilizing a grappling device such as an excavator. Use of machinery is a cheaper option than hand piling, and also enables the building of larger piles. Compaction of soils is often a concern when utilizing heavy equipment, but if important site factors such as soil texture, organic content, and water regime are accounted for, an educated determination as to whether or not to use heavy equipment can be made (Greacen and Sands 1980). Compaction on a site can be reduced by type of equipment used (track equipment typically exerts less pressure than tire equipment) and timing use when soil is dry (Greacen and Sands 1980). Disturbance of vegetation and soils beneath piles is typically reduced in area and magnified in severity in comparison to cutting and treating in place.

In a southwestern ponderosa pine site, Korb et al. (2004) sampled pH and total C, N, and P along a fire intensity gradient established from 3m outside to 3m inside burned pile edges (low to high gradient) finding that C and N decreased and pH increased along this gradient, however their results from P sampling showed no differences. In similar research also from a southwest ponderosa pine site, Seymour and Tecle (2005) compared slash pile burning (by size of piles as well as not burning) by sampling soil nutrients and pH, finding increases in pH and K in burned areas, but insignificant findings for N, P, Mg, and Ca. Research from southwestern ponderosa pine forests has also found that post-burn the ground beneath burned slash piles is nearly void of perennial plant species, viable seeds, and AM (Korb et al. 2004).

Southwestern ponderosa pine forest research by Korb et al. (2004) also found that the ground beneath burned piles was nearly void of viable seeds and AM (arbuscular mycorrihizal). However, through bioassay sampling (with maize), Haskins and Gehring (2004) found that five years after slash pile burning a piñon-juniper site in northern Arizona AM populations were at similar levels as in control sites, but found that pile burned areas had significantly less understory species diversity compared to control areas. Haskins and Gehring (2004) found the composition beneath pile burned sites had four times the abundance of exotic species compared to control sites, speculating that the AM population returns were partially attributed to exotic invasive plants exhibiting 50% more AM colonization than was found in native plants .

To reiterate, on invasive western juniper sites lacking the understory fuels to carry prescribed fires, removal of juniper is typically done with chainsaws and results in large accumulations of juniper slash left on the site. Land managers must then decide whether to leave the slash in place, which creates a potential fire hazard, or to utilize a follow up treatment such as burning the slash in place or piling and burning it. However, research to guide land managers in the use of these follow-up treatments is limited. No research measuring the response of herbaceous vegetation or soils variables following piling and burning of western juniper slash has been done, and past soils research following burning of cut juniper slash left in place is primarily limited to short term (<2 years) OM, C and N response. Comparison of these common slash treatments (leaving, burning in place, or piling and burning) would benefit land managers in determining what to do with slash accumulations resultant of cutting invasive western juniper woodlands.

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CHAPTER 2

Vegetation Response to Tree Removal Methods in Invasive Western Juniper Woodlands

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Abstract

The lack of understory fuels to carry a prescribed fire on invasive piñon - juniper woodlands may limit options for tree removal to mechanical or a combination of mechanical and fire-treatments. On both public and private lands cutting western juniper (*Juniperus occidentalis* spp. *occidentalis* Hook.) with chainsaws and leaving the trees on site has been the primary treatment method used where ground fuels are limited. However this treatment creates a potential fire hazard, particularly in the first 2-3 years when needles remain suspended on downed trees. Broadcast burning downed trees or piling cut trees with machinery followed by burning are becoming more common practices to reduce fuel loads. However, no research to date has compared the impact these three commonly utilized methods (Cut & Leave; Cut & Burn; and Pile & Burn) have on understory herbaceous vegetation recovery. In this study, herbaceous vegetation cover and density was compared among these three methods on a western juniper site in eastern Oregon. A randomized complete block experimental design (RCBD) was used with five 1-hectare blocks and three treatment plots per block. All trees were cut in the summer of 2005, and the piles were created in the fall of 2005. Burn applications were applied in the fall of 2007. Herbaceous vegetation sampling before and after treatment applications was stratified by: the slash zone (under the three treatments; trees and piles), the litter deposition zone (litter zone around the stump) and the interspace zone. Each zone in each treatment plot was sampled using 40, $0.2m^{-2}$ frames, from which cover (herbaceous species, bare ground, rock, juniper litter, other litter, moss and crust) and density (perennial species) were recorded. Vegetation sampling was conducted in July of 2005 (prior to cutting), and 2007 (after prescribed burn implementation). Results indicated increased bare ground and declines of litter and herbaceous cover and density beneath Pile & Burn and Cut & Burn compared to the Cut & Leave treatment. The largest declines in cover and density of herbaceous species/life forms were beneath the burned tree piles. The litter deposition and interspace microsites indicated the most change occurred in the Cut & Burn plots due to fire spreading from the slash treatment into these microsites. Comparison between the Cut & Burn treatment and the other two treatments indicated significant decreases in herbaceous cover and density for several species/life forms in the litter deposition microsite, and a slight increase in cover for most species/life forms in the interspace microsite. Implications of this research are limited to one year of post burn-treatment data and these treatments require further monitoring.

Introduction

As a result of piñon-juniper woodland expansion across the western United States, government and private land managers have been conducting tree removal treatments across extensive areas of the Intermountain Region (Miller and Wigand 1994, Miller et al. 2008). In the northern Great Basin, western juniper (*Juniperus occidentalis* spp. *occidentalis* Hook.) has dramatically expanded its range, with woodlands having increased by 90% since Euro-American settlement (Miller et al.

2005, Miller et al. 2008). Presently 3.5 million hectares of sagebrush steppe are in various stages of conversion to western juniper woodlands (Miller et al. 2005). Juniper dominance can be detrimental to understory species, altering hydrologic and nutrient cycling, decreasing site productivity and diversity, and eliminating habitat for sagebrush obligate species (Miller et al. 2005).

Land managers have utilized prescribed fire, mechanical cutting, and a combination of these treatments to return post-settlement juniper woodlands to sagebrush-steppe communities. On more densely encroached sites, understory vegetation is usually reduced to levels below which prescribed fire can spread and kill invasive junipers. On sites with limited ground fuels, tree removal methods must be mechanically based (Miller et al. 2005). Cutting with chainsaws has been the mechanical method most commonly used on western juniper sites (Miller et al. 2005); however this method creates a potential fire hazard, particularly in the first 2-3 years when needles remain suspended on downed trees. Therefore, subsequent fuel alteration methods such as broadcast burning downed trees or moving cut trees into piles with machinery followed by burning are becoming more frequently applied on private and public lands. These methods, applied in other woody vegetation types, have been shown to reduce potential fireline intensities, heat per unit area, rate of spread, area burned, and scorch heights (Stephens 1998). Prescribed burning of juniper slash in place has been a largely adopted practice by government agencies such as the Bureau of Land Management (BLM) since the 1980's (Miller et al. 2005). The combination of machine piling and burning of slash provides managers with the ability to localize burning disturbance, reduce the probability of the fire to escape, and simplify prescribed fire implementation.

Removal of western juniper on encroached systems can result in a rapid increase in herbaceous production and cover (Bates et al. 1998, Bates et al. 2000), and influence on site-ecological processes such as increased water capture and storage (Pierson et al. 2007) and nutrient cycling (Bates et al. 2002). Research in juniper control treatments has tended to measure positive herbaceous response following; cutting and leaving (Vaitkus and Eddleman 1987, Rose and Eddleman 1994, Bates et al. 1998, Bates et al. 2000, Eddleman 2002, Bates et al. 2005), cutting and burning (Bates and Miller 2004, Bates and Svejcar 2009). However, no studies have sampled herbaceous response following implementation of a mechanical piling treatment, or made a comparison between the responses of this treatment to the other commonly used cutting and leaving or cutting and burning treatments.

The primary study objective was to determine if understory vegetation response was different among the three tree removal and slash treatments: cutting without burning, cutting followed by broadcast burning, and cutting followed by piling and burning of the slash. To do this, comparisons were made for herbaceous density and cover among the three treatments directly beneath slash, in the tree interspace area between slash/stumps, and in the needle deposition zone. We hypothesized that cutting western juniper would increase available resources to herbaceous species across all plots, thus increasing herbaceous cover and density.

We also hypothesized that burning treatments would result in a decrease in herbaceous vegetation in the first post-treatment growing season in comparison to the non-burned treatment.

Methods

Study Area

The project area was located in the north-eastern corner of the High Desert Ecological Province (Anderson et al. 1998), approximately 25 km NE of Burns, Oregon, in the Devine Ridge watershed (T. 21 S., R. 31 E., Section 24) (Fig. 2.1). The study area was located within the Devine Ridge/Forks of Poison Creek vegetation management project (Environmental Assessment: OR-04-025-044) developed by the BLM (Bureau of Land Management). The project's objective was to reduce western juniper abundance on the landscape to improve hydrologic function, species diversity, and productivity of grass and forb forage for wildlife and cattle.

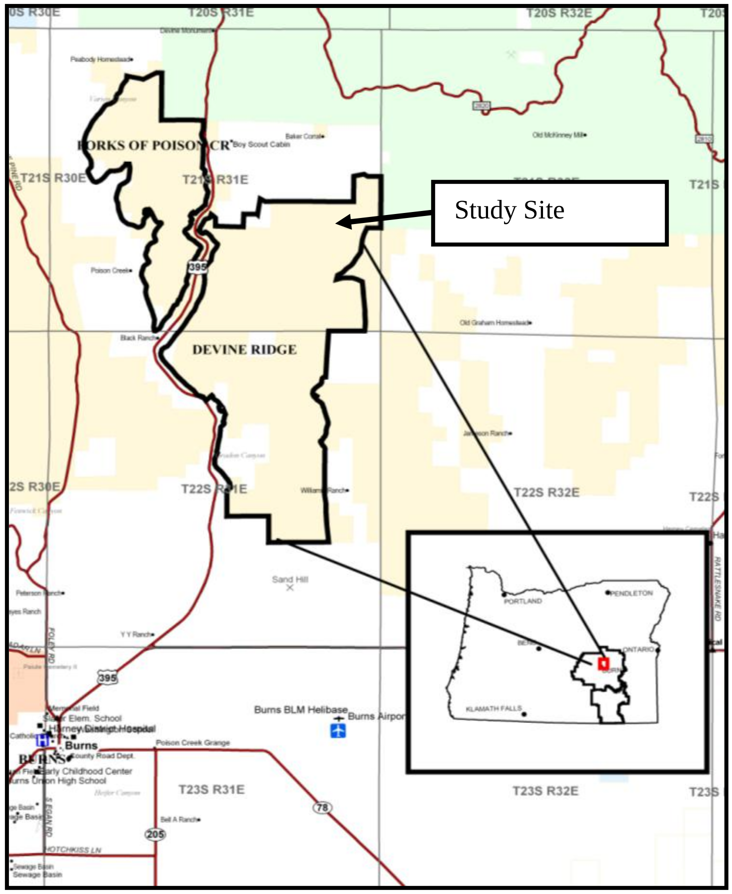

Figure 2.1. Location of Devine Ridge/Forks of Poison Creek vegetation management project area and project study site in Harney County, southeastern Oregon.

Elevation of the study site is approximately 1,890 m on predominately gentle (0-10%) southerly facing slopes that descend into the Harney Basin. Geologically, this site is located on the Danforth formation, which is divided into three distinct layers: the Devine Canyon ash-flow tuff, Prater Creek ash-flow tuff, and Rattlesnake tuff (Orr and Orr 1999). These three layers were all created late in the Miocene, with the Devine Canyon Ash-Flow Tuff occurring 9.7 million years ago, the Prather Creek Ash-Flow Tuff occurring 8.5 million years ago, and the

Rattlesnake tuff occurring 7.1 million years ago (Bishop 2003). These parent materials, as well as thin layers of 6,900 year old Mazama ash influence the local Anatone complex soils (Orr and Orr 1999, Soil Survey Staff 2005). These soils are taxonomically classified as loamy-skeletal, mixed, superactive, frigid, Lithic Haploxerolls (Soil Survey Staff 2005). The mollic epipedon in these soils extends through a shallow A-layer, below which are weakly developed B-layers that extend to lithic contact (basalt) at approximately 43 cm (Soil Survey Staff 2005). The texture throughout the profile of this soil is a silt loam with a "cobbly" coarse fragment modifier in the A-layer, and "gravelly" coarse fragment modifiers for the Bw-layers (Soil Survey Staff 2005).

Climate is typical of the northern Great Basin, with cold-wet winters and wet springs, and warm-dry summers. Based on the PRISM (Parameter-elevation Regressions on Independent Slopes Model) model (PRISM Group, Oregon State University 2004), crop year precipitation (September-August) averages 450 mm (data from 1971-present) (Figure 2.2). Mean annual temperatures at the Burns airport (23 km to the south and 625 m lower in elevation) average -3^{o} C in the winter (December-February), and 17^{o} C in the summer (June-August).

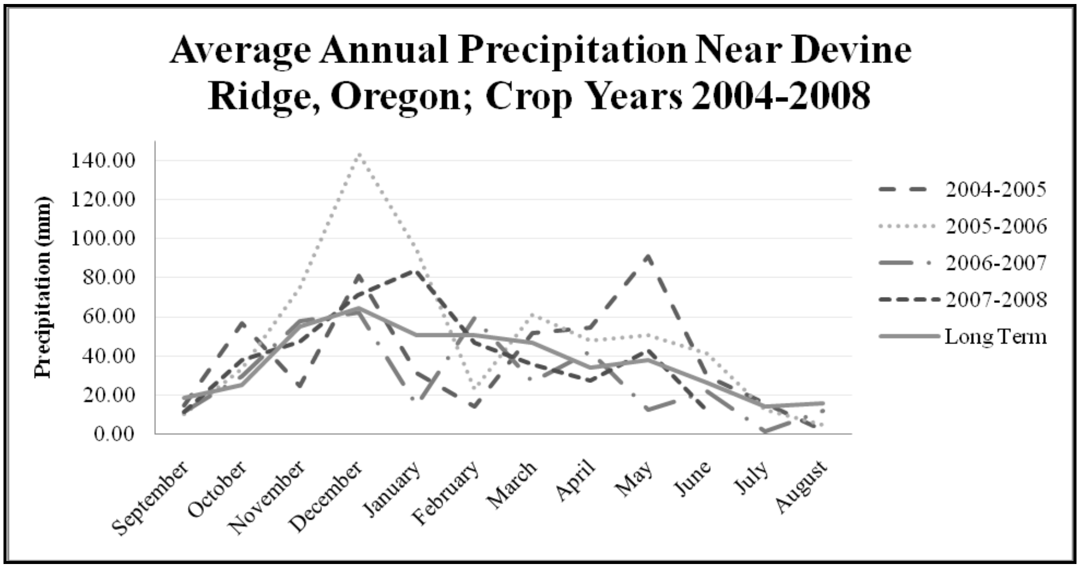

Figure 2.2. Precipitation (mm) at project site with long term, and crop year averages. Data derived from PRISM model (PRISM Group, Oregon State University 2008).

