Quantification of Fuel Loads after Woody Vegetation Reduction Treatments in Pinyon-Juniper Woodlands and Sagebrush Steppe

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Authorization to Submit Thesis

This thesis of Samuel S. Wozniak, submitted for the degree of Master of Science with a Major in Natural Resources and titled "Quantification of Fuel Loads after Woody Vegetation Reduction Treatments in Pinyon-Juniper Woodlands and Sagebrush Steppe" has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

This thesis contains two chapters that analyze and summarize fuel loading data after woody plant reduction treatments in sagebrush steppe and pinyon-juniper woodlands in the Intermountain West. Four treatments were implemented at sagebrush-bunchgrass sites in Washington, Oregon, Nevada, and Utah: untreated control, prescribed fire, mowing, and application of tebuthiuron (herbicide). Three treatments were implemented at all of the pinyon-juniper woodlands sites in Oregon, California, Nevada, and Utah: untreated control, prescribed fire, and cutting (lop and lay), with an additional mastication treatment implemented at the Utah sites. Land managers use these treatments to alter fuel beds and increase understory cover by reducing competition from overstory woody plants. The first chapter of this thesis comprises analysis of treatment longevity and changes in surface fuel loads after mastication of pinyon-juniper woodlands in Utah. The second chapter provides summary statistics of fuel loads for the sagebrush steppe and pinyon-juniper treatments at 10 years post-treatment. The summary data presented in the second chapter is intended to be used in a fuel loading guide that will provide data for land managers to use in fire behavior and effects modeling.

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Dedication

I would like to thank my partner Lisa and my family for their support throughout graduate school.

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Statement of Contribution

The first chapter of this thesis is prepared in the form of a co-authored manuscript to be submitted to the journal of Rangeland Ecology and Management. I completed the analyses and wrote the manuscript. Eva Strand, Timothy Johnson, April Hulet, Bruce Roundy, and Kert Young helped edit the manuscript and provided suggestions for statistical analyses. This research is part of the larger SageSTEP project and builds on the research of Young et al. (2015), and Shakespear et al. (2014). The second chapter is intended to be published as a follow-up fuels guide to Stebleton and Bunting (2009) and Bourne and Bunting (2011). The methods of the second chapter are therefore adapted from Bourne and Bunting (2011).

Chapter 1: Treatment Longevity and Changes in Surface Fuel Loads after Pinyon-Juniper Mastication

Abstract

In the Intermountain West, land managers masticate pinyon pine (*Pinus* spp.) and juniper (*Juniperus* spp.) trees that have encroached sagebrush steppe communities to reduce canopy fuels, alter potential fire behavior, and promote growth of understory grasses and shrubs. At three study sites in Utah, 45 sampling plots spanning a range of tree cover from 5-50% were masticated. We measured surface fuel load components three times over a 10-year period. We also measured tree cover, density, and height as indicators of treatment longevity. Changes in these variables were analyzed across the range of pre-treatment tree cover using linear mixed effects modeling. We detected decreases in 1-hr downed woody debris by 5-6 years post-treatment, and from 5-6 to 10 years post-treatment, but did not detect changes in 10-hr or 100 + 1000-hr down woody debris. By 10 years post-treatment, there was very little duff and tree litter left for all pre-treatment tree cover values. Herbaceous fuels (all standing live and dead biomass) increased through 10 years post-treatment. At 10 years post-treatment, pinyon-juniper cover ranged 0-2.6%, and the majority of trees were less than 1 m in height. Given that 1-hr fuels were the only class of downed woody debris that decreased, it may be beneficial to masticate woody fuels to the finest size possible. Decreases in 1-hr downed woody debris and duff + litter fuels over time may have important implications for fire behavior and effects, but increases in herbaceous and shrub fuel loads should also be taken into account. At 10 years post-treatment, there was no risk of canopy fire, understory grasses and shrubs were not being outcompeted by trees, and average pinyon-juniper canopy cover was less than 1%. In areas where sage-grouse are a management concern, we recommend monitoring mastication treatments at 10-15 years post-treatment.

Introduction

Degradation of rangelands is a global issue, and often results in decreased plant cover and a shift from herbaceous to woody vegetation (Geist and Lambin 2004; D'Odorico et al. 2013). In the past 160 years in the Intermountain West, USA, sagebrush- (*Artemisia* spp.) steppe communities have experienced substantial declines in quality and quantity of habitat for sagebrush-obligate species. One important factor in the decline of these communities is the expansion and infilling of pinyon-juniper (*Pinus* spp. and *Juniperus* spp.) woodlands (Miller and Tausch 2001). Before Euro-Americans settled the Intermountain West, frequent wildfires limited persistent pinyon-juniper woodlands to rocky outcrops and rimrock—places that lacked the understory vegetation often needed to carry fire

(Burkhardt and Tisdale 1976; Miller and Tausch 2001; Waichler et al. 2001; Miller et al. 2008; Miller and Heyerdahl 2008). Due to changes in land management, such as fire suppression, livestock grazing that reduced fine fuels, and a reduction in Native American fire use, fires have become less frequent in the elevation ranges that pinyon-juniper woodlands are able to occupy (Cottam and Steward 1940; Burkhardt and Tisdale 1976; Miller and Rose 1995; Gruell 1999; Miller et al. 2008). Without wildfires that kill pinyon pine and juniper trees, these woodlands have greatly increased in density and area (Miller 2008). Pinyon-juniper woodland expansion has also been facilitated by increases in atmospheric CO_2 (Polley et al. 1996), and an unusually wet climate during the late 1800s and early 1900s that aided pinyon and juniper regeneration (Miller and Tausch 2001). Thus, pinyon-juniper woodlands have expanded into or infilled on more than 18 million ha in Intermountain West since Euro-American settlement (Miller 2008).

As sagebrush-bunchgrass communities transition to dense pinyon-juniper woodlands in the absence of periodic fire, there are many changes to wildlife habitat, ecosystem functions, and fuel loads. During this transition, shrubs, grasses, and forbs decrease due to competition with trees for water (Roundy et al. 2014a; Ray et al. 2019) and nutrients (Bates et al. 2000; Rau et al. 2011; Young et al. 2014). These changes in vegetation reduce forage for ungulates such as cattle (*Bos taurus*; Miller 2005) and mule deer (*Odocoileus hemionus*; Rosenstock 1989); and reduce suitable habitat for sagebrush-obligate species such as sage-grouse (*Centrocercus urophasianus*; Baruch-Mordo et al. 2013; Bates et al. 2017a) and pygmy rabbits (*Brachylagus idahoensis*; Larrucea and Brussard 2008). Due to reduced density of understory plants that aid in water infiltration, pinyon-juniper woodlands often experience increased runoff and soil erosion (Reid et al. 1999; Roundy et al. 2014; Pierson et al. 2015). As pinyon-juniper woodlands mature, the fuel structure of the system changes from one dominated by fine, surface fuels (e.g. herbaceous and shrub fuels), to a system dominated by canopy fuels that include coarse woody fuels not commonly found in sagebrush-steppe communities (Miller and Tausch 2001; Sabin 2008; Tausch 2009; Miller et al. 2013; Young et al. 2015). In older pinyon-juniper woodlands, risk of high intensity crown fires increases as canopy fuel load and continuity increases (Brown 1973; Pyne 1996; Miller et al. 2013; Strand et al. 2013; Keane 2015). High intensity crown fires are not only difficult for wildland firefighters to control, but may also lead to undesirable ecological outcomes, such as water-repellant soils (Zvirzdin et al. 2017) and/or an invasive, annual grass-dominated state that is difficult and costly to restore (Miller et al. 2013; Chambers et al. 2014).