The characteristic vegetation listed by the NRCS for the Anatone complex soil is dominated by curl-leaf mountain mahogany (*Cercocarpus ledifolius* Nutt. *ex* Torr. & A. Gray) and Idaho fescue (*Festuca idahoensis* Elmer), each expected to contribute 25% of the total plant biomass composition, and lesser amounts of antelope bitterbrush (*Purshia tridentata* (Pursh) DC.) and bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Love) estimated to contribute 15% of the total plant biomass composition (Soil Survey Staff 2005). Pretreatment data was indicative of this site shifting towards a dominance of woody species; primarily western juniper (Table 2.1).

Table 2.1. Woody species cover and density prior to treatment.

	Cover (%)			Density (# / hectare)		
	Mean	**&**	**Standard Error**	**Mean**	**&**	**Standard Error**
TREES TOTAL	**47.44**	**+/-**	**1.116**	**640**	**+/-**	**29.16**
Western Juniper	35.15	+/-	1.59	397.5	+/-	31.192
Seedling	0	+/-	0	82.5	+/-	18.875
Sub-dominant	0.055	+/-	0.03259	67.5	+/-	6.29153
Dominant	33.196	+/-	1.53625	212.5	+/-	32.243
Old Growth	0.665	+/-	0.665	32.5	+/-	16.008
Mountain Mahogany	9.244	+/-	1.542	200	+/-	23.805
Seedling	0	+/-	0	32.5	+/-	10.308
Sub-dominant	0.089	+/-	0.05191	30	+/-	14.142
Dominant	7.8275	+/-	0.77843	95	+/-	13.229
Dead	1.333	+/-	0.98199	40	+/-	9.12871
Ponderosa Pine	3.045	+/-	1.0556	25	+/-	8.6603
SHRUBS TOTAL	**1.435**	**+/-**	**0.513**	**315**	**+/-**	**110.9**
Mountain Big Sagebrush	1.104	+/-	0.2699	202.5	+/-	39.449
Antelope Bitterbrush	0.146	+/-	0.0869	22.5	+/-	4.7871

The area has been grazed since the late 1800's. Grazing was discontinued for two years prior to the prescribed fire treatment to increase carrying fuels. To ensure there would be no conflicting disturbances from grazing and enable long term monitoring of the treatments, the blocks were fenced in the spring following the burn treatments.

Experimental Design

The experiment was set up as a randomized complete block experimental design (RCBD) with five 1-hectare blocks (Fig. 2.2). We selected blocks with similar soils, vegetation, and topographic features. Each block was composed of three treatment plots; 1) Cut & Leave, 2) Cut & Burn, and 3) Pile & Burn (Fig. 2.3 and 2.4). Treatment plot locations were chosen randomly within blocks. The Pile & Burn treatment plots covered half of each block, while the remaining two treatment plots each occupied one quarter of each block (Fig. 2.3). The Pile & Burn plots were larger than the other plots in order to provide enough juniper slash (10-15 trees per pile) to create 10 piles needed for each plot.

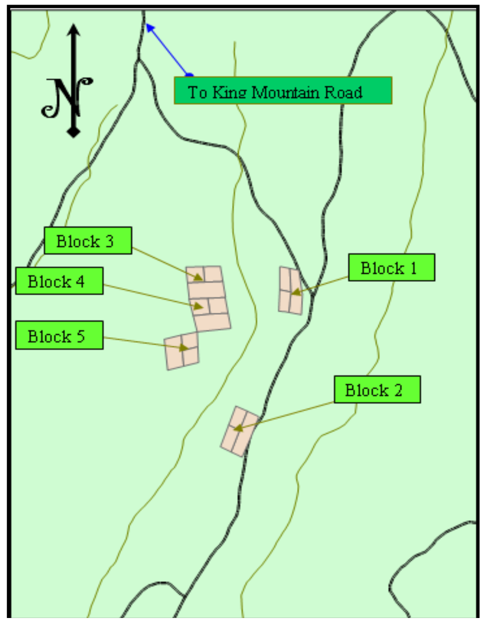

Figure 2.3. Study area map with block Layout

To compare vegetation response among the three treatments we measured plant density and cover in three microsites within each treatment plot; 1) directly beneath cut juniper (slash) (Cut & Leave, Cut & Burn, and Pile & Burn) 2) litter deposition mats around stumps, and 3) interspace areas between deposition areas and slash (Fig. 2.4). Density and cover was recorded by species, and also grouped into life forms which included: shallow-rooted perennial grasses - Sanberg bluegrass (*Poa secunda* J. Presl), deep-rooted perennial grasses, annual grasses – cheatgrass (*Bromus tectorum* L.), perennial forbs, and annual forbs. Slash materials (single trees and piles) were placed on locations that were interspace areas prior to cutting, although trees were located closer to the litter deposition microsites then piles.

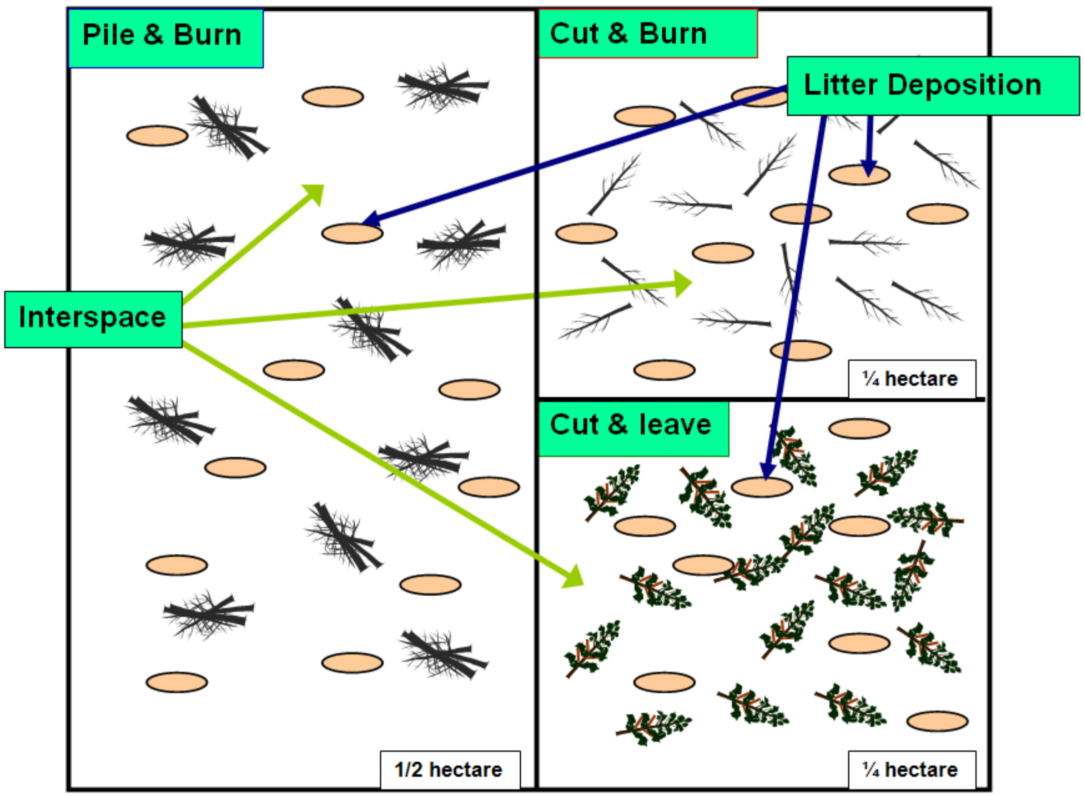

Figure 2.4. Plot and microsite layout of each block. Each block contains three plots: Cut & Burn, Cut & Leave, and Pile & Burn. Within each of these plots three microsites were sampled: under the slash treatment of the plot (trees or piles), in the interspace, and in the litter deposition area.

In July of 2005, prior to treatment, 10 interspace locations were randomly selected in each plot and marked with rebar stakes. Baseline herbaceous sampling was then completed within all blocks, plots, and microsites. Following collection of baseline data, trees were felled with chainsaws in all plots in the late summer/fall of 2005. In the Cut & Leave and Cut & Burn Plots, trees were placed on markers identifying pretreatment quadrat locations by directional falling, and moved by hand if necessary. Piles (about 10-15 trees per pile) for the Pile & Burn plots were placed on marked rebar locations with a small 160LC Deere tracked excavator with a grapple. The prescribed fire treatments were applied in the fall of 2006, with the Cut & Burn plots treated on October, 12 and the Pile & Burn plots treated on October, 19. Burn conditions are described in Table 2.2. Fuel moisture samples were collected from juniper slash by diameter sizes, with <0.625 cm = 1 hr, 0.625 - 2.5 cm = 10 hr, 2.5 - 7.6 cm = 100 hr, and > 7.6 cm = 1000 hr. In July of 2007, post fire treatment sampling was conducted in all blocks, plots, and microsites.

Table 2.2. Conditions from prescribed burn treatments. Fuel and soil moistures determined by drying at 100º C to a constant weight.

		Cut & Burn	Pile & Burn
Weather	Temperature (ºC)	16– 19	9 – 11.5
	Relative Humidity (%)	26 – 28	70 – 79
	Wind (Km/hr)	3 – 8	calm
Soil Moisture (%) *Collected at 0-4 cm*	Under Slash Treatment (± SE)	15.8 ± 1.08	15.3 ± 0.83
	Interspace " "	13.9 ± 0.79	13.4 ± 0.73
Fuel Moisture (%) *Collected from slash in plot*	1 hour " "	4.9 ± 0.20	14.9 ± 0.81
	10 hour " "	4.4 ± 0.20	10 ± 1.79
	100 hour " "	6.1 ± 0.38	7.17 ± 0.34
	1000 hour " "	11.8 ± 1.75	11.8 ± 0.99
Fire Behavior *Burn temps collected with Temple® paints*	Flame Lengths (m)	2.5– 7.5	5 – 9
	Burn Duration (minutes)	5.5 – 7.5	44 – 72
	Max Burn Temps (ºC)…at soil surface	704 – 982	704 – >1093
	" " …2 cm below surface	135 – 316	204 – 538

Herbaceous Vegetation Sampling

Herbaceous canopy cover and density were measured by species in 40 quadrats ($0.2m^{-2}$) in each plot for each microsite in 2005 and 2007 (except for the litter deposition and interspace microsites of the Cut & Leave plots in 2005) (Fig. 2.4 and 2.5). Ground cover of each herbaceous species, life form, bare ground, rock, litter (juniper and other), and biotic crust were visually estimated in each quadrat. Density of herbaceous perennials was measured by counting all individuals within each quadrat. Four quadrats were used to sample beneath each pile and around each stump (litter deposition microsite) and were located about 1 m from the center point (rebar stake or stump edge) in the cardinal directions. Vegetation sampling beneath single cut trees (Cut & Leave and Cut & Burn microsites) was done with two quadrats located beneath branches and two quadrats located beneath the trunk (Fig. 2.5). The interspace microsite data were collected by randomly sampling quadrats from interspace areas not influenced by slash treatments and juniper or shrub canopies.

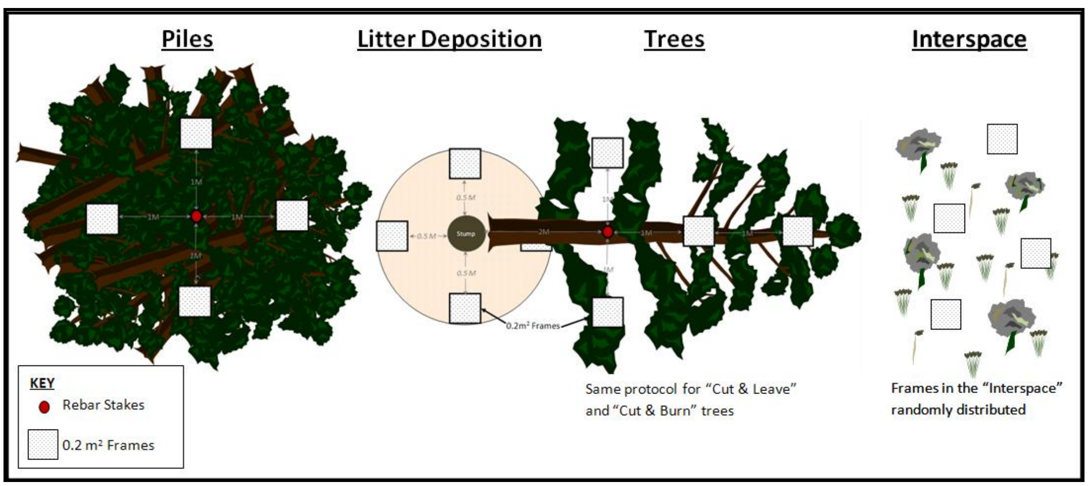

Figure 2.5. Herbaceous sampling protocol for the five microsites. Within each plot, each microsite sampled by 40 frames. 4 at each of the 10 selected piles or trees and stumps, and 40 randomly located throughout Interspace.

Data Analyses

Analysis of variance was used to test for treatment effects on the following response variables; herbaceous cover and density (species and life form), total herbaceous cover and cover of bare ground, rock, juniper litter, other litter, moss, and crust. Density of perennial life form groups was calculated by summing density values for all perennial species within each group. Cover and density response variables were analyzed using a repeated measure ANOVA for a RCBD model (SAS Institute 2002).

Two separate analysis were done; the first analyzing the overall plot treatment effects across all microsites (i.e. plot to plot comparisons, with the three microsites from each plot averaged together) by year, and the second comparing treatment effects by microsite. The overall plot treatment effect model included: block (5 blocks; df=4), treatment plot (Cut & Leave, Cut & Burn, and Cut, Pile, & Burn; df=2), and microsite (slash treatment of plot, Interspace, and Litter deposition; df=2). This model had a total of 6 df, with 28 df for the error term for a corrected total of 34 df. The microsite model included: block (5 blocks; df=4), year (2005 & 2007; df=1), treatment plot (Cut & Leave, Cut & Burn, and Cut, Pile, & Burn; df=2). This model had a total of 8 df, with 16 df for the error term for a corrected total of 24 df.

Data were tested for normality with the SAS univariate procedure. Statistical significance was set at $P<0.05$ and mean separations were done with Fishers's protected LSD procedure.

Results

Fire Characteristics

There were large differences in fire behavior between the two burn treatments in fuel consumption, and fire spread and duration (Table 2.2). In the Cut & Burn plots individual trees produced flames for about 6 ½ minutes before going into the smoldering phase of combustion. Large portions of the trunk and some large diameter limbs were remnant on the site as charred wood. Surface and subsurface (2-cm) soil temperatures beneath the burned trees were higher than anticipated (704-982°C and 135-316°C, respectively) (Table 2.2). Since this was a broadcast burn, the fire spread across the plots moving quickly through the interspace but persisting in the litter deposition areas for long periods in the smoldering phase (some of these areas were still smoldering the next day). Fire spread across the plots in the Cut & Burn treatment resulted in killing many of the associated shrubs. The Pile & Burn treatment burned up to 10 times longer than the Cut & Burn, with active flaming averaging about an hour for each pile, which consumed the majority of slash (Table 2.2). Surface and subsurface (2-cm) soil temperatures reached 704->1093°C and 204-538°C, respectively. Fire was confined to the piles in the Pile & Burn treatment and did not spread across the plot.

Overall Treatment Plot Effect by Year

Pre-treatment cover and plant density were not different between treatment plots. Post treatment cover and plant density were significantly different. Cover groups that differed were total bare ground (*P*-value=0.0001), juniper litter (*P*-value=0.0246), and moss (*P*-value=0.0422). Total herbaceous perennial density was also different between treatments (*P*-value=0.0001). Among species, cover and density were significantly different among treatments for Sandberg bluegrass (cover *P*-value=0.0097; density *P*-value=0.0028) and squirreltail (*Elymus elymoides* Raf. Swezey) (cover *P*-value=0.0397; density *P*-value=0.0006) (Table 2.3). The Cut & Leave treatment had greater cover of juniper litter, moss, lower levels of bare ground, and greater herbaceous cover and density than the other treatments.

Table 2.3. Treatment plot comparison for 2007. Understory cover (%) and density (# plants m^{-2}) means (±SE) by treatment. Column means sharing the same lower case letter are not significantly different (P>0.05).

Cover (%) for 2007 Overall Treatment Plot							
Parameter	Treatment	Bare Ground	Juniper Litter	Moss	Total Herbaceous	*Poa secunda*	*Elymus elymoides*
Cover	Cut & Leave	11.45 ± 3.59 **a**	46.02 ± 6.94 **a**	5.20 ± 1.72 **a**	20.71 ± 2.85 **a**	5.29 ± 0.98 **a**	2.61 ± 0.51 **a**
	Cut & Burn	31.12 ± 2.38 **b**	29.01 ± 4.85 **b**	1.46 ± 0.52 **b**	13.94 ± 2.49 **a**	1.68 ± 0.39 **b**	1.08 ± 0.22 **b**
	Pile & Burn	37.26 ± 5.02 **b**	25.10 ± 3.36 **b**	1.65 ± 0.61 **b**	14.60 ± 2.87 **a**	2.69 ± 0.87 **b**	1.90 ± 0.39 **ab**
Density (# Plants m^{-2}) for 2007 Overall Treatment Plot							
Parameter	Treatment	Bare Ground	Juniper Litter	Moss	Total Herbaceous (perennial sp.)	*Poa secunda*	*Elymus elymoides*
Density	Cut & Leave	NA	NA	NA	5.08 ± 0.66 **a**	2.84 ± 0.61 **a**	0.70 ± 0.10 **a**
	Cut & Burn	NA	NA	NA	2.49 ± 0.54 **b**	0.60 ± 0.13 **b**	0.21 ± 0.04 **b**
	Pile & Burn	NA	NA	NA	3.29 ± 0.68 **ab**	1.30 ± 0.41 **b**	0.47 ± 0.09 **a**

Microsite Response

<u>Slash Treatments</u>

Ground Cover

Year by treatment interactions were significant for herbaceous, bare ground, rock, and juniper litter (Table 2.4). Herbaceous cover decreased in the Cut & Burn and Pile & Burn treatments and were less than the Cut & Leave treatment in 2007 (Table 2.5). Bare ground cover increased significantly in the Pile & Burn and decreased in the Cut & Leave treatments. Juniper litter increased in the Cut & Leave and Cut & Burn treatments and decreased in the Pile & Burn treatment. Cover of other litter, moss and biological crust declined between 2005 and 2007 across all treatments.

Life Forms

Year by treatment interactions were significant for cover of perennial grasses and Sandberg bluegrass (Table 2.4). Cover of these two response variables declined in the Cut & Burn and Pile & Burn treatments and were less than the Cut & Leave treatment in 2007 (Table 2.5). Annual forb cover in the Cut & Leave and Cut & Burn was less in 2007 than in 2005. Cover of both perennial and annual forbs was lowest in the Pile & Burn treatment. Density of total herbaceous perennial species, perennial grasses, and Sandberg bluegrass, declined between 2005 and 2007 in the Cut & Burn, and Pile & Burn treatments and were both less than the Cut & Leave treatment (Tables 2.4 and 2.5). Perennial forb density was higher in the Cut & Leave and Cut & Burn treatments than in the Pile & Burn treatment.

Species

Several main effects and interactions were significant for perennial and annual forb species (Table 2.4). For perennial grass species, year by treatment interactions occurred for density of needlegrass (*Achnatherum thurberianum* [Piper] Barkworth, *A. occidentale* [Thurb.] Barkworth, and *A. lettermanii* [Vasey] Barkworth), and cover and density of squirreltail (Tables 2.4 and 2.5). Needlegrass cover was lower in the Pile & Burn and Cut & Burn than in the Cut & Leave in 2007. Cover and density of squirreltail was greater in the Cut & Leave than the Pile & Burn treatment. Year by treatment interactions occurred for cover of maiden blue eyed Mary (*Collinsia parviflora* Lindl.), miner's lettuce (*Claytonia perfoliata* Donn ex Willd.) and knotweed (*Polygonum* L. spp.), with these species decreasing in all treatments between 2005 and 2007, with the greatest decline in the burn treatments. Cover of other annual forb species was lower in 2007 than in 2005 across all treatments.

Table 2.4. *P*-values for treatment comparisons by cover and density within the slash treatment microsite.

Slash treatment…Analysis of variance *P*-values for canopy cover by groups and species for main effects and interactions			
Ground Cover/ Life Forms/ Species	P-values From Canopy Cover (%) Data Analysis		
	Year (Y)	Treatment Plot (T)	Y*T
Ground Cover			
Total herbaceous	0.0004*	0.3748	0.0016*
Bare ground	0.2994	0.0005*	<0.0001*
Rock	0.0004*	0.0087*	0.0018*
Juniper litter	<0.0001*	<0.0001*	<0.0001*
Other litter	0.0294*	0.7565	0.8339
Moss	<0.0001*	0.0801	0.0640
Crust	0.0006*	0.4250	0.3795
Life Forms			
Perennial grasses	0.0031*	0.7525	0.0008*
Poa secunda	0.0009*	0.7432	0.0094*
Bromus tectorum	0.5352	0.5228	0.0645
Perennial forb	0.6372	0.0385*	0.0632
Annual forb	<0.0001*	0.0089*	0.1455
Species			
Elymus elymoides	0.2301	0.3006	0.0085*
Achnatherum spp.	0.0145*	0.3483	0.0077*
Collinsia parviflora	<0.0001*	0.0073*	0.0159*
Cryptantha spp.	0.0299*	0.1672	0.1394
Epilobium spp.	0.3508	0.2142	0.5010
Gayophytum spp.	0.0042*	0.8138	0.8540
Microsteris gracilis	<0.0001*	0.1163	0.3019
Claytonia perfoliata	0.0347*	0.1507	0.0429*
Polygonum spp.	0.0004*	0.0361*	0.0082*
Slash treatment…Analysis of variance *P*-values for density by groups and species for main effects and interactions			
Groups/ Species	P-values from Density (# plants m^{-2}) Data Analysis		
	Year (Y)	Treatment Plot (T)	Y*T
Groups			
Total herbaceous perennial sp.	<0.0001*	0.0302*	<0.0001*
Total perennial grasses (ex. *Poa*)	0.0003*	0.0142*	0.0004*
Poa secunda	<0.0001*	0.2137	0.0015*
Total perennial forbs	0.0056*	0.0223*	0.8548
Species			
Elymus elymoides	0.0010*	0.0229*	0.0047*
Achnatherum spp.	0.0006*	0.2785	0.1073
Asterisks (*) indicate significance at the 0.05 level.			

Table 2.5. Cover and density means (±SE) from the slash treatment microsite for treatments from years 2005 and 2007.

Treatment Means (±SE) For Cover (%) Within the Slash Treatment Microsite						
Ground Cover/ Life Forms/Species	2005 Means			2007 Means		
	Cut & Leave	Cut & Burn	Pile & Burn	Cut & Leave	Cut & Burn	Pile & Burn
Ground Cover						
Total herbaceous	9.1 ± 2.0 **a***	15.2 ± 2.3 **a***	14.7 ± 1.5 **a***	11.9 ± 3.5 **b***	4.9 ± 1.3 **a***	0.8 ± 0.3 **a***
Bare ground	37.6 ± 7.0 **b**	24.8 ± 4.7 **a**	22.3 ± 2.0 **a**	3.8 ± 1.6 **a**	32.0 ± 3.3 **b**	60.1 ± 3.2 **c**
Rock	24.6 ± 4.4 **b***	31.1 ± 3.6 **c***	14.0 ± 4.1 **a***	4.9 ± 1.4 **a***	16.8 ± 1.7 **b***	17.6 ± 3.1 **b***
Juniper litter	22.1 ± 5.0 **a***	21.8 ± 3.2 **a***	38.4 ± 4.9 **b***	77.3 ± 5.1 **c***	43.2 ± 1.3 **b***	18.8 ± 0.8 **a***
Other litter	4.7 ± 0.9 **a***	4.8 ± 1.0 **a***	5.9 ± 2.2 **a***	2.1 ± 0.6 **a***	3.2 ± 1.4 **a***	2.8 ± 1.2 **a***
Moss	1.8 ± 1.2 **a***	1.6 ± 0.5 **a***	4.3 ± 0.9 **a***	0.2 ± 0.07 **a***	0 ± 0 **a***	0.01 ± 0.005 **a***
Crust	0.5 ± 0.2 **a***	1.1 ± 0.3 **a***	0.6 ± 0.4 **a***	0.03 ± 0.02 **a***	0 ± 0 **a***	0.001 ± 0.001 **a***
Life Forms						
Perennial grasses	1.7 ± 0.44 **a***	2.67 ± 0.50 **a***	3.4 ± 0.77 **a***	2.66 ± 0.58 **c***	1.1 ± 0.21 **b***	0.38 ± 0.22 **a***
Poa secunda	2.3 ± 1.08 **a***	3.98 ± 0.86 **a***	5.5 ± 1.49 **a***	2.86 ± 0.57 **b***	0.32 ± 0.30 **a***	0.16 ± 0.16 **a***
Bromus tectorum	0.16 ± 0.09 **a**	0.82 ± 0.43 **a**	1.22 ± 0.57 **a**	2.73 ± 1.68 **a**	0.64 ± 0.39 **a**	0.03 ± 0.03 **a**
Perennial forb	0.60 ± 0.34 **a**	0.47 ± 0.18 **a**	0.54 ± 0.35 **a**	1.29 ± 0.23 **b**	0.57 ± 0.20 **ab**	0.03 ± 0.02 **a**
Annual forb	4.36 ± 0.70 **ab***	7.3 ± 1.08 **b***	4.02 ± 0.54 **a***	2.36 ± 0.87 **b***	2.18 ± 0.82 **b***	0.18 ± 0.11 **a***
Species						
Elymus elymoides	0.65 ± 0.27 **a**	0.59 ± 0.20 **a**	1.1 ± 0.14 **a**	1.0 ± 0.28 **b**	0.52 ± 0.09 **ab**	0.25 ± 0.11 **a**
Achnatherum spp.	0.89 ± 0.23 **a***	1.9 ± 0.55 **a***	1.34 ± 0.48 **a***	1.53 ± 0.37 **b***	0.25 ± 0.11 **a***	0.08 ± 0.08 **a***
Treatment Means (±SE) for Density (# Plants m^{-2}) Within the Slash Treatment Microsite						
Total perennial sp.	3.34 ± 0.61 **a***	3.60 ± 0.20 **a***	5.07 ± 0.84 **a***	3.32 ± 0.46 **b***	0.92 ± 0.13 **a***	0.31 ± 0.15 **a***
Perennial grasses	1.17 ± 0.20 **a***	1.24 ± 0.13 **a***	1.55 ± 0.27 **a***	1.51 ± 0.37 **b***	0.39 ± 0.14 **a***	0.12 ± 0.09 **a***
Poa secunda	1.35 ± 0.41 **a***	1.79 ± 0.14 **a***	3.09 ± 0.71 **a***	1.34 ± 0.14 **b***	0.18 ± 0.16 **a***	0.14 ± 0.14 **a***
Perennial forb	0.83 ± 0.32 **a***	0.57 ± 0.2 **a***	0.44 ± 0.14 **a***	0.47 ± 0.07 **b***	0.31 ± 0.09 **b***	0.03 ± 0.01 **a***
Elymus elymoides	0.44 ± 0.14 **a***	0.3 ± 0.09 **a***	0.63 ± 0.08 **a***	0.47 ± 0.05 **b***	0.11 ± 0.05 **a***	0.08 ± 0.05 **a***
Achnatherum spp.	0.67 ± 0.16 **a***	0.86 ± 0.17 **a***	0.71 ± 0.24 **a***	0.55 ± 0.17 **a***	0.14 ± 0.05 **a***	0.02 ± 0.02 **a***

Rows within each of the year mean columns sharing the same lower case letter are not significantly different (*P*-value >0.05). Rows displaying an asterisk (*) in the cells indicate a significant difference between year means (i.e year effect).

Litter Deposition Area

Ground Cover

There was a significant year effect among ground cover groups in the litter deposition microsite with the exception of soil crusts (Tables 2.6 and 2.7). Year comparisons indicated that juniper litter and moss were the only variables that decreased between 2005 and 2007 with all other variables increasing during this period. Treatment effects were significantly different for cover of total herbaceous, bare ground, rock, and moss (Tables 2.6 and 2.7). Herbaceous cover was lowest in the Cut & Burn treatment and highest in the Cut & Leave treatment. Cover of both bare ground and rock was higher and moss was lower in both burning treatments compared to the Cut & Leave treatment.

Life Forms

There was a significant year effect among several of the cover and density response variables. Perennial grass and cheatgrass cover increased between 2005 and 2007 (Tables 2.6 and 2.7). Density of total herbaceous perennial species and Sandberg bluegrass significantly decreased between 2005 and 2007, while the density of perennial forb species increased. Cover of perennial grasses was higher in the Cut & Leave treatment than in the two burning treatments with cover in the Cut & Burn treatment the lowest. Perennial forb cover was significantly lower in the Cut & Burn treatment compared to the other treatments. Density of total herbaceous perennial species and perennial forbs was also significantly lower in the Cut & Burn treatment compared to the other treatments.

Species

There were significant year by treatment interactions for cover of needlegrass, and cover and density of squirreltail (Tables 2.6 and 2.7). Needlegrass cover was lower in the Pile & Burn and Cut & Burn than the Cut & Leave treatment in 2007. Cover and density of squirreltail was greater in the Cut & Leave treatment than in both of the burn treatments. Cover of slender phlox (*Microsteris gracilis* [Hook.] Greene) was higher in 2005 than 2007 in all treatments.

Table 2.6. *P*-values for treatment comparisons by cover and density within the litter deposition microsite.