One treatment that land managers use to reduce pinyon-juniper woodlands and restore sagebrush-bunchgrass communities is mechanical mastication. During this treatment, whole trees are shredded to finer-sized downed woody debris (i.e. mulch), thereby converting canopy fuels to surface fuels (Figure 1.1). In addition to reducing canopy fuels, mastication treatments release understory plants from competition with trees and reduce the risk of high severity crown fires. However, the increase in masticated down woody debris on the soil surface can lead to longer smoldering times and greater soil heating during fires (Busse et al. 2005; Sikkink et al. 2017), especially in areas where masticated debris overlays tree litter and duff (Sikkink et al. 2017). Quantifying fuel loads after mastication of pinyon-juniper woodlands is important because the quantity of fuel, and its distribution among different fuel classes can alter fire behavior, severity, and effects (Pyne 1996; Strand et al. 2013; Weiner et al. 2016). In addition, different-sized woody fuels may decompose at different rates (Harmon et al. 1986; Fasth et al. 2011; Battaglia et al. 2015; Ostrogović et al. 2015; Varner et al. 2016; Coop et al. 2017), but decomposition rates may vary with soil moisture and temperature patterns (Harmon et al. 1986; Berbeco et al. 2012; Ostrogović et al. 2015). Many studies have described the changes in shrub and herbaceous cover after pinyon-juniper mastication treatments (Ross et al. 2012; Redmond et al. 2014; Roundy et al. 2014b; Bybee et al. 2016; Coop et al. 2017; Fornwalt et al. 2017), but few have described these changes in terms of fuel loads (Young et al. 2015; Coop et al. 2017), especially on a decadal timeframe in pinyon-juniper woodlands (Coop et al. 2017). A few studies have quantified changes in masticated downed woody debris fuel loads over time in pinyon-juniper woodlands (Shakespear 2014; Battaglia et al. 2015; Coop et al. 2017), but several of these studies took place outside of the Great Basin in Colorado (Battaglia et al 2015; Coop et al. 2017). These studies detected decreases in fine woody fuels over 5-10 years post-treatment; yet only one of these studies has been published (Coop et al. 2017), and inferences may be limited because the finest size classes of woody debris were analyzed together. Young et al. (2015) demonstrated pre-treatment tree cover is a reasonable predictor of post-treatment fuel loads and can be used as a covariate to explain variability in sampled fuel loads.

This analysis of changes in fuel loads after pinyon-juniper mastication is important because there are few studies of masticated pinyon-juniper woodlands that extend out to 10 years post-treatment, account for variability in masticated fuel loads related to differences in pre-treatment tree cover, and analyze other surface fuel loading components in addition to downed woody debris (e.g. herbaceous, shrub, tree litter and duff fuels). The primary objectives of this study are to analyze changes in: 1) components of surface fuel loads (tree litter and duff, downed woody debris, herbaceous, and shrub fuels), and 2) indicators of treatment longevity (pinyon-juniper cover and density) across 10 years after mastication of pinyon-juniper woodlands. The intent of analyzing surface fuel loading components is to gain a better understanding of how quickly downed woody debris, tree litter, and duff decompose, and how quickly herbaceous and shrub fuel loads increase following pinyon-juniper mastication. Land managers are also interested in how long it takes for trees to re-invade a site, and therefore how frequently these sites need to be treated.

Methods and Materials

Study Locations and Treatment Implementation

Data were collected at three study sites situated along a north to south gradient in western Utah—Onaqui, Scipio, and Greenville Bench (see McIver & Brunson 2014 for a map). These study sites and data are part of the Sagebrush Steppe Treatment Evaluation Project (SageSTEP; McIver et al. 2014). An additional mastication treatment at the Stansbury SageSTEP site was not included in this analysis because the site burned in the Big Pole wildfire in 2009 (two years post-treatment). Elevations of the sampled plots ranged from 1674-1761 m. Soils were classified as: Loamy-skeletal, carbonatic, mesic, shallow Petrocalcic Palexerolls at Onaqui; Loamy-skeletal, mixed superactive, mesic, shallow, Calcic Petrocalcids at Scipio; and Loamy-skeletal, carbonatic, mesic Typic Calcixerepts at Greenville Bench (Rau et al. 2011). The three sites were located in the 305-356 mm (12-14 in.) precipitation zone (Bourne and Bunting 2011). Daily precipitation was measured using a tipping bucket at each site as described by Roundy et al. (2014). The October-June precipitation was generally at or below the 30-year average (1988-2018) for the course of the study, except for the water year of 2010-2011, which was substantially above average (Figure 1.2).

The study sites were comprised of Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*)-bunchgrass communities encroached by Utah juniper (*Juniperus osteosperma)* and Colorado pinyon-pine (*Pinus edulis*). Utah juniper is the dominant tree species at Onaqui and Scipio, and is co-dominant with Colorado pinyon-pine at Greenville Bench. The dominant bunchgrasses were: bluebunch wheatgrass (*Pseudoroegneria spicata*) at Onaqui and Scipio, and needle-and-thread (*Hesperostipa comata*) at Greenville Bench. Prior to treatment, cover of the introduced annual cheatgrass (*Bromus tectorum*) ranged 0-31% on the sampling plot level.

Mastication treatments were implemented at Onaqui in 2006 and at Scipio and Greenville Bench in 2007. Tractors equipped with Fecon® Bullhog® masticators (horizontal shaft) were used to shred pinyon-juniper trees greater than 0.5 m in height. We recognize that foresters may refer to some of these trees as seedlings, saplings, poles, sawlogs, or mature trees, but hereafter we will refer to all pinyon pine and juniper individuals collectively as trees. At each site, 15 randomly-placed sampling plots (30 by 33 m) were established in the treated area. Treatments were implemented in locations such that sampling plots would cover a range of pre-treatment tree cover: 7-34% at Greenville Bench, 5-36% at Onaqui, and 9-50% at Scipio.

Field Measurements

Masticated downed woody debris (DWD) were collected within 0.25 m by 0.25 m quadrats placed every other meter along two 30 m transects (30 quadrats per sampling plot). Down woody debris are defined as dead, detached woody material within 2 m of the soil surface (Keane et al. 2015). DWD were collected 1, 5 (Scipio and Greenville Bench) or 6 (Onaqui), and 10 years post-treatment. In successive sampling periods, fuels were collected at different positions along the transects to avoid destructively sampling the same area twice. Fuels that were partially outside of the quadrat were cut to the length inside in the quadrat. Masticated DWD were weighed by time-lag fuel moisture class (1-hr, 10-hr, 100-hr, 1000-hr) after being dried at 60°C for at least 96 hours (Young et al. 2015). Time-lag was defined by Fosberg et al. (1970) as the time it takes for a piece of wood (of a specific diameter) to lose 63% of the difference between its initial moisture content (after a precipitation event) and its equilibrium moisture content when in an environment of 80°F and 20% relative humidity. Given this definition, DWD were classified by time-lag fuel moisture classes based on their diameters: 1-hr fuels have a diameter of 0-0.64 cm, 10-hr DWD have diameters of 0.64-2.54 cm, 100-hr DWD have a diameter of 2.54-7.62 cm, and 1000-hr DWD have a diameter greater than 7.62 (Keane 2015).

Tree litter and duff fuels were collected together. Tree litter refers to debris (e.g. leaves) from trees that have fallen to the ground and are easily recognizable because they have not yet decomposed (Robichaud and Miller 1999). Duff is the layer of decomposing organic material between the litter layer and mineral soil (Keane 2015; Robichaud and Miller 1999). Tree litter and duff were collected from 0.25 m by 0.25 m quadrats at 1 and 10 years post-treatment. Within each sampling plot, duff and litter were collected in six quadrats placed at one-third the distance from the bole of the tree to the edge of the tree canopy. A quadrat was placed under the four trees closest to the corners and two trees closest to the center of the sampling plot with a canopy greater than 2 m in diameter. Collected samples were dried at 50°C for 48 hours.

Herbaceous fuels (a combination of standing live, standing dead, and interspace litter) were collected in 0.50 by 0.50 m quadrats placed every other meter along one 30 m transect for a total of 15 quadrats per sampling plot. Herbaceous fuels were sampled at 1, 6, and 10 years post-treatment. These fuels were weighed after being dried at 50°C for 48 hours.

In 2007, measurements of shrub height, longest canopy diameter, and perpendicular canopy diameter were recorded for 19-21 shrubs of each major species from outside the sampling plots at each site. These shrubs were then destructively sampled, dried at 50°C for 48 hours, and weighed (Young et al. 2015). Site-specific allometric equations were developed to estimate shrub fuel loads from shrub volume measurements (Bourne and Bunting 2011). Shrub volume measurements were collected for shrubs taller than 15 cm within five nested-circular frames with a radius of 1, 2, or 3 m so that at least 10 shrubs of each common species were measured per sampling plot (Bonham 1989; Young et al. 2015). Shrub volume measurements were collected at 1, 6, and 10 years post-treatment, and the site-specific allometric equations were used to estimate shrub fuel loads at each time interval. R^2 values for the allometric equations are available in Bourne and Bunting (2011) and ranged from 0.62 to 0.97.

Bare ground cover (%) was measured using the line-point intercept method with data recorded every 0.5 m along five 30-m long transects for a total of 300 points per sampling plot. A point was considered bare ground if the only contact point was mineral soil (i.e. masticated debris did not count as bare ground).