Litter Deposition…Analysis of variance *P*-values for canopy cover by groups and species for main effects and interactions			
Ground Cover/ Life Forms/ Species	P-values From Canopy Cover (%) Data Analysis Year (Y)	Treatment Plot (T)	Y*T
Ground Cover			
Total herbaceous	0.0031*	0.0003*	0.1387
Bare ground	<0.0001*	<0.0001*	0.0547
Rock	0.0297*	0.0198*	0.5516
Juniper litter	<0.0001*	0.6271	0.6395
Other litter	0.0050*	0.8409	0.1027
Moss	<0.0001*	0.0094*	0.2097
Crust	0.7850	0.3469	0.6675
Life Forms			
Perennial grasses	0.0249*	0.0020*	0.0836
Poa secunda	0.8341	0.1008	0.7172
Bromus tectorum	0.0024*	0.0520	0.3205
Perennial forb	0.0971	0.0057*	0.0134*
Annual forb	0.5005	0.4217	0.5837
Species			
Elymus elymoides	0.0002*	<0.0001*	0.0451*
Achnatherum spp.	0.0012*	0.0265*	0.0024*
Collinsia parviflora	0.4060	0.5316	0.3246
Cryptantha spp.	0.4328	0.3659	1.0000
Epilobium spp.	0.1558	0.3941	0.3223
Gayophytum spp.	0.9352	0.1123	0.9352
Microsteris gracilis	0.0439*	0.2110	0.4822
Claytonia perfoliata	0.2801	0.5478	0.2801
Polygonum spp.	0.4120	0.6472	0.3080
Litter Deposition…Analysis of variance *P*-values for density by groups and species for main effects and interactions			
Groups/ Species	P-values from Density (# plants m^{-2}) Data Analysis Year (Y)	Treatment Plot (T)	Y*T
Groups			
Total herbaceous perennial sp.	0.0025*	0.0124*	0.3639
Total perennial grasses (ex. *Poa*)	0.9072	0.4894	0.2414
Poa Secunda	0.0017*	0.0873	0.7804
Total perennial forbs	0.0128*	0.0111*	0.0024*
Species			
Elymus elymoides	0.3499	0.0004*	0.6744
Achnatherum spp.	0.1648	0.7293	0.0128*
Asterisks (*) indicate significance at the 0.05 level.			

Table 2.7. Cover and density means (±SE) from the litter deposition microsite for treatments from years 2005 and 2007.

Treatment Means (±SE) for Cover (%) Within the Litter Deposition Microsite						
Ground Cover/ Life Forms/ Species	2005 Means			2007 Means		
	Cut & Leave	Cut & Burn	Pile & Burn	Cut & Leave	Cut & Burn	Pile & Burn
<u>Ground Cover</u>						
Total herbaceous	N/A	6.7 ± 0.3 **a***	8.9 ± 1.9 **b***	31.5 ± 4.3 **c**	11.6 ± 2.4 **a***	22.0 ± 2.0 **b***
Bare ground	N/A	0.95 ± 0.4 **b***	1.7 ± 0.7 **b***	1.8 ± 0.7 **a**	31.4 ± 6.0 **b***	19.4 ± 3.3 **b***
Rock	N/A	1.3 ± 0.6 **a***	2.5 ± 1.8 **a***	0.8 ± 0.3 **a**	3.4 ± 1.3 **b***	6.0 ± 1.2 **b***
Juniper litter	N/A	65.9 ± 2.3 **a***	65.6 ± 2.4 **a***	43.9 ± 3.1 **a**	39.8 ± 2.9 **a***	42.1 ± 2.0 **a***
Other litter	N/A	2.4 ± 0.5 **a***	4.1 ± 1.4 **a***	8.1 ± 2.3 **a**	9.8 ± 1.3 **a***	6.3 ± 1.2 **a***
Moss	N/A	23.0 ± 2.8 **a***	17.3 ± 3.7 **a***	13.8 ± 1.7 **b**	3.8 ± 0.8 **a***	4.3 ± 1.1 **a***
Crust	N/A	0.08 ± 0.04 **a**	0.04 ± 0.02 **a**	0.4 ± 0.3 **a**	0.2 ± 0.2 **a**	0.01 ± 0.01 **a**
<u>Life Forms</u>						
Perennial grasses	N/A	2.1 ± 0.56 **a***	1.4 ± 0.18 **a***	9.6 ± 0.77 **b**	2.8 ± 1.67 **a***	5.8 ± 1.0 **a***
Poa secunda	N/A	2.6 ± 0.7 **a**	3.7 ± 0.39 **a**	6.4 ± 2.32 **a**	1.8 ± 0.50 **a**	3.9 ± 2.1 **a**
Bromus tectorum	N/A	1.1 ± 0.20 **a***	1.5 ± 0.32 **a***	11.8 ± 3.1 **a**	5.3 ± 1.46 **a***	8.9 ± 1.2 **a***
Perennial forb	N/A	0.27 ± 0.06 **b**	0.16 ± 0.07 **a**	1.2 ± 0.33 **b**	0.09 ± 0.03 **a**	0.96 ± 0.23 **b**
Annual forb	N/A	0.53 ± 0.12 **a**	2.2 ± 1.8 **a**	2.6 ± 0.65 **a**	1.7 ± 0.42 **a**	2.4 ± 0.49 **a**
<u>Species</u>						
Elymus elymoides	N/A	0.41 ± 0.05 **a***	0.41 ± 0.04 **a***	5.0 ± 0.20 **c**	1.4 ± 0.49 **a***	2.9 ± 0.51 **b***
Achnatherum spp.	N/A	0.10 ± 0.07 **b***	0.01 ± 0.007 **a***	0.28 ± 0.09 **a**	0.14 ± 0.08 **a***	0.79 ± 0.19 **b***
Treatment Means (±SE) for Density (# Plants m^{-2}) Within the Litter Deposition Microsite						
Total perennial sp.	N/A	4.9 ± 0.69 **a***	5.9 ± 0.45 **a***	5.0 ± 0.61 **b**	1.8 ± 0.58 **a***	4.1 ± 0.87 **b***
Perennial grasses	N/A	1.6 ± 0.43 **a**	1.16 ± 0.14 **a**	2.0 ± 0.34 **a**	1.02 ± 0.75 **a**	1.7 ± 0.29 **a**
Poa secunda	N/A	3.1 ± 0.92 **a***	4.6 ± 0.43 **a***	2.6 ± 0.79 **a**	0.62 ± 0.18 **a***	1.7 ± 0.91 **a***
Perennial forb	N/A	0.16 ± 0.03 **a***	0.14 ± 0.04 **a***	0.43 ± 0.08 **b**	0.09 ± 0.03 **a***	0.67 ± 0.18 **b***
Elymus elymoides	N/A	0.44 ± 0.09 **a**	0.77 ± 0.13 **b**	1.0 ± 0.11 **c**	0.28 ± 0.08 **a**	0.71 ± 0.10 **b**
Achnatherum spp.	N/A	0.11 ± 0.07 **a**	0.01 ± 0.007 **a**	0.10 ± 0.04 **a**	0.05 ± 0.03 **a**	0.20 ± 0.06 **a**
Rows within each of the year mean columns sharing the same lower case letter are not significantly different (*P*-value >0.05). Rows displaying an asterisk (*) in the cells indicate a significant difference between year means (i.e year effect).						

Interspace Area

Ground Cover

Ground cover attributes in the interspace showed significant year effects for total herbaceous and other litter cover (Tables 2.8; Table 2.9), both increasing by 2007. Rock and juniper litter cover both indicated significance for year by treatment interactions, while moss cover showed a significant treatment effect. Rock cover decreased between 2005 and 2007 and was significantly lower in the Pile & Burn treatment in 2007 compared to the other treatments. Juniper litter decreased in the Cut & Burn treatment between 2005 and 2007 and was significantly lower in 2007 compared to the other treatments. Moss cover increased in the Cut & Leave treatment compared to the two burn treatments which maintained similar levels between 2005 and 2007.

Life Forms

Comparisons of the life form attributes between 2005 and 2007 indicated a trend of increasing cover and density (except Sandberg bluegrass density) (Tables 2.8 and 2.9). There were significant differences among treatments for cover and density of perennial forbs and Sandberg bluegrass. Perennial forb cover and density were higher in the two burn treatments than in the Cut & Leave treatment. Cover and density of Sandberg bluegrass was higher in the Cut & Leave treatment than in the other two treatments. Annual forb cover was significantly higher in the Cut & Burn treatment than in the Pile & Burn treatment in 2007.

Species

There was significant year effect of increasing cover for squirreltail, and needlegrass, as well as in all annual forb species, except miner's lettuce (Table 2.8; Table 2.9). Needlegrass cover was significantly higher in both of the burning treatments than in the Cut & Leave treatment. Cover values for cryptantha (*Cryptantha* Lehm. Ex G. Don spp.) and groundsmoke (*Gayophytum* A. Juss. spp.) indicated a treatment by year effect (Table 2.8), with both species increasing between 2005 and 2007 in all treatments. However, cover of these species was two times more in the Cut & Burn plots than in either of the other treatments. In 2007, slender phlox and knotweed had significant treatment effects with cover in the Cut & Burn treatment being higher than the Cut & Leave and Pile & Burn treatments.

Table 2.8. *P*-values for treatment comparisons by cover and density within the interspace microsite

Interspace…Analysis of variance *P*-values for Interspace cover by groups and species for main effects and interactions			
Ground Cover/ Life Forms/ Species	P-values From Canopy Cover (%) Data Analysis		
	Year (Y)	Treatment Plot (T)	Y*T
Ground Cover			
Total herbaceous	<0.0001*	0.1149	0.4236
Bare ground	0.4456	0.9162	0.5607
Rock	<0.0001*	0.7956	0.0110*
Juniper litter	0.6071	0.0705	0.0321*
Other litter	0.0412*	0.0957	0.0934
Moss	0.8934	0.0189*	0.7150
Crust	0.3316	0.2143	0.7651
Life Forms			
Perennial grasses	<0.0001*	0.0871	0.6059
Poa secunda	0.0246*	0.0074*	0.3351
Bromus tectorum	0.0025*	0.6543	0.3711
Perennial forb	0.0001*	0.0346*	0.5859
Annual forb	<0.0001*	0.0008*	0.0183*
Species			
Elymus elymoides	0.0007*	0.4171	0.1898
Achnatherum spp.	<0.0001*	0.0169*	0.1273
Collinsia parviflora	0.0048*	0.1647	0.5435
Cryptantha spp.	<0.0001*	0.0011*	0.0024*
Epilobium spp.	0.0009*	0.0564	0.1920
Gayophytum spp.	0.0005*	0.0045*	0.0371*
Microsteris gracilis	<0.0001*	0.0295*	0.1170
Claytonia perfoliata	0.8479	0.1883	0.8479
Polygonum spp.	0.0003*	0.0003*	0.0540
Interspace…Analysis of variance *P*-values for density by groups and species for main effects and interactions			
Groups/ Species	P-values from Density (# plants m^{-2}) Data Analysis		
	Year (Y)	Treatment Plot (T)	Y*T
Groups			
Total herbaceous perennial sp.	0.0012*	0.1131	0.5113
Total perennial grasses (ex. *Poa*)	0.0129*	0.7265	0.5906
Poa secunda	0.6246	0.0044*	0.3584
Total perennial forbs	0.0016*	0.0184*	0.2283
Species			
Elymus elymoides	0.0066*	0.1767	0.0853
Achnatherum spp.	0.1181	0.5497	0.8683

Asterisks (*) indicate significance at the 0.05 level.

Table 2.9. Cover and density means (±SE) from the interspace microsite for treatments from years 2005 and 2007.

Treatment Means (±SE) For Cover (%) Within the Interspace Microsite						
Ground Cover/ Life Forms/ Species	2005 Means			2007 Means		
	Cut & Leave	Cut & Burn	Pile & Burn	Cut & Leave	Cut & Burn	Pile & Burn
<u>Ground Cover</u>						
Total herbaceous	N/A	5.7 ± 1.1 **a***	4.8 ± 0.2 **a***	18.7 ± 2.4 **a**	25.3 ± 1.9 **a***	21.0 ± 3.3 **a***
Bare ground	N/A	29.1 ± 4.9 **a**	26.0 ± 6.3 **a**	28.8 ± 4.3 **a**	30.0 ± 3.5 **a**	32.3 ± 5.2 **a**
Rock	N/A	42.6 ± 4.1 **a***	51.6 ± 6.1 **a***	25.4 ± 3.1 **b**	30.0 ± 2.9 **b***	16.9 ± 2.5 **a***
Juniper litter	N/A	12.3 ± 4.5 **a**	9.1 ± 2.1 **a**	16.9 ± 3.6 **b**	4.0 ± 1.0 **a**	14.4 ± 1.8 **b**
Other litter	N/A	9.0 ± 3.3 **a***	7.6 ± 1.0 **a***	7.7 ± 1.3 **a**	9.8 ± 1.4 **a***	14.4 ± 1.0 **b***
Moss	N/A	0.7 ± 0.2 **a**	0.6 ± 0.3 **a**	1.7 ± 0.5 **b**	0.6 ± 0.2 **a**	0.7 ± 0.3 **a**
Crust	N/A	0.8 ± 0.2 **a**	0.6 ± 0.07 **a**	1.0 ± 0.3 **a**	0.5 ± 0.2 **a**	0.4 ± 0.2 **a**
<u>Life Forms</u>						
Perennial grasses	N/A	1.3 ± 0.39 **a***	1.5 ± 0.20 **a***	5.2 ± 1.0 **a**	8.5 ± 1.2 **a***	7.7 ± 1.4 **a***
Poa secunda	N/A	1.9 ± 0.41 **a***	1.5 ± 0.33 **a***	6.6 ± 1.5 **b**	2.96 ± 0.63 **a***	4.0 ± 1.1 **a***
Bromus tectorum	N/A	0.05 ± 0.02 **a***	0.008± 0.006 **a***	1.9 ± 0.83 **a**	1.6 ± 0.61 **a***	2.7 ± 0.72 **a***
Perennial forb	N/A	0.35 ± 0.08 **a***	0.26 ± 0.09 **a***	0.73 ± 0.082 **a**	1.8 ± 0.46 **b***	1.4 ± 0.30 **b***
Annual forb	N/A	2.14 ± 0.56 **a***	1.46 ± 0.08 **a***	4.2 ± 0.89 **a**	10.4 ± 0.91 **b***	5.2 ± 1.1 **a***
<u>Species</u>						
Elymus elymoides	N/A	0.13 ± 0.05 **a***	0.12 ± 0.05 **a***	1.8 ± 0.7 **a**	1.4 ± 0.37 **a***	2.5 ± 0.56 **a***
Achnatherum spp.	N/A	1.1 ± 0.4 **a***	1.3 ± 0.23 **a***	2.7 ± 0.6 **a**	5.78 ± 0.82 **b***	4.1 ± 0.75 **b***
Treatment Means (±SE) for Density (# Plants m^{-2}) Within the Interspace Microsite						
Total perennial sp.	N/A	2.68 ± 0.30 **a***	2.50 ± 0.22 **a***	6.88 ± 1.54 **a**	4.79 ± 0.83 **a***	5.48 ± 0.74 **a***
Perennial grasses	N/A	1.01 ± 0.20 **a***	1.04 ± 0.14 **a***	1.83 ± 0.33 **a**	1.83 ± 0.38 **a***	2.27 ± 0.58 **a***
Poa secunda	N/A	1.29 ± 0.21 **a**	1.10 ± 0.07 **a**	4.61 ± 1.40 **b**	1.00 ± 0.20 **a**	2.04 ± 0.62 **a**
Perennial forb	N/A	0.38 ± 0.04 **a***	0.37 ± 0.12 **a***	0.43 ± 0.08 **a**	1.95 ± 0.73 **b***	1.16 ± 0.22 **b***
Elymus elymoides	N/A	0.10 ± 0.04 **a***	0.07 ± 0.02 **a***	0.60 ± 0.19 **a**	0.24 ± 0.065 **a***	0.63 ± 0.15 **a***
Achnatherum spp.	N/A	0.88 ± 0.19 **a**	0.94 ± 0.15 **a**	0.99 ± 0.20 **a**	1.14 ± 0.19 **a**	1.23 ± 0.22 **a**

Rows within each of the year mean columns sharing the same lower case letter are not significantly different (*P*-value >0.05). Rows displaying an asterisk (*) in the cells indicate a significant difference between year means (i.e year effect).

Discussion

Treatment Response

The two burning treatments increased bare ground, and decreased cover of litter and several perennial grass species compared to the Cut & Leave. However, this comparison averaged microsites equally for each treatment and does not account for the proportion of area occupied by each zone. Thus the microsite analysis was more effective at evaluating differences between treatments.

Microsite Response

Cut & Leave

Herbaceous cover increased in the Cut & Leave treatment after cutting as had been hypothesized. Bates et al. (1998, 2000) and Bates and Svejcar (2009) also measured increased herbaceous cover after cutting on a drier mountain big sagebrush / Thurber's needlegrass (*A. thurberianum*) site. Herbaceous cover in the litter deposition microsite had 1.5 and 3 times more total herbaceous cover than the interspace and slash treatment microsites, respectively in 2007. Bates et al. (1998) reported higher levels of Sandberg bluegrass and squirreltail in the litter deposition microsite compared to other microsites. In this study cover of squirreltail was greater in the litter deposition microsite, however Sandberg bluegrass cover was nearly equal between the litter deposition and interspace microsites. The herbaceous cover and density increases we measured after cutting juniper trees was consistent with other western juniper removal studies where herbaceous production increased (Vaitkus and Eddleman 1987, Rose and Eddleman 1994). On a ponderosa pine (*Pinus ponderosa* C. Lawson) / western juniper ecotone similar to ours, Rose and Eddleman (1994) found that after one year of juniper removal biomass for total grasses increased 1.5 times compared to an uncut control, with squirreltail and Sandberg bluegrass increasing 2.4 and 1.95 times, respectively. In another production study on a drier sagebrush-steppe site, Vaitkus and Eddleman (1987) also noted a response variation between microsites, finding that total herbaceous production increased 67% in litter deposition microsites, and 40% in interspace microsites after western juniper removal.

Burn Treatments

The Cut & Burn and Pile & Burn treatments exhibited more differences among microsites then were observed in the Cut & Leave treatment. Of the three microsites, the slash treatment changed the most after burn treatments, with declines in cover and density for many life forms/species. This supported the hypothesis that burning would negatively impact vegetation and slow response. The magnitude of perennial grass species declines we observed beneath slash treatments was inconsistent with most species specific fire research (Wright and Klemmedson 1965,Young and Miller 1984) because the high fire intensities that were created beneath the juniper slash. Subsurface soil (2 cm) temperatures in this study were between 135-538°C beneath burned slash treatments, and mortality of plant roots and seeds can occur between 48 and 94°C (Neary et al. 1999). The intensity and duration of the burn treatments likely killed many of the perennial species and reduced the available seedbank.

Cut & Burn

The decline in cover and density of herbaceous groups/species beneath Cut & Burn slash treatments were similar to findings by Bates et al. (2006) in a fall burn, but contradicted Bates et al. (2006) findings from a spring burn and Bates and Svejcar's (2009) findings after winter burning. Bates et al. (2006) compared seasonality of burning in juniper stands that were partially cut to facilitate broadcast burn behavior by redistribution of fuels on a more productive aspen (*Populus tremuloides* Michx.) site. Beneath the fall broadcast burn they reported a first year post-fire decline of litter and perennial grass cover which is consistent to the measurements in the Cut & Burn slash treatments of this research. Contrary to findings from this research, Bates et al. (2006) observed significant first year post-fire increases in herbaceous cover beneath juniper slash that was burned in the spring. Bates and Svejcar (2009) also measured slight increases in cover and density of perennial forbs after winter burning of slash compared to cut and leave trees.

The differences in first year post-fire vegetation response between this study and spring burning slash (Bates et al. 2006), and winter burning juniper slash (Bates and Svejcar 2009), are best explained by differences in burning conditions influencing fire intensities. Bates et al.'s spring burn treatment and Bates and

Svejcar's winter burn treatments all had significantly higher relative humidity's, greater1-hr fuel and soil moisture content, and lower air temperatures compared to the burn conditions of this study's Cut & Burn treatment. The "hotter" conditions of this study's burn resulted in fire behavior that carried between cut trees through the interspace and needle deposition microsites, and had a higher percentage of consumption in all hour-fuel categories in comparison to previous research of burning juniper slash in the spring (Bates et al. 2006) and winter (Bates and Svjecar 2009). The higher burn intensities of this study account for the observed higher moralities of herbaceous species compared to previous research, as well as potential depletion of the seedbank.

Fire intensity may have also contributed to differences between treatments in the litter deposition and interspace microsites. The lower cover and densities of life forms and species observed in the litter deposition microsite of the Cut & Burn treatment in comparison to the other treatments was probably due this microsite having been exposed to a smoldering fire for a long duration. However, the interspace area of the Cut & Burn treatment responded with an increase in cover of annual and perennial forbs and some grass species compared to the other treatments. Due to the light fuel loads and short burn durations in the interspace it is likely that this area had lower fire severities, thus existing plants/seed pools were able to respond positively to increased available resources the first year post-burn.

Pile & Burn

There has been no research of herbaceous response following Pile & Burn treatment in western juniper woodlands. However Haskins and Gehring (2004) sampled herbaceous response five years after piñon pine (*Pinus edulis* Engelm.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little.) hand piles were burned on a northern Arizona site. Unfortunately, they did not report what time of year the piles were burned, or what the burn conditions were therefore it is difficult to make an accurate comparison with this study. Haskins and Gehring measured exotic species to be four times greater in density beneath slash piles compared to unburned controls. However, in this research we observed an increase in cheatgrass between 2005 and 2007 in all three of the slash treatment interspaces likely resulting from release from western juniper interference; a trend observed in other western juniper removal studies (Evans and Young 1985, Vaitkus and Eddleman 1986). Although pile burned areas in this research indicated no increase in invasive species, only one year of post-fire data has been sampled and the declines in herbaceous vegetation suggest they may be susceptible to invasive species establishment. In accordance with Davis et al.'s (2006) "theory of fluctuating resource availability," the pile burned areas are highly invasible due to the reduced vegetation and release of resources from burning.

Although herbaceous cover declined the first year after fire, one growing season of post-fire response is unlikely to provide meaningful interpretation of fuel reduction alternatives. The literature suggests that post-fire succession of herbaceous species following western juniper control will often take several years before successional trends emerge (Bates and Svejcar 2009). The juniper treatments compared in this study need to be evaluated for several more growing seasons before solid inferences of the effects of these treatments on herbaceous recovery can be developed.

Conclusions and Management Implications

Selecting fuel reduction treatments to use on private and public lands is typically driven by individual project goals, resource management policies, and cost. Follow-up treatments after cutting juniper trees, such as piling and/or burning, have been developed primarily to mitigate the risk of wildfire resulting from leaving downed trees and slash on site. Applied in other woody vegetation types, these treatments have been shown to reduce fireline intensities, heat per unit area, rate of spread, area burned, and scorch heights (Stephens 1998). Relocating cut trees into large piles with machinery is a relatively new method after juniper cutting that has begun to be used in place of Cut & Burn. Pile & Burn puts all slash into piles, thus breaking up the fuel continuity immediately after cutting. This method also localizes the disturbance of fire to a small area, and has very few weather or logistical constraints when implementing the burn treatment. Another important advantage of Pile & Burn over Cut & Burn is the minimized impact of fire on non target shrub and tree species during prescribed burn implementation; a value recognized in silviculture fuel treatments of other woody species (Jerman 2004).

Although this research found no equipment effect on herbaceous vegetation between treatment plots in 2006 after piles were created, utilizing heavy machinery can subject a site to adverse physical disturbances such as plant mortalities and soil compaction. Surface disturbance from equipment can also manifest into increased surface erosions, particularly on sites with steep slopes (Brady and Weil 2002). Land managers must be cognizant of where and when the use of heavy machinery won't be a practical option due to potential for undesirable effects. Compaction issues typically lesson as soil textures become courser (Gomez et al. 2002) and with decreased soil surface pressure from equipment; which can be achieved by utilizing tracked rather than wheeled equipment (Greacen and Sands 1980).

Although cutting and leaving western juniper trees has been shown to decrease soil erosion (Pierson et al. 2007), burned sites are highly susceptible to erosion due to increased bare ground and weakened soil aggregation (Neary et al. 1999). Similar to the use of equipment, the application of fire becomes a less desirable treatment option as soils become finer textured and slopes steeper. On sites with high erosion potentials such as these, land management options may be limited to cutting and leaving juniper in place or simply not treating the site.

Management implications of this research are limited because only one year of post treatment data was available. First year post-treatment results indicate the Cut & Leave treatment had the lowest effect on cover and density of herbaceous life forms/species, and cover increases were measured in litter deposition and interspace microsites. Both burning treatments indicated significant reductions in juniper litter, with varying degrees of reduced species/life form cover and density. Comparison of burn treatments indicated differences in fire severity and impacted area. Cutting and burning slash indicated slightly lower severities beneath slash treatment, but treatments covered a larger percentage of the ground in comparison to piles. Piling and burning reduced the area impacted by burning slash, and had little to no spread into the interspace or litter deposition microsites however the high fire severities observed beneath piles could facilitate future establishment of invasive species, as observed by Haskins and Gehring (2004). Future research will continue to monitor succession on these plots to make better long term inferences between these juniper fuel reduction treatments.

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CHAPTER 3

Soil Response to Tree Removal Methods in Invasive Western Juniper Woodlands

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Abstract

The lack of understory fuels to carry a prescribed fire on invasive juniper and piñon sites may limit options for tree removal to mechanical or a combination of mechanical and fire treatments. In western juniper (*Juniperus occidentalis* spp. *occidentalis* Hook.), cutting with chainsaws and leaving the trees on site has been the primary treatment method used where ground fuels are limited. However this method creates a potential fire hazard, particularly in the first 2-3 years when needles remain suspended on downed trees. Follow-up such as broadcast burning downed trees or moving slash into piles with machinery followed by burning, are becoming more common practices to reduce large amounts of ground fuels created by the downed trees on private and public lands. In piñon and juniper woodlands throughout the Intermountain West research evaluating the affects of mechanical and fire treatments on soil attributes is limited. In this study, we evaluated soil response in western juniper woodlands to three common methods of tree removal (Cut & Leave; Cut & Burn; and Pile & Burn) eastern Oregon. Soil variables measured before and after treatment implementation were: carbon (C), nitrogen (N), carbon:nitrogen ratio (C:N), phosphorus (P), potassium (K), sulfate-sulfur (SO_4^-), calcium(Ca), magnesium (Mg), organic matter (OM~loss on ignition), cation exchange capacity (CEC), and power of hydrogen (pH). A randomized complete block experimental design with five 1-hectare blocks and three treatments per block (Pile & Burn plots were ½ hectare in size and the other two treatments were ¼ hectare in size) was used for this project. Soil sampling was stratified between the

cut tree or slash microsite (beneath Cut & Leave, Cut & Burn, and Pile & Burn treatments) and the interspace. Three composited soil samples from each microsite, before and after treatment, were collected in summer 2006 and 2007. Results indicated compared slash treatments had little effect on concentrations of C, N, OM, and CEC. Sulfate-sulfur, Mg, Ca, K, and pH all increased in response to burning.

Introduction

As a result of piñon-juniper woodland expansion in the western United States (Gottfried and Severson 1994, Miller et al. 2005) government and private land managers have been conducting tree removal treatments to restore understory productivity, wildlife habitat and watershed values. In the northern Great Basin, western juniper (*Juniperus occidentalis* spp. *occidentalis* Hook.) has dramatically expanded its range, with woodlands having increased by 90% since Euro-American settlement (Miller et al. 2005, Miller et al. 2008). Presently 3.5 million hectares of sagebrush steppe are in various stages of conversion to western juniper woodlands (Miller et al. 2005). Juniper dominance can result in the disruption of hydrologic and nutrient cycles, decreased site productivity and diversity, and the loss of sagebrush obligate species (Miller et al. 2005).

Land managers have used prescribed fire, mechanical cutting, and combinations of these treatments to return post-settlement juniper woodlands to sagebrush-steppe communities. On more densely encroached sites, understory vegetation is usually reduced to levels below which prescribed fire can spread across the site. On sites with limited ground fuels, tree removal methods must be mechanically based (Miller et al. 2005). Cutting with chainsaws has been the mechanical method most commonly used to remove western juniper (Miller et al. 2005); however this method creates a potential fire hazard, particularly in the first 2-3 years when needles remain suspended on downed trees. Therefore, subsequent fuel alteration methods such as broadcast burning downed trees or moving slash into piles with machinery followed by burning are becoming more common practices on private and public lands. These methods, applied in other woody vegetation types, have been shown to reduce potential fireline intensities, heat per unit area, rate of spread, area burned, and scorch heights (Stephens 1998). Prescribed burning of juniper slash in place has been a largely adopted practice by government agencies such as the Bureau of Land Management (BLM) since the 1980's (Miller et al. 2005). The combination of machine piling and burning of slash has recently been applied by public and private land managers to localize burning disturbance and to simplify the administration of prescribed fires.

Removal of invasive western juniper can result in a rapid increase in herbaceous production and cover (Bates et al. 1998, Bates et al. 2000), restore hydrologic processes such as increased water capture and decreased erosion (Pierson et al. 2007), and increase soil nitrogen (N) availability (Bates et al. 2002).

Variable fire intensities and soil heating produces variable effects to soil organisms, consumption of soil organic matter (OM), and losses or redistribution of nutrients pools (Neary et al. 1999, Weast 1988). Knowledge of fire impacts to soil characteristics following applied fire treatments within piñon and juniper woodlands is limited throughout the Intermountain West. Stubbs and Pyke (2005) found that a prescribed burn in a western juniper woodland resulted in significantly higher levels of nitrate (NO_3^-) and ammonium (NH_4^+) in burned canopy areas in comparison to unburned canopy areas. In a pinyon-juniper site in Utah that was burned 7 years after chaining, Gifford (1981) measured increased electrical conductivity (EC) and greater phosphorus (P), potassium (K), and carbon (C).

The purpose of this research was to compare the response of soils to three commonly utilized treatment methods of removing western juniper in eastern Oregon: cutting and leaving (Cut & Leave); cutting and burning (Cut & Burn); and cutting, piling, and burning (Pile & Burn). Soil variables evaluated were: C, N, C:N, P, K, sulfate-sulfur (SO_4^-), calcium(Ca), magnesium (Mg), OM, and cation exchange capacity (CEC). It was hypothesized that pH, P, and K, would increase and C and N would decrease beneath both burn treatments, with these shifts hypothesized to be the greatest under the Pile & Burn treatment due to expected higher burn intensities and durations beneath piles. It was also hypothesized that soil nutrients beneath the Cut & Leave treatment would not change significantly from pretreatment levels.