Tree cover was collected pre-treatment and 10 years post-treatment, and tree density was collected at 1, 6, and 10 years post-treatment. Tree cover was estimated after measuring the longest canopy diameter and the perpendicular diameter of each tree greater than 0.5 m in height, within a sampling plot, and multiplied by 100. Using these diameter measurements, a total canopy area was estimated and divided by the area of the sampling plot. Tree density was measured using different methods depending on the size class of the tree. Every tree greater than 0.5 m in height was counted. Trees between 0.05 and 0.5 m in height were counted in three 30 x 2 m belt transects. Trees under 0.05 m in height were measured in the same 0.5 by 0.5 m quadrats used for sampling herbaceous biomass, but there were not enough trees under 0.05 m in height to statistically analyze.

Data Analysis

We modeled fuel loads using linear mixed effects modeling in the statistical program R (R Core Team 2017) with the lme4 package (Bates et al. 2015). A separate model was created for each of the following surface fuel loading components: 1-hr DWD, 10-hr DWD, 100-hr + 1000-hr DWD, Duff + Litter, Herbaceous, Shrub. The 1000-hr DWD were combined with 100-hr DWD because there were not enough 1000-hr DWD left after the mastication treatment to analyze these fuels separately. Herbaceous fuel loads were analyzed as the sum of live standing herbaceous fuel, dead standing herbaceous fuel, and interspace litter. Tree density was also analyzed using a linear mixed effects model**.** Pre-treatment tree cover, year since treatment, and the interaction between the two were used as fixed effects for all models. Years since treatment was treated as a factor in each model, because the effect of each year since treatment was not incremental. Site and sampling plot were included in the models as random effects, with sampling plot nested within site. Response variables were square-root transformed for all models to better meet assumptions of homoscedasticity as assessed using residual plots, and all contrasts (see below) were thus on the square-root scale of the response variables. Differences in fuel loads by year since treatment were analyzed using linear contrasts at the following pre-treatment tree cover values: 10, 20, and 40%; these values can be interpreted as low, medium, and high tree covers for pinyon-juniper woodlands in Utah. Linear contrasts were not performed for pre-treatment tree cover values greater than 40% due to a lack of data; there were only two sampling plots with pre-treatment tree cover greater than 40%. Linear contrasts and Wald tests were conducted using the trtools package (Johnson 2019), and marginal and conditional R^2 (Nakagawa et al. 2017) were estimated using the MuMIn package (Barton 2018). Marginal R^2 estimates the variance explained by the fixed effects of the model, and conditional R^2 estimates the variance explained by both the fixed and random effects of the model (Nakagawa et al. 2017). A conservative critical value of $\alpha = 0.01$ was used to determine significance of linear contrasts to reduce familywise Type I error rates. Tree height and cover were only measured at pre-treatment and 10 years post-treatment, so these variables were not analyzed statistically. A summary table of means and standard deviations based on the raw data is also provided in Table 1.1. This work is an extension of Young et al. (2015) and Shakespear (2014). In Young et al. (2015), pre-treatment fuel loads were compared to fuel loads at 1, 2, and 3 years post-treatment. Therefore, this analysis will not include information on pre-treatment fuel loads, or short-term changes in in fuel loads. Shakespear (2014) conducted similar analyses on these data at 1 and 5-6 years post-treatment for masticated down woody debris fuels, and 1, 2, 3, 4, 5, and 6 years post-treatment for herbaceous fuels, but included additional fixed effects in their models.

Results

Downed Woody Debris

We detected decreases in fuel loads of 1-hr DWD from 1 to 5-6 years post-treatment at 10, 20, and 40% pre-treatment tree cover ($p < 0.01$; Figures 1.3 and 1.4, Tables 1.1, 1. 2, and 1.3). We also detected decreases from 5-6 to 10 years post-treatment at 20 and 40% pre-treatment tree cover. The model of 1-hr DWD had a marginal $R^2 = 0.51$, and conditional $R^2 = 0.66$ (Table 1.2). In terms of raw data, sampling plots with pre-treatment tree cover ranging 15-25% decreased from a mean and standard deviation of 7.04 ± 0.43 Mg·ha^{-1} at 1 year post-treatment to 2.23 ± 0.43 Mg·ha^{-1} at 10 years post-treatment. We failed to detect changes in fuel loads for the 10-hr and 100 + 1000-hr classes of DWD (Figure 1.4, Table 1.1).

Tree Litter + Duff

We detected decreases in tree litter + duff from 1 to 10 years post-treatment at 10, 20, and 40% pre-treatment tree cover (Figure 1.5; Table 1.3). The estimated marginal and conditional R^2 values for the model were 0.89 and 0.93 respectively (Table 1.2), demonstrating that the fixed effects of the model explained 89% of the variability in the data. By 10 years post-treatment, there were very low fuel loads at all levels of pre-treatment tree cover. Means and standard deviations for fuel loads in sampling plots with: 5-15% pre-treatment tree cover were 0.34 ± 0.59 $Mg·ha^{-1}$, 15-25% pre-treatment tree cover were 0.33 ± 0.43 $Mg·ha^{-1}$, and 25-50% pre-treatment tree cover were 0.53 ± 1.02 $Mg·ha^{-1}$ (Table 1.1). The mean and standard deviation for the proportion of tree litter + duff mass remaining at 10 years post-treatment was 4.5 ± 7.5%.

Herbaceous

We detected increases in herbaceous fuel loads from 1 to 6 years post-treatment at 20 and 40% pre-treatment tree cover, and from 6 to 10 years at 10, 20, and 40% pre-treatment tree cover (Figure 1.5, Table 1.3). The marginal and conditional R^2 values were both 0.45. By 10 years post-treatment, mean herbaceous fuel loads were greater than 1 $Mg·ha^{-1}$ across the range of pre-treatment tree cover (Table 1.1).

Shrub

We detected increases in shrub fuel loads from 1 to 6 years post-treatment at 20% pre-treatment tree cover, and increases at 10, 20, and 40% pre-treatment tree cover from 1 to 10 years post-treatment (Figure 1.5, Table 1.3). We failed to detect differences in shrub fuel loads between 6 and 10 years post-treatment. The estimated marginal and conditional R^2 values were 0.34 and 0.77 (Table 1.2). Based on the raw data, mean shrub fuel loads in sampling plots between 5-15% and >15-25% increased almost twice as much as mean shrub fuel loads between 25-50% tree cover from 1 to 10 years post-treatment (Table 1.1).

Total Fuel Load

We detected decreases in total fuel loads from 1 to 10 years post-treatment at 10, 20, and 40% pre-treatment tree cover (Tables 1.1 and 1.3, Figure 1.6). The marginal and conditional R^2 values were 0.63 and 0.75 (Table 1.2). Based on the raw data, the mean (± standard deviation of) total fuel load for sampling plots with: 5-15% pre-tree cover decreased from 14.53 ± 5.38 to 8.41 ± 4.83 $Mg·ha^{-1}$, >15-25% pre-treatment tree cover decreased from 24.43 ± 7.74 to 12.02 ± 7.12 $Mg·ha^{-1}$, and 25-50% pre-treatment tree cover decreased from 32.38 ± 11.17 to 13.23 ± 7.07 $Mg·ha^{-1}$ (Table 1.1) from 1 to 10 years post-treatment. At 1 year post-treatment, tree litter + duff and 1-hr down woody debris comprise the majority of the mean total fuel load (Figure 1.8). These fuels decompose such that at 10 years post-treatment, the mean total fuel load has decreased by about 50%, even though there have been significant increases in herbaceous and shrub fuels (Figure 1.8).

Bare Ground Cover

We detected decreases in bare ground cover (%) at 20 and 40% pre-treatment tree cover from 1 to 6 years post-treatment, but we failed to detect significant changes in bare ground cover between 6 and 10 years (Table 1.3, Figure 1.6). Bare ground cover varied substantially by site and sampling plot, which is demonstrated by the large difference between the marginal and conditional R^2 values of 0.20 and 0.39 (Table 1.2).

Tree Density, Cover, and Height

Tree density increased between 1 and 6 years post-treatment at 10 and 20% pre-treatment tree cover (Table 1.3, Figure 1.8). Tree density varied substantially among sampling plots and sites (Figures 1.2D and 1.7), demonstrated by the difference between the marginal and conditional R^2 values of 0.10, and 0.72 (Table 1.2). At 10 years post-treatment, trees were recorded in 107 of 135 sampling plots. In sampling plots with trees, the tree density was composed of 72 ± 39% trees between 0.05 and 0.5 m in height. In sampling plots where there were trees greater than 0.5 m in height, the mean tree height and standard deviation of trees greater than 0.5 m in height were 0.9 ± 0.2 m. At 10 years post-treatment, mean tree cover and standard deviation were 0.6% ± 0.7%, with a range of 0-2.6%. All of the sampling plots with greater than or equal to 1% tree cover occurred at the Greenville Bench site.

Discussion

Changes in Surface Fuel Loads

Several studies have shown that pinyon-juniper litter decomposes relatively quickly, but most of these studies are short-term (Bates et al. 2007; Murphy et al. 1998; Vanderbilt et al. 2008)**.** Bates et al. (2007) found a 27% mean mass loss of juniper litter two years after a juniper cutting treatment. Murphy et al. (1998) also found that after two years, juniper and pinyon pine litter lost 25-35% of its mass in the elevation ranges that pinyon-juniper woodlands occur. Our analysis shows that by 10 years after mastication, there was little tree litter or duff left on site (4.5 ± 7.5%).

We also detected significant decreases in the finest size fuel class of down woody debris (1-hr), but did not detect changes in coarser fuels. Several studies have shown that finer sized fuels (intact or masticated) decompose at a higher rate than coarser fuels (Mattson et al. 1987; Harmon et al. 1995; Hyvönen et al. 2000; Lyons and McCarthy 2010; Berbeco et al. 2012; Battaglia 2015; Ostrogović et al. 2015; Reed 2016; Coop 2017), but few have demonstrated that this pattern in decomposition of fine masticated fuels occurs on a timescale relevant to land managers in arid and semi-arid regions of the Intermountain West (Shakespear 2014; Coop et al. 2017). Reed (2016) found that 1-hr masticated down woody debris decreased significantly over 8 to 9 years post-treatment in northern California and southern Oregon; 1-hr fuels lost 69% of their mass over 8 to 9 years post-treatment. The 69% mass loss over 8 to 9 years post-treatment is slightly greater than the 65% mass loss over 10 years that we documented. Battaglia et al. (2015) documented a mass loss of ~50% for pine mulch chips placed in a pinyon-juniper woodland in Colorado. Reed (2016) showed that 10-hr masticated fuels decompose significantly, but at a slower rate than 1-hr fuels on the same time scale.

We did not detect changes in 10-hr fuel loads by 10 years post-treatment in our study area. Other locations may experience different decomposition rates than observed in our study due to many factors including: climate, substrate quality (species of wood or litter), microbial and fungal communities, soil nutrient availability, and solar photodegradation (Harmon et al. 1986; Murphy et al. 1998; Bates et al. 2007; Gallo et al. 2009).

The substantial decreases in tree litter + duff and 1-hr DWD documented in this study have important implications for wildfires that occur within a couple years versus 5-10 years after pinyon-juniper mastication. Both tree litter + duff and masticated debris tend to smolder for long periods of time, resulting in extensive soil heating, increased fire severity, bunchgrass mortality, and a potential increase in exotic species (Stephan et al. 2010; Strand et al. 2013; Kreye et al. 2014; Weiner et al. 2016; Sikkink et al. 2017). Sikkink et al. (2017) demonstrated that smoldering duration of masticated fuels was more than twice as long when the masticated fuels were burned over duff rather than sandy soil. Greater fuel loads of masticated debris can increase soil heating (Busse et al. 2005) and increase fireline intensity (Kreye et al. 2014). These aspects of potential fire behavior and effects would likely be reduced by 10 years after mastication treatments, due to reduced fuel loads of tree litter, duff, and 1-hr down woody debris (via decomposition). The decreases in tree litter + duff and 1-hr DWD were much greater in magnitude than the increases in herbaceous and shrub fuel loads, and therefore total fuel loads decreased about 42-59% from 1 to 10 years post-treatment depending on pre-treatment tree cover (Table 1.1). In this study, trees were masticated using horizontal shaft masticators, which are more effective at reducing a high proportion of coarse fuels to finer-sized mulches than vertical shaft masticators (Jain et al. 2018). If decomposition of masticated fuels is a primary management goal, it would be beneficial to use horizontal shaft masticators and contract experienced operators; operator skill can have a substantial impact on masticated fuel size (Jain et al. 2018).

Although bare ground cover was our only direct measure of fuel continuity, significant increases in herbaceous and shrub fuel loads also serve as indicators of increased fuel continuity. Bare ground cover decreased significantly from 1 to 6 years post-treatment at 20 and 40% pre-treatment tree cover, but no significant change was detected at 10% pre-treatment tree cover. This trend could be expected because on sites with low tree cover, the understory generally remains intact until greater increases in tree cover (Miller et al. 2005). At 10 years after pinyon-juniper reduction treatments, land managers should expect high fuel continuity, and the potential for increased risk of fire ignition and rate of spread due to high herbaceous fuel loads (Keane 2015). Some areas treated with mastication in the Intermountain West may have lower herbaceous fuel loads than those analyzed in our study due to differences in ecological site and/or herbaceous biomass removal via grazing.

Although shrub fuels increased at 10, 20, and 40% pre-treatment tree cover, there was still a substantial effect of pre-treatment cover on shrub fuel loads. Sampling plots treated at high pre-treatment tree cover had substantially lower shrub fuel loads at 10 years post-treatment than sampling plots treated at lower pre-treatment tree cover (see Tables 1.1 and 1.3). A similar trend of slower recovery of shrubs (especially sagebrush) after treating dense pinyon-juniper woodlands (e.g. Phase III as defined by Miller et al. 2005) was demonstrated in Bates et al. (2017). Shrub biomass and fuel loads likely increased in response to an increase in soil water and nutrient availability after removing trees (Roundy et al. 2014; Ray et al. 2019). Increased sagebrush biomass and cover plays an important role in wildlife habitat and ecosystem functions, but increases in shrub fuels can also play important roles in fire behavior and effects. In extreme weather conditions, sites with high shrub canopy continuity and fuel loads can carry fire even in areas where herbaceous fuel loads and continuity are very low (Launchbaugh et al. 2008). In addition, fire intensity is typically greater under sagebrush, and can result in higher bunchgrass mortality under sagebrush than in interspaces (Boyd et al. 2015; Hulet et al. 2015).

Treatment Longevity

Although our linear mixed effects models detected significant increases in tree density from 1 to 6 years post-treatment at 10 and 20% pre-treatment tree cover, these results should be interpreted conservatively. Since we could not statistically analyze trees from the size class <0.05 m, it is difficult to determine the magnitude of increase in tree density depicted in our models that is due to new recruitment, or to trees <0.05 m in height growing into taller trees by 10 years post-treatment. Other studies, however, have documented mean increases in tree density of about 5-10 $stems \cdot ha^{-1} \cdot yr^{-1}$ following mechanical reduction of pinyon-juniper woodlands (Bristow et al. 2014; Bates et al. 2017). By 15 years post-treatment, Bates et al. (2017) found that western juniper density in a cut treatment reached pre-treatment levels, and that three-fourths of these trees were recruited after the treatment.

Treatment longevity is a frequently used term that is context-specific and difficult to define, especially when land managers are implementing treatments to address multiple objectives. If defined in terms of risk of canopy fire, none of the sites or sampling plots were at risk of being able to carry a crown fire at 10 years post-treatment, and would likely not be able to carry a canopy fire for many decades more (Miller et al. 2008). Bates et al. (2017), however, suggested a treatment longevity of 25-30 years for western juniper cutting treatments on Steens Mountain, Oregon based on the goal of maintaining dominance of understory perennial bunchgrasses and shrubs. In many areas of the Intermountain West, however, many mastication treatments are implemented to improve sage-grouse habitat. If treatment longevity is defined in terms of sage-grouse potential use of the site, treatment longevity would be much shorter. Baruch-Mordo et al. (2013) suggest that tree cover of 4% can influence sage-grouse to abandon lek sites, and Coates et al. (2017) suggest treating encroaching pinyon pine and juniper at tree cover values as low as 1.5% to improve sage-grouse survival. In our study, tree density and tree cover were highly dependent on site and sampling plot. Based on the Coates et al. (2017) interpretation, the Greenville Bench site in our study should be re-treated at 10-15 years post-treatment because more than one-third of the sampling plots had tree cover values ranging 1.5-2.6%. There were not any sampling plots at the Onaqui or Scipio sites that had >0.7% tree cover at 10 years post-treatment. Once established however, tree cover can increase quickly: Bates et al. (2017) documented mean tree cover <1% by 12 years after a cutting treatment, but 3.8% cover by 25 years post-treatment.