Methods

Study Area

The project area was located in the north-eastern corner of the High Desert Ecological Province (Anderson et al. 1998), approximately 25 km NE of Burns, Oregon, in the Devine Ridge watershed (T. 21 S., R. 31 E., Section 24) (Fig. 3.1). The study area was part of the Devine Ridge/Forks of Poison Creek vegetation management project developed by the BLM (Bureau of Land Management). The projects objective was to reduce juniper abundance on the landscape in order to improve hydrologic function, species diversity, and herbaceous productivity for wildlife and cattle.

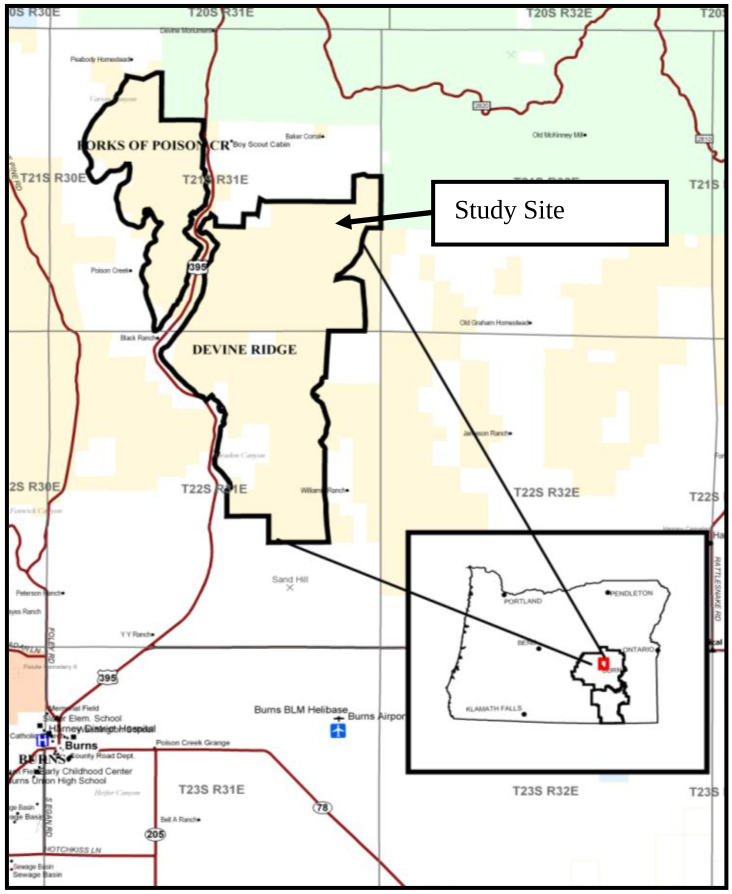

Figure 3.1. Location of Devine Ridge/Forks of Poison Creek vegetation management project area and project study site in Harney County, southeastern Oregon.

Elevation of the study site is approximately 1,890 m on predominately gentle (0-10%) southerly facing slopes that descend into the Harney Basin. Geologically, this site is located on the Danforth formation, which is divided into three distinct layers: the Devine Canyon ash-flow tuff, Prater Creek ash-flow tuff, and Rattlesnake tuff (Orr and Orr 1999). These three layers were all created late in the Miocene, with the Devine Canyon Ash-Flow Tuff occurring 9.7 million years ago, the Prather Creek Ash-Flow Tuff occurring 8.5 million years ago, and the

Rattlesnake tuff occurring 7.1 million years ago (Bishop 2003). These parent materials, as well as thin layers of 6,900 year old Mazama ash influence the local Anatone complex soils (Orr and Orr 1999, Soil Survey Staff 2005). These soils are taxonomically classified as loamy-skeletal, mixed, superactive, frigid, Lithic Haploxerolls (Soil Survey Staff 2005). The mollic epipedon in these soils extends through a shallow A-layer, below which are weakly developed B-layers that extend to lithic contact (basalt) at approximately 43 cm (Soil Survey Staff 2005). The texture throughout the profile of this soil is a silt loam with a “cobbly” coarse fragment modifier in the A-layer, and “gravelly” coarse fragment modifiers for the Bw-layers (Soil Survey Staff 2005).

Climate is typical of the northern Great Basin, with cold-wet winters and wet springs, and warm-dry summers. Based on the PRISM (Parameter-elevation Regressions on Independent Slopes Model) model (PRISM Group, Oregon State University 2004), crop year precipitation (September-August) averages 450 mm (data from 1971-present) (Fig. 3.2). Mean annual temperatures at the Burns airport (23 km to the south and 625 m lower in elevation) average -3^{o} C in the winter (December-February), and 17^{o} C in the summer (June-August).

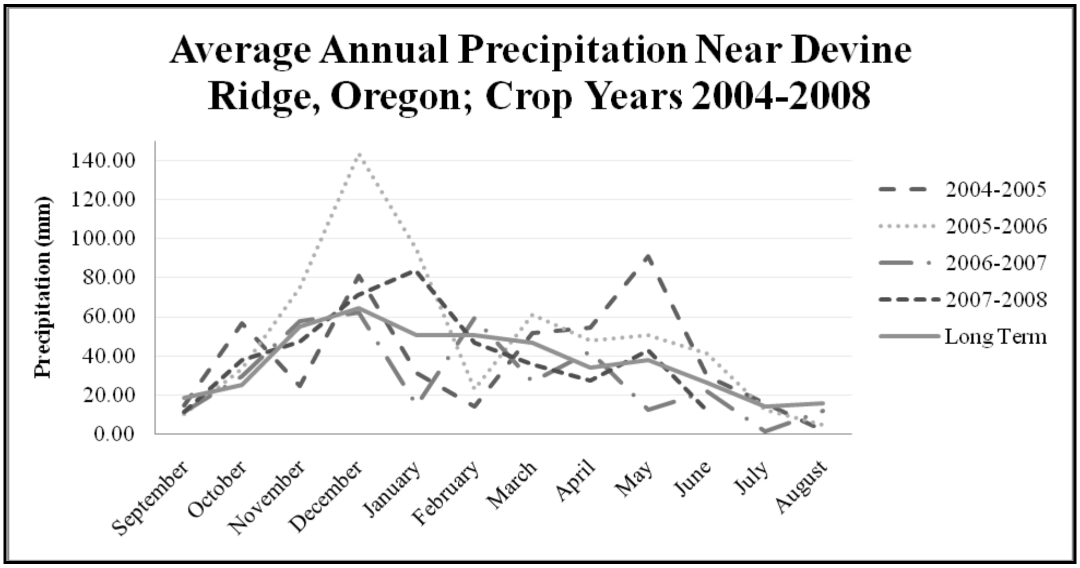

Figure 3.2. Precipitation (mm) at project site with long term, and crop year averages. Data derived from PRISM model (PRISM Group, Oregon State University 2008).

The characteristic vegetation listed by the NRCS (Natural Resource Conservation Service) for the Anatone complex soil is dominated by curl-leaf mountain mahogany (*Cercocarpus ledifolius* Nutt. *ex* Torr. & A. Gray) and Idaho fescue (*Festuca idahoensis* Elmer), each expected to contribute 25% the dried plant biomass composition, and lesser amounts of antelope bitterbrush (*Purshia tridentata* (Pursh) DC.) and bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Love) are estimated to contribute 15% of the dried plant biomass composition (Soil Survey Staff 2005). Pretreatment data was indicative of this site shifting towards a dominance of woody species; primarily western juniper (Table 3.1).

Table 3.1. Woody species cover and density prior to treatment.

	Cover (%)			Density (# / hectare)		
	Mean	&	Standard Error	Mean	&	Standard Error
TREES TOTAL	**47.44**	**+/-**	**1.116**	**640**	**+/-**	**29.16**
Western Juniper	35.15	+/-	1.59	397.5	+/-	31.192
Seedling	0	+/-	0	82.5	+/-	18.875
Sub-dominant	0.055	+/-	0.03259	67.5	+/-	6.29153
Dominant	33.196	+/-	1.53625	212.5	+/-	32.243
Old Growth	0.665	+/-	0.665	32.5	+/-	16.008
Mountain Mahogany	9.244	+/-	1.542	200	+/-	23.805
Seedling	0	+/-	0	32.5	+/-	10.308
Sub-dominant	0.089	+/-	0.05191	30	+/-	14.142
Dominant	7.8275	+/-	0.77843	95	+/-	13.229
Dead	1.333	+/-	0.98199	40	+/-	9.12871
Ponderosa Pine	3.045	+/-	1.0556	25	+/-	8.6603
SHRUBS TOTAL	**1.435**	**+/-**	**0.513**	**315**	**+/-**	**110.9**
Mountain Big Sagebrush	1.104	+/-	0.2699	202.5	+/-	39.449
Antelope Bitterbrush	0.146	+/-	0.0869	22.5	+/-	4.7871

The area has been grazed since the late 1800's. Grazing was discontinued for two years prior to the prescribed fire treatment to increase fine fuels to carry fire in the broadcast treatment. To ensure there would be no conflicting disturbances from grazing and enable long term monitoring of the treatments, the blocks were fenced in the spring 2007, following the burn treatments.

Experimental Design

The experiment was set up as a randomized complete block design (RCBD) with five 1-hectare blocks (Fig. 3.3). We selected blocks with similar soils, vegetation, and topographic features. Each block was composed of three treatment plots; 1) Cut & Leave, 2) Cut & Burn, and 3) Pile & Burn (Fig 3.3 and 3.4). Treatment plot locations were chosen randomly within blocks. The Pile & Burn treatment plots covered half of each block, while the remaining two treatment plots each occupied one quarter of each block (Fig. 3.3). The Pile & Burn plots were larger than the other plots in order to provide enough cut juniper (10-15 trees per pile) to create 10 piles needed for each plot.

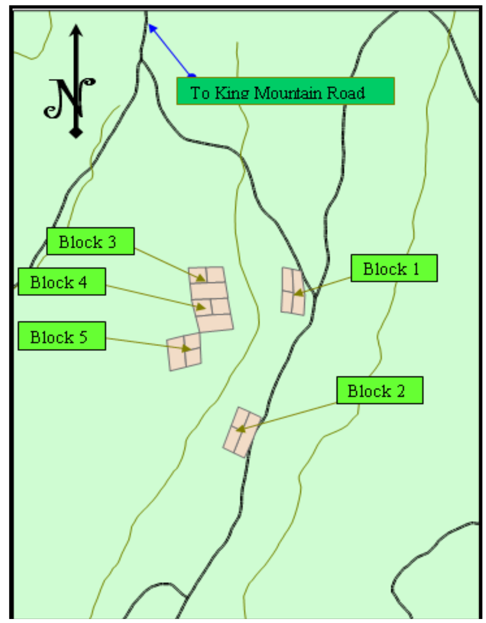

Figure 3.3. Study area map with block Layout

To compare the response of soil response variables among the three treatments we collected composited samples (groups of 3) from two microsites within each treatment plot; 1) directly beneath cut juniper (slash) (Cut & Leave, Cut & Burn, or Pile & Burn), and 2) in the Interspace areas outside the influence of juniper duff or slash (Fig. 3.4). Slash materials (single trees and piles) were placed on locations that were interspace areas prior to cutting, however trees were in closer proximity to litter deposition microsites compared to piles.

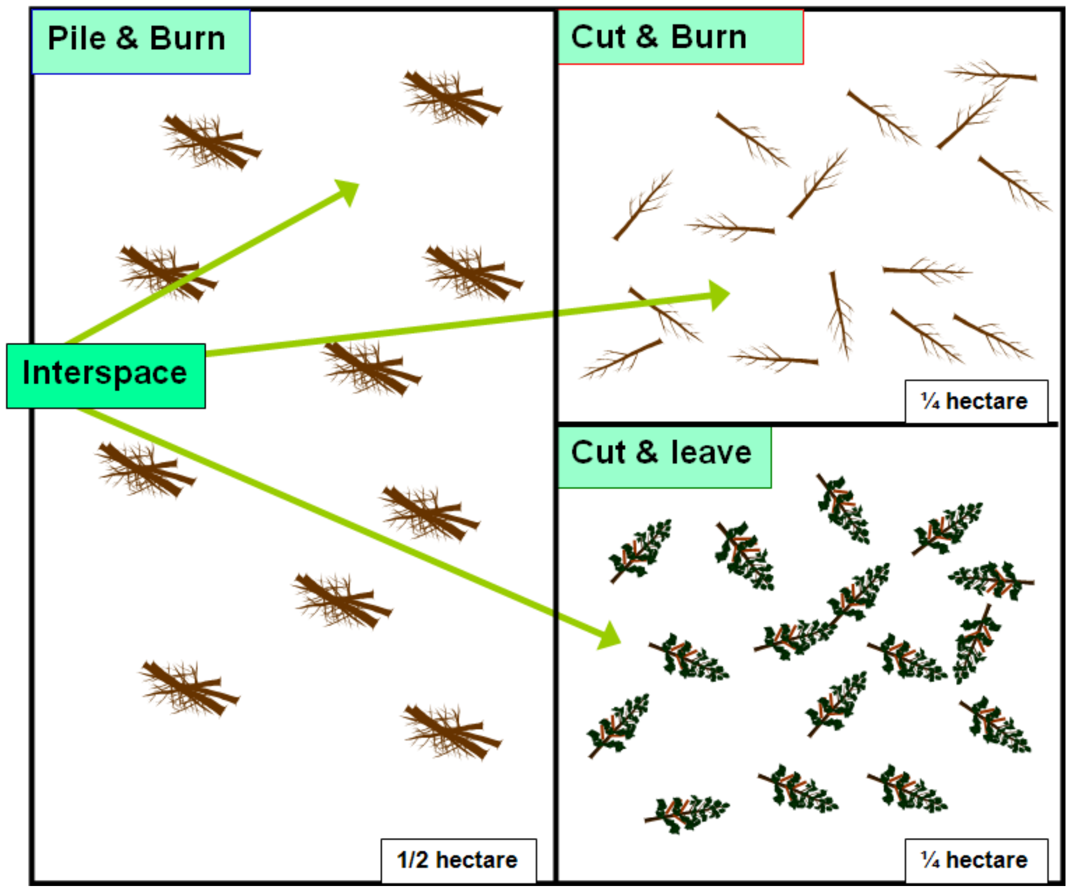

Figure 3.4. Plot and microsite layout of each block. Each block contains three plots: Cut & Burn, Cut & Leave, and Pile & Burn. Within each of these plots two microsites were sampled: under the slash treatment of the plot (trees or piles), and in the interspace (area outside the influence of slash or canopies of trees/shrubs).