Management Implications

After mastication of pinyon-juniper woodlands, there are complex changes in surface fuel loads due to some components decreasing (tree litter + duff, and 1-hr DWD), other components increasing (herbaceous, shrub, and small trees), and a high variability in changes. Land managers should account for changes in all components of surface fuel loads when analyzing potential fire behavior and effects after mastication treatments. Areas that were treated at high pre-treatment tree cover, will likely be at greater risk of ignition and rate of fire spread as herbaceous fuels increase. These effects may be coupled with a decrease in potential lethal soil heating as tree litter + duff and 1-hr downed woody debris fuels decompose. If decomposition of down woody debris is a primary management goal, land managers should seek skilled operators who utilize horizontal shaft masticators to produce a high percentage of 1-hr fuels. Increases in tree cover and density are highly site dependent, and depending on management goals treatment longevity may be defined differently. In areas where sage-grouse productivity is a management priority, we recommend monitoring mastication treatments 10-15 years post-treatment to assess the need for follow-up treatment. This recommendation may be conservative, but there are many benefits to reducing pinyon-juniper trees when tree cover is still low, and trees are not yet dominating the ecological processes occurring on site.

Future Directions

If funding is available for more research into treatment longevity and changes in surface fuel loads after pinyon-juniper mastication, there are several areas of potential research interest. Research into remote sensing of changes in herbaceous and shrub fuel loads, and changes in tree density of small trees in treated areas (it is more difficult to detect very small trees) may reduce sampling costs and help predict changes in fuel loads with a spatial component. It would be beneficial to conduct studies into the decomposition of masticated debris by size class using litter bags and a finer scale of temporal sampling to establish decay rates of different size classes of down woody debris. In addition, it would be beneficial to conduct these decomposition studies in different regions and across gradients of elevation, temperature, and precipitation on a 10-15 year timeframe.

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Figures

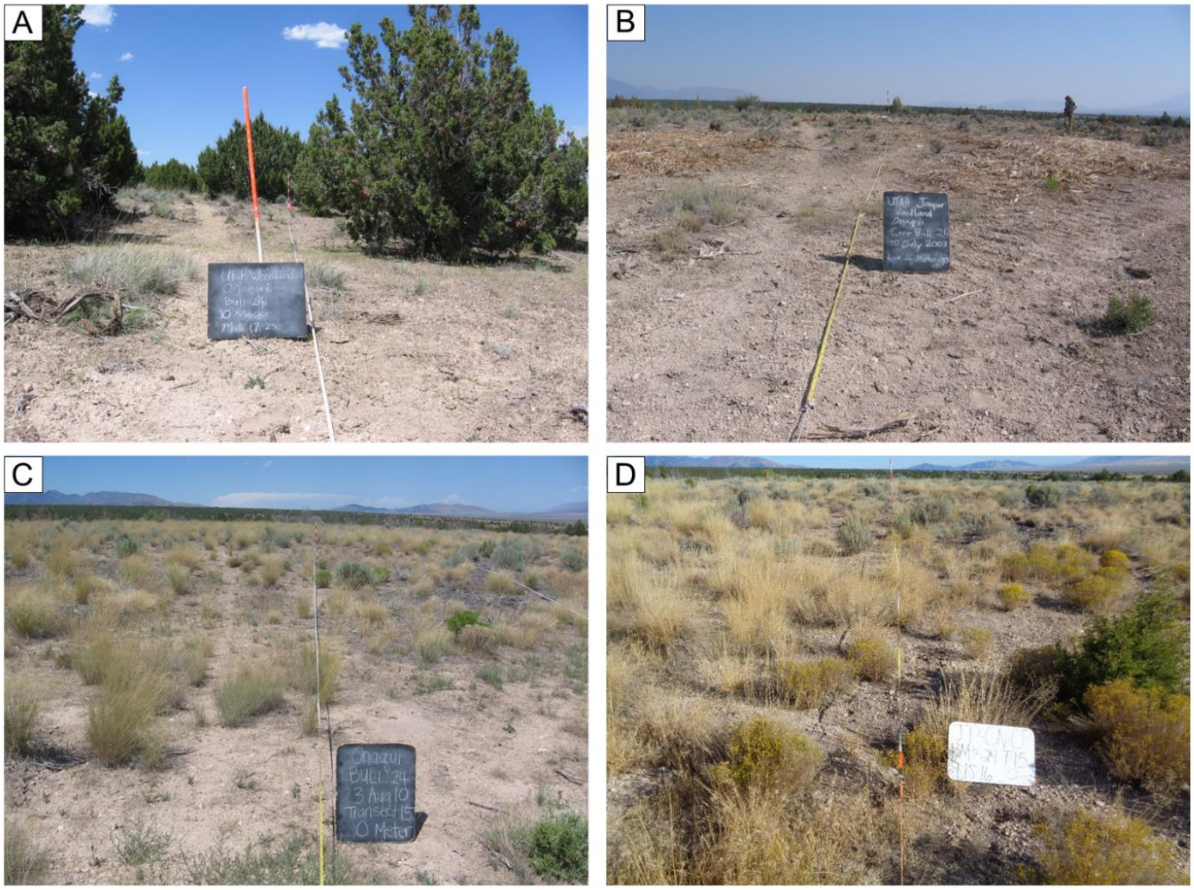

Figure 1.1. Photoseries of increases in herbaceous fuels and decreases in bare ground: (A) pre-treatment, (B) 1 year post-treatment, (C) 6 years post-treatment, and (D) 10 years post-treatment. This sampling plot is located at the Onaqui study site.

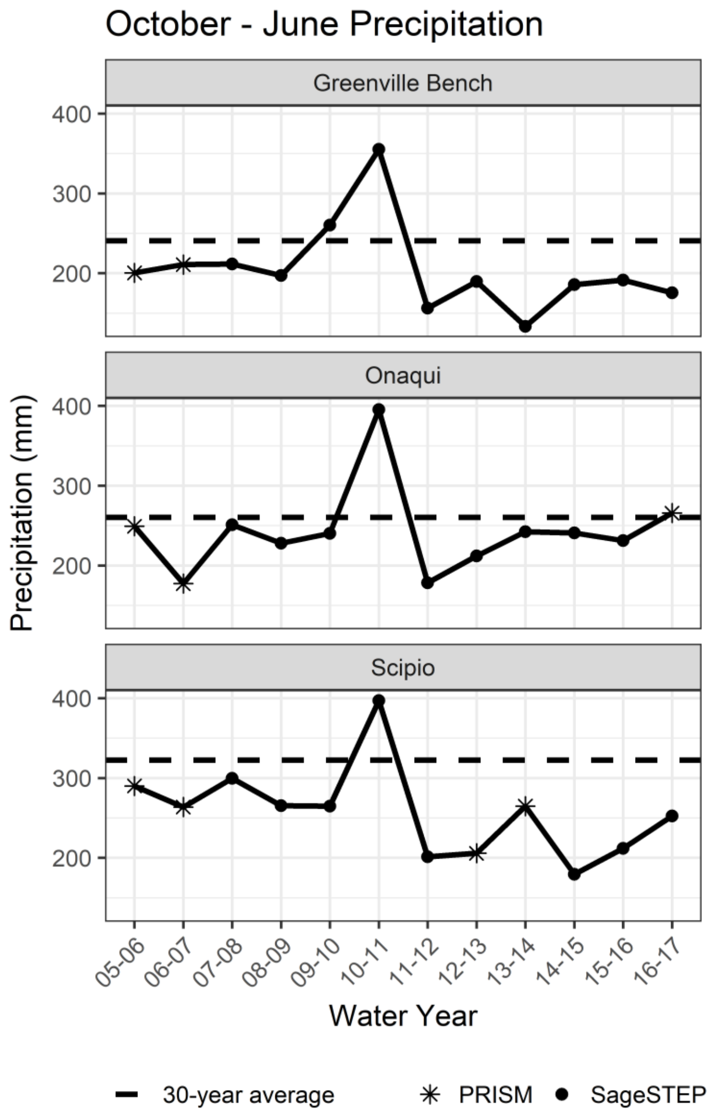

Figure 1.2. October-June precipitation recorded at the three study sites across the course of the study. Data from PRISM Climate Group were used to estimate October-June precipitation for years with missing data (i.e. years before precipitation gauges were installed or years in which the gauges malfunctioned), and a 30-year average.