Soil samples were collected beneath 3 randomly selected piles or individual cut trees in each plot and composited for each block (these slash locations were marked with rebar stakes). Interspace soil samples were also collected at 3 randomly selected locations in the Interspace of each plot and composited for each block. At each soil sample location, both “deep” (surface to contact with restrictive layer; ~25 cm deep) and “shallow” (surface to 4 cm in depth) samples were collected (except in 2005 data collection, during which only “deep” samples were collected). “Deep” samples were collected to monitor overall C and N pools in the soil profile, while “shallow” samples were collected to measure surface nutrient and chemical changes resulting from the treatments. “Shallow” samples were analyzed for C, N, C:N, P, K, SO_4^-, Ca, Mg, OM, CEC, and pH. Soil samples were dried, sifted through a 2 mm screen, ground and sent in to Central Analytical Laboratories at Oregon State University, where the soil variables were extracted and analyzed. Organic matter, C, and N were reported as percentages of the total sample weight, while P, K, SO_4^-, Ca, and Mg were all reported in parts per million (ppm). Cation exchange capacity was reported as meq/100g. Organic matter was determined using the loss on ignition technique (LOI), and P was extracted with the Bray technique due to the samples being slightly acidic.

Baseline data for 2005 collected only “deep” C and N soil samples. Samples were collected from where the slash treatments were to be placed in each plot and in the interspace of only the Cut & Burn plots. Following collection of the 2005 baseline soil samples, trees were felled with chainsaws in all plots. In the Cut & Leave and Cut & Burn plots, trees were felled on rebar markers, and moved by hand if necessary. Piles (about 10-15 trees per pile) for the Cut, Pile, & Burn plots were made with a small 160LC Deere tracked excavator with a grapple. Piles were placed on marked rebar locations. In the fall of 2006, prior to burn applications, "deep" and "shallow" samples were collected.

The prescribed fire treatment was applied to the Cut & Burn plots on October, 12 and to the Cut, Pile, & Burn plots on October, 19. Burn conditions are described in Table 3.2. Fuel moisture samples were collected from juniper slash by diameter sizes, with <0.625 cm = 1 hr, 0.625 - 2.5 cm = 10 hr, 2.5 - 7.6 cm = 100 hr, and > 7.6 cm = 1000 hr. Post fire treatment sampling in the fall of 2007 repeated the protocols used for the baseline sampling conducted in 2005 and 2006.

Table 3.2. Conditions from prescribed burn treatments. Fuel and soil moistures determined by drying at 100º C to a constant weight.

		Cut & Burn	Cut, Pile, & Burn
Weather	Temperature (ºC)	16– 19	9 – 11.5
	Relative Humidity (%)	26 – 28	70 – 79
	Wind (Km/hr)	3 – 8	calm
Soil Moisture (%) *Collected at 0-4 cm*	Under Slash Treatment (± SE)	15.8 ± 1.08	15.3 ± 0.83
	Interspace " "	13.9 ± 0.79	13.4 ± 0.73
Fuel Moisture (%) *Collected from slash in plot*	1 hour " "	4.9 ± 0.20	14.9 ± 0.81
	10 hour " "	4.4 ± 0.20	10 ± 1.79
	100 hour " "	6.1 ± 0.38	7.17 ± 0.34
	1000 hour " "	11.8 ± 1.75	11.8 ± 0.99
Fire Behavior *Burn temps collected with Temple® paints*	Flame Lengths (M)	2.5 – 7.5	5 – 9
	Burn Duration (minutes)	5.5 – 7.5	44 – 72
	Max Burn Temps (ºC)…at soil surface	704 – 982	704 – >1093
	" " …2 cm below surface	135 – 316	204 – 538

Collection of Soil Samples

Prior to collection of all samples, a small broom was used to sweep off any organic litter on the surface of the soil sampling location. Due to the high amount of fragmented parent material within the soil profile on this site, sampling using soil cores was not feasible. Deep samples were collected by pushing a soil shovel into the ground until it hit a restrictive layer (typically fractured basalt at ~ 25 cm), and extracting a scoop of soil. Next, the shovel was pushed in approximately 2 cm horizontally back from the created hole, and a proportionally uniform (with respect to soil vertical amount) soil sample was collected to the depth of the restrictive layer (Fig 3.5).

The “shallow” sample was collected from the side profile of the small hole left from the collection of the “deep” sample. This was done with a trowel with square dimensions and a 4 cm marker on the side walls. The trowel was pushed into the exposed soil profile to a depth of 4 cm, and the removed square slice of the surface soil was collected (Fig 3.5).

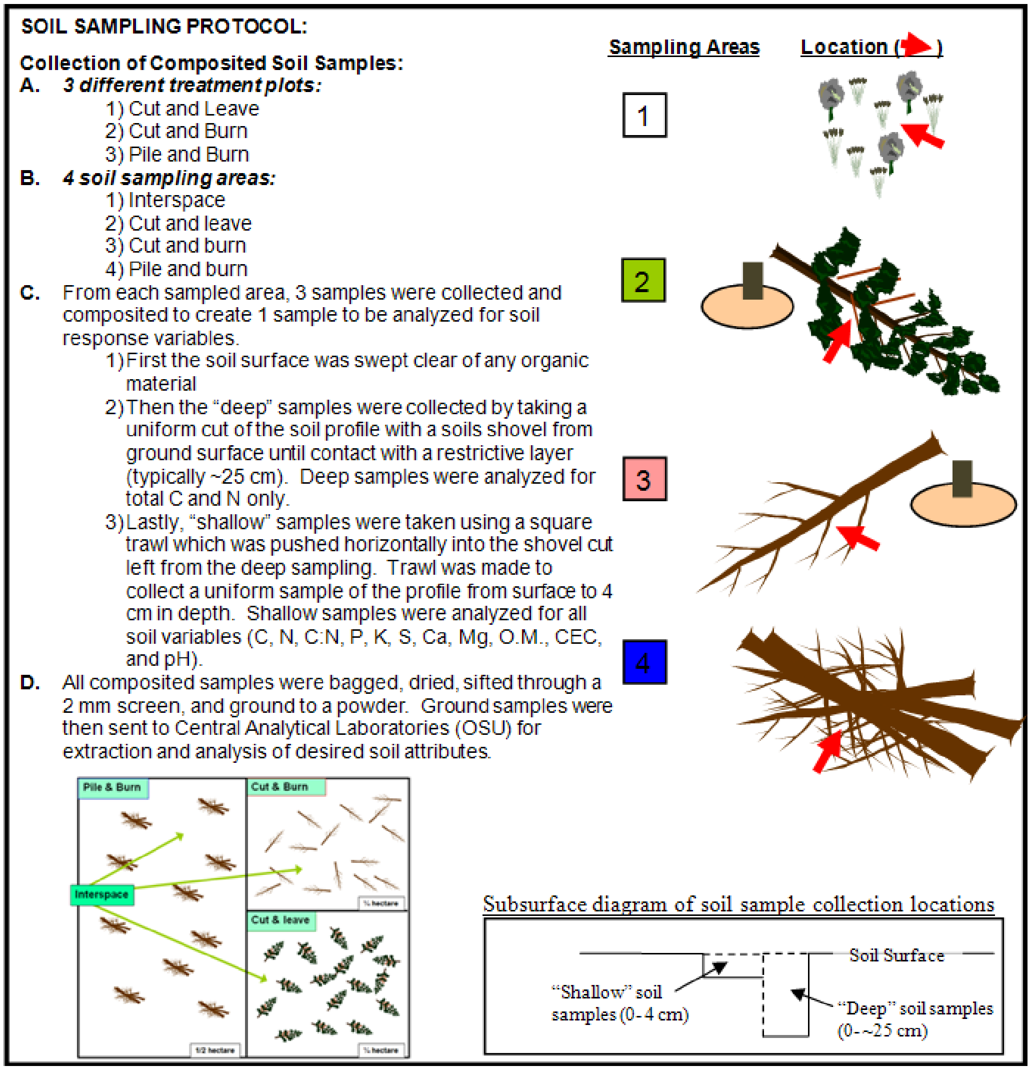

Figure 3.5. Protocol for collection of soil samples.

Data Analyses

Data analysis was done with two separate models; one for the "deep" soil samples, and one for the "shallow" soil samples. Analysis for the deep samples (0-~25cm) compared the 3 treatments (each with slash and interspace microsites), replicated through 5 blocks, for three response variables (C, N, and C:N). Soil response attributes were analyzed using a repeated measure ANOVA for a RCBD model (SAS Institute 2002). The analysis model compared two years of pretreatment data (2005 and 2006) and one year of post treatment data (2007). The model included: block (5 blocks; df=4), year (2005-2007 df=2), treatment (Cut & Leave, Cut & Burn, and Cut, Pile, & Burn df=2), microsite (Slash Treatment and Interspace; df=1), year by treatment interaction (df=3), year by microsite interaction (df=2), treatment by microsite interaction (df=2), and year by treatment by microsite interaction (df=2). This model had a total of 18 df, with 56 df for the error term for a corrected total of 74 df.

For the shallow (0-4cm samples), analysis of variance was used to test for the effect of 3 slash treatments (each with 2 separate microsites), replicated through 5 blocks, on 11 sampled soil attributes. Soil attributes were: C, N, C:N, P, K, SO_4^-, Ca, Mg, pH, OM, and CEC. Soil response attributes were analyzed using a repeated measure ANOVA for a RCBD model (SAS Institute 2002). The analysis model compared pretreatment data (2006) to post treatment data (2007). The model included: block (5 blocks; df=4), year (2006 vs. 2007 df=1), treatment (Cut & Leave, Cut & Burn, and Cut, Pile, & Burn df=2), microsite (Slash Treatment and Interspace; df=1), year by treatment interaction (df=2), year by microsite interaction (df=1), treatment by microsite interaction (df=2), and year by treatment by microsite interaction (df=2). This model had a total of 15 df, with 44 df for the error term for a corrected total of 59 df.

Both the deep, and shallow soil data were also analyzed by year (2005-2007 for the deep, and 2006-2007 for the shallow) to assist in explaining any interactions with year. This model included: block (5 blocks; df=4), treatment (Cut & Leave, Cut & Burn, and Cut, Pile, & Burn df=2), microsite (Slash Treatment and Interspace; df=1), and treatment by microsite interaction.

Data were tested for normality with the SAS univariate procedure. Statistical significance was set at $P<0.05$ and mean separations were done with Fishers's protected LSD procedure.

Results

Fire Characteristics

There were large differences in fire behavior between the two burn treatments in fire spread, duration, and fuel consumption (Table 3.2). The Cut & Burn plots burned relatively quick, with individual trees actively burning for about 6 ½ minutes before going into the smoldering phase of combustion. Trees were mostly consumed, though charred trunks and some large diameter limbs remained. Surface and subsurface (2 cm) soil temperatures beneath the burned trees were higher than anticipated (704-982°C and 135-316°C, respectively) (Table 3.2). Since this was a broadcast burn, the fire spread across the plots moving quickly through the interspace but persisting in the litter deposition areas for long periods in the smoldering phase (some of these areas were still smoldering the next day). Fire spread across the plots in the Cut & Burn treatment resulting in killing many of the non-target shrubs. The Pile & Burn treatment burned for a longer period of time, with active flaming averaging about an hour. Nearly all the piled slash was consumed. Surface and subsurface (2-cm) soil temperatures reached 704->1093°C and 204-538°C, respectively. Although peak soil temperatures were similar between treatments the Pile & Burn resulted in longer durations of fire. Fire in the Pile & Burn treatment was confined to the slash piles and did not spread into adjacent interspaces.

Deep (0~25 cm)

A treatment by year interaction was found to be significant for the deep soil depth (0~25 cm) for both C and N. Carbon and N was significantly higher in the Cut & Leave treatment compared to the two burn treatments in 2006 (pre-burn) but not in 2007 (post-burn).

Shallow (0-4 cm)

Carbon content and C:N were significant for treatment by microsite interactions, and N content was significant for treatment and microsite main effects (Table 3.3). During both years C content and C:N ratio was lower in the interspace compared to the slash treatment microsite, with the Pile & Burn treatment having the lowest C content beneath slash treatments and the lowest C:N in the interspace microsite in comparison to the other treatments in 2006 and 2007 (Table 3.4). The largest C content declines between 2006 and 2007 were beneath the Cut & Leave slash and in the interspace of the Cut & Burn. Nitrogen content was lower in the interspace compared to beneath slash for all treatments. Beneath slash treatments N content was lower beneath piles compared to the other treatments during both 2006 and 2007, however the largest declines between 2006 and 2007 were measured beneath Cut & Leave slash.

Potassium content was significant for treatment by year and microsite by year interactions (Table 3.3). Potassium levels were similar between microsites in 2006 and increased in 2007, with the largest measured increases beneath slash treatments. Increases in the slash treatments were the largest beneath the burned treatments with the Pile & Burn treatment having approximately 250 ppm more K than the Cut & Leave treatment in 2007 (Table 3.4).

Sulfate-sulfur, Ca, Mg, pH, and OM all indicated significant treatment by microsite by year interactions (Table 3.3). Although Ca, OM and pH had significant differences for treatments and microsites in 2006 (post burning), this was primarily due to lower OM and nutrients in the interspace compared to litter deposition microsites. Organic Matter showed declines in both microsites for most treatments between 2006 and 2007, with the most significant decline beneath slash in the Cut & Leave treatment, and the most significant decline in the interspace in the Cut & Burn treatment (Table 3.4). The pH increase in 2007 compared to 2006 was due to burning treatments, with the Cut & Burn and Pile & Burn more basic than the Cut & Leave treatment. Interspace pH levels remained similar between years (2006 and 2007). The two-fold increase in SO_4, and Ca across all treatments and microsites in 2007 compared to 2006 was primarily a result of the burning treatments with SO_4 and Ca beneath burned slash (piles and trees) >1.5 times higher than beneath the Cut & Leave treatment in 2007 (Table 3.4). However, SO_4 increased similarly between treatments in the interspace microsite between 2006 and 2007. Calcium content remained similar between 2006 and 2007 in the interspace for all treatments and beneath Cut & Leave slash; however beneath the burn treatments a 3-fold increase was measured. Although Ca levels were comparable between the burn treatments in 2007, the Pile & Burn treatment experienced a more substantial increase from 2006. Magnesium declined between 2006 and 2007 in both microsites with the interspace showing the largest declines for all treatments. The slash treatment microsite indicated a positive response to burning with Mg beneath the Cut & Burn and Pile & Burn being 2 and 4 times higher, respectively, in comparison to the Cut & Leave in 2007. Phosphorus indicated no response between treatments, microsites, or years (Table 3.3).

Year comparison with all treatments and microsites indicated a decrease in CEC between 2006 and 2007, with the largest declines measured beneath the Cut & Leave slash (Table 3.4). During both years CEC was higher beneath the slash treatments compared to the interspace. In 2007 the Pile & Burn treatment had significantly lower CEC's compared to the Cut & Burn treatment in 2007.

Table 3.3 Soil response variables *P*-values

Analysis of variance *P*-values from analyzed soil attributes for main effects and interactions

Nutrients and Other Soil Attributes Analyzed	Main Effects			Interactions			
	Treatment Plot(T)	Microsite(M)	Year(Y)	T*M	T*Y	M*Y	T*M*Y
Shallow (0-4 cm) Samples							
Nutrients							
Carbon (C)	0.0004*	<0.0001*	0.1078	0.0442*	0.0894	0.8619	0.0618
Nitrogen (N)	0.0018*	<0.0001*	0.1399	0.1691	0.0727	0.7684	0.0639
C:N ratio	0.2069	0.1059	0.4980	0.0033*	0.2829	0.5709	0.4220
Phosphorus (P)	0.1717	0.9854	0.8983	0.9110	0.8821	0.1753	0.1843
Potassium (K)	0.0001*	<0.0001*	<0.0001*	0.0028*	0.1145	<0.0001*	0.6392
Sulfur (SO^4)	0.0203*	<0.0001*	<0.0001*	0.0046*	0.0001*	0.0011*	0.0002*
Calcium (Ca)	0.0329*	<0.0001*	<0.0001*	0.1320	<0.0001*	<0.0001*	<0.0001*
Magnesium (Mg)	0.0046*	<0.0001*	<0.0001*	0.2408	<0.0001*	<0.0001*	<0.0001*
Other							
pH	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	0.0138*
Organic Mater (O.M.)	0.0002*	<0.0001*	0.0026*	0.0123*	0.0321*	0.2854	0.0408*
Cation Exchange Capacity (CEC)	0.0023*	<0.0001*	0.0033*	0.4325	0.0714	0.9030	0.1827
Deep (0- ~25 cm) Samples							
Nutrients							
Carbon (C)	0.0216*	<0.0001*	0.5223	0.6053	0.0046*	0.5588	0.2032
Nitrogen (N)	0.0154*	<0.0001*	0.4359	0.7367	0.0036*	0.3235	0.1409
C:N ratio	0.6787	0.0171*	0.5809	0.1983	0.3043	0.0741	0.1767

Asterisks (*) indicate significance at the 0.05 level.

Table 3.4. Soil attribute means for 2006 and 2007 from the slash treatment and interspace microsites of all juniper slash treatments.

Slash Treatment											
			Nutrients						Other		
Microsite	Year	Treatment	Carbon (C) (%)	Nitrogen (N) (%)	Potassium (K) (ppm)	Sulfur (SO_4) (ppm)	Calcium (Ca) (ppm)	Magnesium (Mg) (ppm)	Organic Matter (%)	pH (scale)	CEC (meq/100g)
Slash Treatment	2006	Cut & Leave	10.9 ± 0.9 **c**	0.67 ± 0.07 **c**	191 ± 22 **a***	5.3 ± 0.56 **b***	3624 ± 410 **c***	123 ± 17 **c***	22.6 ± 2.5 **c***	6.1 ± 0.09 **a***	40 ± 2.3 **c***
		Cut & Burn	6.8 ± 0.8 **b**	0.43 ± 0.05 **b**	218 ± 21 **a***	4.3 ± 0.88 a**b***	2592 ± 195 **b***	110 ± 5.6 **c***	12.7 ± 2.0 **b***	6.22 ± 0.07 **a***	31 ± 1.6 **a***
		Pile & Burn	5.5 ± 0.71 **a**	0.35 ± 0.05 **a**	307 ± 14 **b***	3.6 ± 0.53 **a***	1724 ± 260 **a***	78 ± 11.5**b***	9.8 ± 1.4 **a***	6.28 ± 0.06 **a***	29 ± 3.8 **a***
	2007	Cut & Leave	7.6 ± 1.3 **b**	0.45 ± 0.09 **b**	497 ± 37 **c***	5.4 ± 0.40 **a***	3526 ± 407 **c***	36 ± 8.9 **a***	12.4 ± 2.2 **b***	6.24 ± 0.14 **a***	31± 3.5 a**b***
		Cut & Burn	8.4 ± 1.0 **b**	0.53 ± 0.06 **b**	575 ± 54 **d***	11.7± 0.48 **b***	6528 ± 398 **d***	88 ± 2.8 **b***	12.8 ± 1.7 **b***	6.88 ± 0.09 **b***	33 ± 3.0 **b***
		Pile & Burn	5.1 ± 0.48 **a**	0.35 ± 0.03 **a**	752 ± 80 **d***	14.8 ± 2.3 **c***	6426 ± 366 **d***	151 ± 14.8**d***	8.1 ± 1.0 **a***	7.18 ± 0.09 **c***	25 ± 2.4 **a***
Interspace											
			Nutrients						Other		
Microsite	Year	Treatment	Carbon (C) (%)	Nitrogen (N) (%)	Potassium (K) (ppm)	Sulfur (SO_4) (ppm)	Calcium (Ca) (ppm)	Magnesium (Mg) (ppm)	Organic Matter (%)	pH (scale)	CEC (meq/100g)
Interspace	2006	Cut & Leave	5.4 ± 1.1 **b**	0.35 ± 0.06 **b**	230 ± 18 **a***	3.7 ± 0.53 **a***	2210 ± 283 **a***	85 ± 7.8 **b***	9.8 ± 2.1 **b***	6.1 ± 0.05 **a***	29 ± 4.0 **b***
		Cut & Burn	5.5 ± 1.3 **b**	0.36 ± 0.09 **b**	241 ± 22.5 **a***	3.7 ± 0.7 **a***	2412 ± 258 **a***	108 ± 3.0 **c***	10 ± 2.5 **b***	6.06 ± 0.07 **a***	27 ±2.7a**b***
		Pile & Burn	3.6 ± 0.66 **a**	0.23 ± 0.04 **a**	231 ± 10 **a***	3.1 ± 0.42 **a***	1912 ± 238 **a***	114 ±11.9**c***	6.6 ± 1.2 **a***	6.06 ± 0.04 **a***	22.3 ± 2.3 **a***
	2007	Cut & Leave	4.2 ± 0.91 **a**	0.27 ± 0.06 **a**	309 ± 15 **b***	6.4 ± 0.83 **b***	2534 ± 334 **a***	28 ± 8.6 **a***	7.3 ± 1.5 **a***	6.02 ± 0.07 **a***	22.5 ± 2.6 **a***
		Cut & Burn	3.8 ± 0.46 **a**	0.24 ± 0.03 **a**	348 ± 24 **b***	6.1 ± 0.15 **b***	2620 ± 281 **a***	23 ± 4.2 **a***	6.4 ± 0.6 **a***	6.16 ± 0.05 **a***	21.6 ± 1.5 **a***
		Pile & Burn	4.0 ± 0.40 **a**	0.26 ± 0.03 **a**	365 ± 26.3 **b***	6.2 ± 0.58 **b***	2608 ± 289 **a***	23 ± 2.6 **a***	7.2 ± 0.6 **a***	6.16 ± 0.07 **a***	21.9 ± 1.5 **a***

Means within the same column sharing the same lower case letter are not significantly different (*P*-value >0.05). Means within the same column displaying an asterisk (*) in the cells indicate a significant difference (*P*-value <0.05) between year means (i.e year effect). Comparison between microsites indicated significance (*P*-value <0.05) for all soil attributes in this table.

Discussion

Fire intensities appeared to be the largest contributing factor to observed differences of measured soil attributes. The slash treatments exhibited the largest differences between the Cut & Leave and Pile & Burn for all response variables, thus supporting the first hypothesis. Soil attribute levels beneath the Cut & Burn treatment tended to range between the other two treatments. Most of the observed year effects were concluded to be reflections of fire effects because most attributes expressed significant increases or decreases between 2006 and 2007. The higher levels of OM, C, and N observed beneath the Cut & Leave treatment compared to the Cut & Burn 2006 samples can only be explained by sampling variation, since both the Cut & Leave and Cut & Burn treatments should have exhibited similar baseline (2006) nutrient levels. Observed differences between the Pile & Burn and the other treatments in 2006 were likely due to piles being located further from the litter deposition microsite than felled trees.

Both burn treatments indicated higher fire intensity values than reported from other fire research (Table 3.2) (Gifford 1981, Debano et al. 1998, Neary et al. 1999, Massman et al. 2003). The Pile & Burn treatment had the lowest levels of C, N, OM, and CEC in comparison to the other treatments during both years, however levels of these attributes were similar between years, suggesting this difference was caused more by the location of piles than the actual treatment. Significant N volatilization losses likely occurred from burned slash in both the burned treatments since measured soil surface temperatures during the prescribed fire exceed reported volatilization levels (White et al. 1973). However, enough N must have been retained in the ash beneath the burn treatments to maintain N levels in 2007 at and above (Pile & Burn and Cut & Burn, respectively) those measured in 2006. The N declines between 2006 and 2007 observed beneath the Cut & Leave slash were likely due to immobilization of N. Bates et al. (2002) measured lower available N under unburned slash as a result of increased litter decomposition (Bates et al. 2007).

Macronutrients (SO^4, Mg, Ca, and K) and soil pH all increased beneath one or both of the burn treatments despite burn temperatures being above reported volatilization levels for most of these elements (Weast 1988). Others have measured similar increases in pH and K after burning (Korb et al. 2004, Seymour and Tecle 2005). The increases in soil pH and base cations Mg and Ca in the soil surface beneath burned piles are likely closely linked, as increased base cations results in the displacement of H (hydrogen) and Al (aluminum) ions, causing a liming effect on the soil (Killham 1994). The lower amount of slash burned in the Cut & Burn treatment compared to the Pile & Burn treatment is likely the reason the Mg, Ca and pH level increases weren’t as substantial in the soils beneath Cut & Burn slash. Phosphorus has been reported to increase after burning piñon-juniper slash piles (Gifford 1981), however in this study soil P did not change in response to treatment.

Conclusions and Management Implications

Determination of which of these treatments to use is largely dependent upon management objectives and site conditions. The high level of vegetation mortality and nutrient release measured beneath the Pile & Burn slash treatment could open up these areas to invasive species establishment in the future, as was observed by Haskins and Gehring (2004). The Cut & Burn treatment had similar vegetation disturbances and nutrient releases beneath burned slash. However, because of the number of cut trees covering the area in the Cut & Burn treatment, burning impacted a much larger area than the Pile & Burn treatment. Thus a potential that invasive species establishment might become more of a management problem in disturbed areas of the Cut & Burn treatment than the Pile & Burn treatment. The Cut & Leave treatment was the least impacted of the three treatments in soil response variables. However, leaving slash in place increases the risk of a higher severity wildfire than the other treatments (Stephens 1998). Soil chemistry beneath each of the treatments will likely continue to shift and impact future vegetation changes. The Cut & Leave treatment will continue to incorporate nutrient rich OM into soils beneath slash as trees break down over time (Bates et al. 2002, Bates et al. 2007). Although we observed first year post-fire increases for most nutrients measured beneath the burned slash treatments, volatilization of nutrients in aboveground slash might actually have resulted in a net loss of site nutrient pools (DeBano et al. 1998).

Although not measured in this research, erosion and compaction of soils are important considerations for land managers when trying to determine the appropriate method to treat cut juniper slash. Cutting and leaving of juniper in place has shown to reduce soil erosion in comparison to not cutting (Pierson et al. 2007), however burned sites become more susceptible to erosion due to increased bare ground and dissemination of soil aggregates (Neary et al. 1999). Erosion potential is most pronounced on sites with steep slopes facilitating surface movement of water (Brady and Weil 2002). Similarly, use of heavy machinery for the Pile & Burn treatment can subject soils to compaction, especially on finer textured (clayey) soils (Gomez et al. 2002). Compaction risk can be reduced by using equipment when soils are dry, and reducing the pressure applied to the soil surface by using tracked rather than wheeled equipment (Greacen and Sands 1980). On sites with steep slopes, low vegetation cover, and fine textured soils that are at high risk for soil erosion and compaction, management options should be limited to the Cut & Leave treatment or not treating the site at all.

Long term monitoring of the soil chemistry alterations between these three slash treatments is needed to make solid inferences of the site recovery following treatments. In treating of invasive western juniper woodlands, land managers must be cognizant of the soil alterations each of these treatments has, as well as the effect these alterations have on other site resources. Inference of our findings is limited to similar soils, climate, and treatments, and is constricted to one year post-treatment.

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CHAPTER 4

Vegetation and Soil Response to Tree Removal Methods in Invasive Western Juniper Woodlands: General Conclusions

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General Conclusions

Vegetative recovery following disturbance is linked to the soil's physical, chemical, and biological functions and processes (Neary et al. 1999). Analysis from both vegetation and soils data the first year following treatment indicated that beneath the slash microsite the largest impacts occurred in the burned slash treatments (Pile & Burn, Cut & Burn) while the fewest changes occurred in the Cut & Leave treatment.

Management objectives and site characteristics are important factors in determining which of these treatments to use to reduce slash amounts and decrease fire risk after cutting juniper trees. Presence of invasive species on site, such as cheatgrass, is one of the most important site conditions to consider when selecting between these slash treatments, however all of these treatments pose potential for invasive species establishment. High levels of vegetation mortality and nutrient releases observed beneath the burned slash will potentially make these sites available for invasive species establishment. Haskins and Gehring (2004) measured a four-fold increase of invasive species from sampling under piñon-juniper pile sites five years after burning. Although we measured smaller, but similar vegetation mortalities and soil attribute changes beneath the Cut & Burn slash in comparison to the Pile & Burn slash, there is also potential for establishment of invasive species after this treatment. Bates et al. (2006) found that high mortalities of native herbaceous species following a fall burn of cut juniper trees resulted in dominance by invasive annuals and biennials. However, Bates et al. (2006, 2009) also demonstrated that invasive establishment following burning of cut juniper trees can be reduced or prevented by implementing burn treatments when fuel and weather conditions produce lower fire intensities. Although the Cut & Leave treatment resulted in increased herbaceous cover and few soil attribute changes, leaving slash in place initially increases the potential of a higher severity wildfire than would be expected in the other treatments (Stephens 1998).

Erosion and compaction are important considerations for land managers prior to choosing a juniper slash reduction treatment. Burning increases bare ground and weakens soil aggregation making sites more susceptible to erosion (Neary et al. 1999). Sites with steep slopes are most susceptible to erosion and treatment disturbances exposing soil, such as burning or using equipment, should be avoided (Brady and Weil 2002). Compaction risk from heavy equipment is highest on fine textured soils, and is increased with higher soil water contents (Gomez et al. 2002). Equipment that subjects the soils surface to less pressure (such as tracked equipment) can help mitigate soil compaction (Greacen and Sands 1980), however there are site conditions when equipment should not be used.

Although this research demonstrated the short term soils and vegetation response to these three slash treatments there are several improvements that could be made.

Improvements

I. Comparison of these slash treatments is inadequate with only one year of post-fire vegetation and soil attribute sampling. Research is being continued to better determine the long-term vegetation and nutrient dynamics associated with these treatments. In similar vegetation research, Bates and Svejcar (2009) found that vegetation dynamics can take several years to reach a stable community. The post fire nutrient increases and decreases observed were probably the biggest changes to be captured, however another year of sampling would be useful to determine how long these observed nutrient shifts persisted. A degree of nutrient leaching out of the remnant ash beneath the burn treatments will likely occur (DeBano et al. 1998). In soil nitrogen research following slash pile burning, Covington et al. (1991) found that inorganic nitrogen took five years to return to baseline levels.

II. Although an array of nutrients known to be critical to plants and respond to fire were selected for this research, one shortcoming was in the nitrogen (N) sampling. Determining the response of available soil N would improve understanding of the connection between soils and vegetation compositional changes to these treatments. Determining what available N levels did in the Cut & Burn interspace microsite compared to the other two treatments would have been useful data to have collected. Likely the two-fold increase of annual forbs observed in the Cut & Burn interspace compared to the other treatments was a result to increased available N, which has been observed in other research following fire application (Bates et al. 2002, Stubbs and Pyke 2005).

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