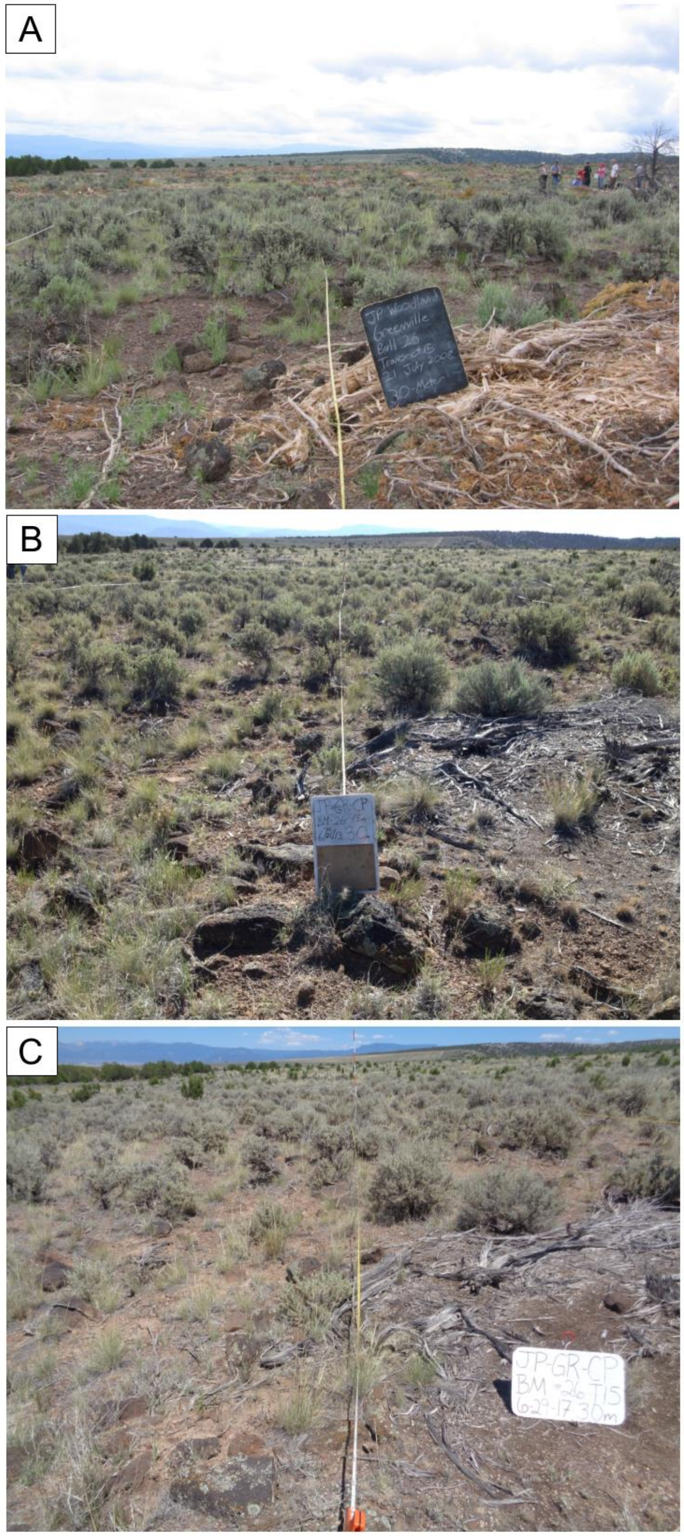

Figure 1.3. Photoseries of decomposition of fine-sized down woody debris at 1 year post-treatment (A), 5 years post-treatment (B), and 10 years post-treatment (C). This sampling plot is located at the Greenville Bench study site.

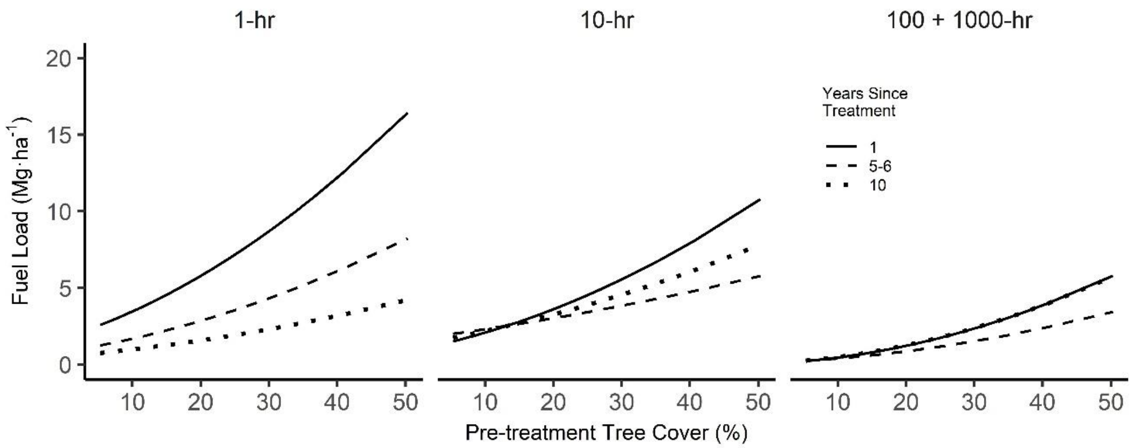

Figure 1.4. Model-based estimates of the median of down woody debris fuel loads (Mg·ha^{-1}) by pre-treatment tree cover (%), year since treatment, and time lag fuel moisture classes: 1-hr down woody debris (left), 10-hr down woody debris (center), and 100+1000-hr down woody debris (right). No significant differences were detected in 10-hr or 100 + 1000-hr fuel loads between years sampled.

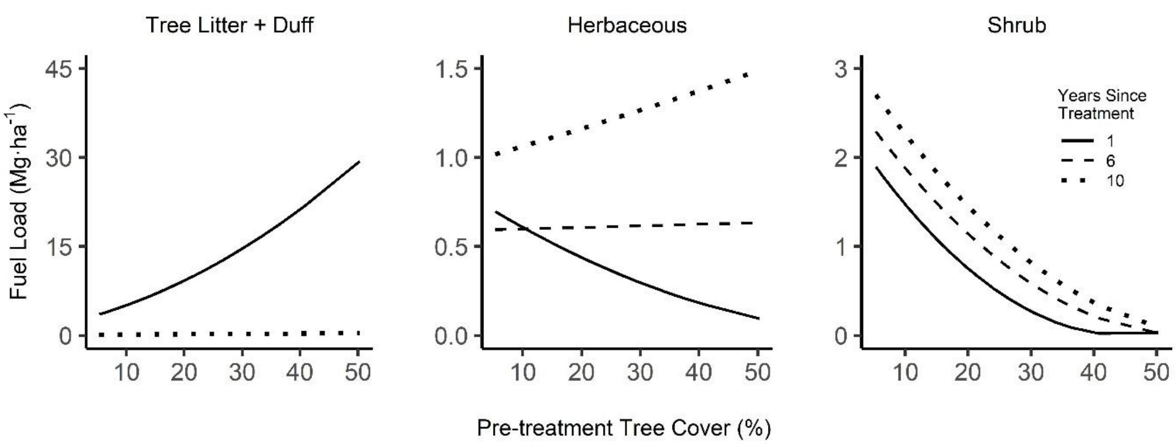

Figure 1.5. Model-based estimates of the median fuel loads (Mg·ha^{-1}) of tree litter + duff (left), herbaceous (center), and shrub (right) across a gradient of pre-treatment tree cover, and at 1, 6, and 10 years post-treatment. Note: tree litter + duff fuel loads were not collected (nor estimated) at 6 years post-treatment.

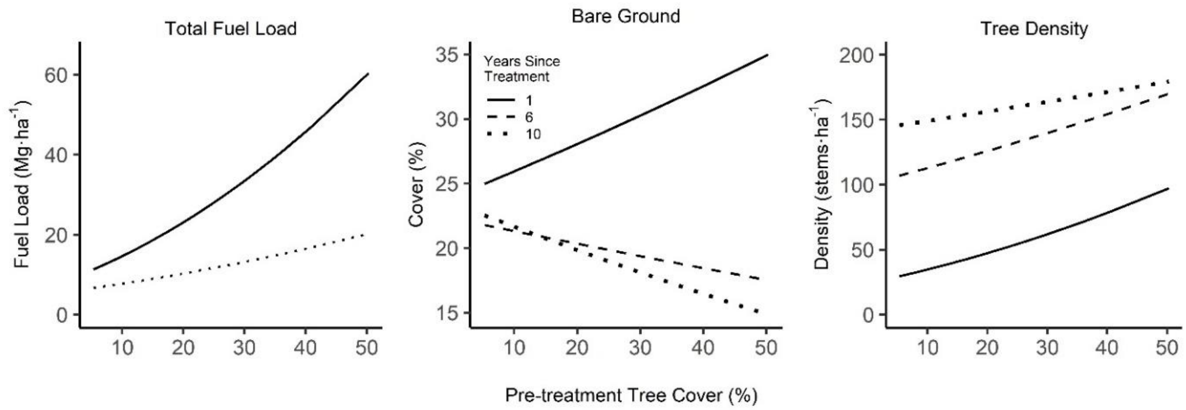

Figure 1.6. Model-based estimates of median total fuel load (Mg·ha^{-1}), bare ground cover (%; top) and tree density (stems·ha^{-1}; bottom) across a gradient of pre-treatment tree cover, and at 1, 6, and 10 years post-treatment. Note: total fuel load was only estimated at 1 and 10 years post-treatment because tree litter + duff fuel loads were not collected 6 years post-treatment.

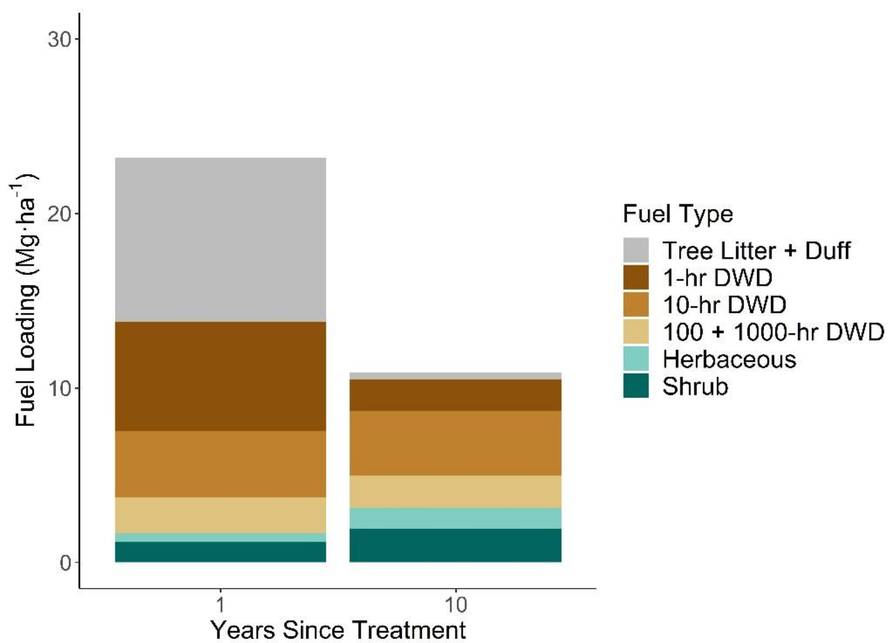

Figure 1.7. Mean total fuel load (Mg·ha^{-1}) by fuel type at 1 and 10 years post-treatment.

Figure 1.8. High tree density at a Greenville Bench sampling plot at 10 years post-treatment.

Tables

Table 1.1. Means ± standard deviations of fuel loads ($Mg \cdot ha^{-1}$), bare ground cover (%), and tree density ($stems \cdot ha^{-1}$) for sampling plots that had ranges of pre-treatment tree cover from 5-15, >15-25, and >25-50%. Means and standard deviations provided are based on raw data.

Response Variable	Years Post-treatment	Pre-treatment Tree Cover Range (%) 5-15	>15-25	>25-50
1-hr DWD Fuel Load	1	3.39 ± 2.16	7.04 ± 4.46	10.87 ± 4.49
	5-6	1.67 ± 1.59	3.68 ± 2.87	5.38 ± 1.68
	10	0.89 ± 0.81	2.23 ± 1.44	3.12 ± 2.06
10-hr DWD Fuel Load	1	1.93 ± 1.11	4.44 ± 1.7	6.62 ± 2.22
	5-6	2.17 ± 1.16	3.68 ± 1.89	4.46 ± 2.15
	10	2.57 ± 2.28	3.98 ± 2.23	5.46 ± 2.96
100 + 1000-hr DWD Fuel Load	1	1.37 ± 2.13	1.59 ± 2.84	4.01 ± 2.95
	5-6	0.56 ± 0.62	1.24 ± 1.61	2.58 ± 3.27
	10	0.94 ± 1.05	1.9 ± 3.07	3.7 ± 3.6
Tree Litter + Duff	1	5.27 ± 2.72	10.59 ± 3.03	15.96 ± 6.82
	10	0.34 ± 0.59	0.33 ± 0.43	0.53 ± 1.02
Herbaceous Fuel Load	1	0.72 ± 0.28	0.37 ± 0.2	0.3 ± 0.2
	6	0.65 ± 0.29	0.6 ± 0.39	0.7 ± 0.4
	10	1.02 ± 0.35	1.43 ± 0.64	1.2 ± 0.42
Shrub Fuel Load	1	1.84 ± 1.62	0.86 ± 0.7	0.29 ± 0.51
	6	2.16 ± 1.6	1.69 ± 1.21	0.39 ± 0.33
	10	2.66 ± 1.95	1.68 ± 1.31	0.76 ± 0.58
Total Fuel Load	1	14.53 ± 5.38	24.43 ± 7.74	32.38 ± 11.17
	10	8.41 ± 4.83	12.02 ± 7.12	13.23 ± 7.07
Bare Ground Cover	1	27.57 ± 11.37	30.51 ± 8.84	28.42 ± 7.91
	6	22.68 ± 6.09	21.29 ± 7.31	17.93 ± 9.4
	10	22.98 ± 6.98	20.13 ± 5.58	17.04 ± 5.36
Tree Density	1	91.75 ± 85.11	81.6 ± 91.23	77.9 ± 111.68
	6	202.9 ± 176.86	170.33 ± 172.32	161.1 ± 187.67
	10	219.7 ± 161.64	193.6 ± 190.26	159.2 ± 207.85

Table 1.2. Summary of output from Wald tests on linear mixed effects models. Note: estimates, standard errors, and confidence intervals are on the square-root transformed and cannot be back-transformed. R^2_m and R^2_c are the marginal and conditional R^2. 'YST' represents year since treatment. *P* values for significant results are bolded ($p < 0.01$).

Response Variable	Fixed Effect	Estimate	SE	Lower 99% CI	Upper 99% CI	*T*-value	*P*-value
1-hr DWD	Intercept (YST 1)	1.317	0.191	0.827	1.808	6.9	**<0.0001**
	Pre Tree Cover	0.054	0.009	0.031	0.077	6.1	**<0.0001**
R^2_m = 0.51	YST 5-6	-0.408	0.225	-0.988	0.172	-1.8	0.0700
R^2_c = 0.66	YST 10	-0.592	0.224	-1.168	-0.016	-2.6	**0.0081**
	Pre Tree Cover * YST 5-6	-0.015	0.011	-0.043	0.012	-1.5	0.1400
	Pre Tree Cover * YST 10	-0.028	0.011	-0.055	-0.001	-2.7	**0.0076**
10-hr DWD	Intercept (YST 1)	0.985	0.205	0.457	1.513	4.8	**<0.0001**
	Pre Tree Cover	0.046	0.008	0.025	0.066	5.7	**<0.0001**
R^2_m = 0.28	YST 5-6	0.315	0.229	-0.275	0.905	1.37	0.1700
R^2_c = 0.42	YST 10	0.167	0.228	-0.419	0.754	0.73	0.4600
	Pre Tree Cover * YST 5-6	-0.024	0.011	-0.051	0.004	-2.22	0.0260
	Pre Tree Cover * YST 10	-0.013	0.011	-0.041	0.015	-1.22	0.2200
100 + 1000-hr	Intercept (YST 1)	0.247	0.373	-0.713	1.208	0.663	0.5100
DWD	Pre Tree Cover	0.043	0.009	0.019	0.067	4.578	**<0.0001**
	YST 5-6	0.074	0.258	-0.590	0.738	0.288	0.7700
R^2_m = 0.20	YST 10	0.034	0.256	-0.625	0.694	0.134	0.8900
R^2_c = 0.60	Pre Tree Cover * YST 5-6	-0.012	0.012	-0.043	0.019	-1.038	0.3000
	Pre Tree Cover * YST 10	-0.001	0.012	-0.032	0.030	-0.076	0.9400
Tree Litter +	Intercept (YST 1)	1.470	0.206	0.940	2.000	7.1	**<0.0001**
Duff	Pre Tree Cover	0.078	0.006	0.064	0.093	13.7	**<0.0001**
R^2_m = 0.89	YST 10	-1.149	0.168	-1.583	-0.715	-6.8	**<0.0001**
R^2_c = 0.93	Pre Tree Cover * YST 10	-0.072	0.008	-0.092	-0.052	-9.1	**<0.0001**
Herbaceous	Intercept (YST 1)	0.896	0.063	0.734	1.058	14.24	**<0.0001**
	Pre Tree Cover	-0.012	0.003	-0.019	-0.004	-3.97	**<0.0001**
R^2_m = 0.45	YST 6	-0.129	0.089	-0.359	0.101	-1.44	0.1500
R^2_c = 0.45	YST 10	0.088	0.089	-0.142	0.317	0.98	0.3300
	Pre Tree Cover * YST 6	0.012	0.004	0.001	0.023	2.91	**0.0036**
	Pre Tree Cover * YST 10	0.016	0.004	0.006	0.027	3.93	**<0.0001**
Shrub	Intercept (YST 1)	1.560	0.153	1.166	1.954	10.2	**<0.0001**
	Pre Tree Cover	-0.035	0.007	-0.053	-0.016	-4.84	**<0.0001**
R^2_m = 0.34	YST 6	0.114	0.129	-0.219	0.447	0.88	0.3800
R^2_c = 0.77	YST 10	0.242	0.127	-0.084	0.568	1.91	0.0560
	Pre Tree Cover * YST 6	0.004	0.006	-0.011	0.020	0.73	0.4600
	Pre Tree Cover * YST 10	0.005	0.006	-0.011	0.020	0.8	0.4200
Total	Intercept (YST 1)	2.8474	0.324	2.0127	3.682	8.79	**<0.0001**
Fuel Load	Pre Tree Cover	0.0979	0.0108	0.0702	0.1256	9.1	**<0.0001**
R^2_m = 0.64	YST 10	-0.4905	0.3089	-1.2862	0.3052	-1.59	0.1120
R^2_c = 0.73	Pre Tree Cover * YST 10	-0.0554	0.0145	-0.0927	-0.0181	-3.82	**0.0001**
Bare Ground	Intercept (YST 1)	4.889	0.304	4.105	5.673	16.07	**<0.0001**
Cover	Pre Tree Cover	0.020	0.011	-0.008	0.049	1.85	0.0640
	YST 6	-0.165	0.311	-0.965	0.635	-0.53	0.6000
R^2_m = 0.20	YST 10	-0.037	0.311	-0.836	0.763	-0.12	0.9100
R^2_c = 0.39	Pre Tree Cover * YST 6	-0.031	0.015	-0.069	0.006	-2.14	0.0330

	Pre Tree Cover * YST 10	-0.040	0.015	-0.078	-0.003	-2.76	**0.0057**
Tree Density	Intercept (YST 1)	4.916	3.630	-4.433	14.270	1.35	0.1756
	Pre Tree Cover	0.098	0.074	-0.093	0.290	1.32	0.1853
R^2_m = 0.10	YST 6	5.109	1.843	0.362	9.860	2.77	**0.0056**
R^2_c = 0.72	YST 10	6.998	1.843	2.250	11.740	3.8	**0.0002**
	Pre Tree Cover * YST 6	-0.038	0.086	-0.261	0.180	-0.45	0.6562
	Pre Tree Cover * YST 10	-0.069	0.086	-0.291	0.150	-0.8	0.4253

Table 1.3. Summary of linear contrasts estimates; significant contrasts are bolded ($p < 0.01$). Note: estimates are on the square-root transformed scale.

Response Variable	Years Compared	Pre-treatment Tree Cover (%)		
		10	20	40
1-hr DWD Fuel Load	1 : 5-6	**-0.56**	**-0.72**	**-1.03**
	5-6 : 10	-0.31	**-0.44**	**-0.69**
	1 : 10	**-0.87**	**-1.15**	**-1.71**
10-hr DWD Fuel Load	1 : 5-6	0.08	-0.16	-0.64
	5-6 : 10	-0.04	0.07	0.28
	1 : 10	0.04	-0.09	-0.35
100 + 1000-hr DWD Fuel Load	1 : 5-6	-0.05	-0.18	-0.43
	5-6 : 10	0.08	0.19	0.00
	1 : 10	0.03	0.02	0.42
Tree Litter + Duff	1 : 10	**-1.90**	**-2.59**	**-4.00**
Herbaceous Fuel Load	1 : 6	-0.01	**0.12**	**0.36**
	6 : 10	**0.26**	**0.30**	**0.38**
	1 : 10	**0.25**	**0.42**	**0.74**
Shrub Fuel Load	1 : 6	0.16	**0.20**	0.29
	6 : 10	0.13	0.14	0.14
	1 : 10	**0.29**	**0.34**	**0.43**
Total Fuel Load	1:10	**-1.04**	**-1.60**	**-2.71**
Bare Ground Cover	1 : 6	-0.48	**-0.79**	**-1.41**
	6 : 10	0.04	-0.05	-0.24
	1 : 10	-0.44	**-0.84**	**-1.65**
Tree Density	1 : 6	**4.72**	**4.34**	3.57
	6 : 10	1.58	1.28	0.672
	1 : 10	**6.31**	**5.62**	4.24

Chapter 2: Quantification of Fuel Loads 10 Years After Woody Vegetation Reduction Treatments in Sagebrush Steppe and Pinyon-Juniper Woodlands

Abstract

Increased woody plant dominance and degraded understory vegetation are important issues on rangelands in the Intermountain West. Land managers implement woody plant reduction treatments of sagebrush (*Artemisia* spp.), juniper (*Juniperus* spp.), and pinyon pine (*Pinus* spp.) to increase understory diversity and cover, restore wildlife habitat, increase forage, improve ecosystem functions, and reduce or manipulate fuels to increase ecosystem resilience and resistance to invasive annual grasses. Woody plant reduction treatments alter fuel orientation, continuity, and loading, and therefore have important implications for wildfire behavior, effects, and management. Currently, there is a lack of knowledge of the longer-term implications of these treatments on fuel loads and vegetation structure. Using data collected as part of the Sagebrush Steppe Treatment Evaluation Project (SageSTEP), this chapter summarizes fuel loads, vegetation cover by functional group, and shrub and tree stem density 10 years after sagebrush and pinyon-juniper reduction treatments. The data was collected at 16 study sites in Washington, Oregon, California, Nevada, and Utah, and is summarized by treatment type, region, and groups or woodland development phases based on pre-treatment vegetation. These summarized data will be published in a fuels guide to be used by land managers to quickly estimate fuel loads in older treatments or to predict fuel loads 10 years after a potential treatment. These fuel loading data can be used to create custom fuel beds to model fire behavior and effects.

Introduction

In the past 160 years, there have been substantial changes in vegetation and fuel loads on rangelands in the Intermountain West. These changes are complex and vary substantially along gradients of elevation and precipitation (Bradley 2010; Chambers et al. 2014). In many low elevation Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*)-bunchgrass communities, the invasive annual grass, cheatgrass (*Bromus tectorum*), has substantially increased, or in some cases, completely replaced sagebrush and native bunchgrasses (Bradley et al. 2018). When an area becomes dominated by cheatgrass, fuel continuity increases because cheatgrass grows close together leaving little to no space between plants, compared to bunchgrasses which are often separated by bare ground. In some cases, dense stands of cheatgrass can have greater fuel loads than bunchgrass communities. These factors have led more frequent fires than historically occurred (Balch et al. 2013) in some low elevation Wyoming big sagebrush. After repeated fires, cheatgrass often outcompetes sagebrush and bunchgrass seedlings, and can form a monoculture.

At higher elevations, pinyon pine (*Pinus* spp.) and juniper (*Juniperus* spp.) have increased substantially, resulting in a decrease in understory shrubs and bunchgrasses (Miller et al. 2005; Miller et al. 2008). This shift from sagebrush-bunchgrass communities to pinyon-juniper woodlands has been attributed to decreases in fire return intervals due to: historic livestock grazing which reduced fine fuel loads, active fire suppression, a decrease in Native American set fires, increases in atmospheric CO_2, and an unusually wet climate during the late 1800s and early 1900s which provided beneficial germination conditions for pinyon pine and juniper trees (Cottam and Steward 1940; Burkhardt and Tisdale 1976; Miller and Rose 1995; Polley et al. 1996; Gruell 1999; Miller and Tausch 2001; Miller et al. 2008). These new woodlands have greater fuel loads, especially of canopy fuels and coarse woody fuels, than occurred prior to Euro-American settlement.

Land managers reduce sagebrush or pinyon-juniper woodlands to reduce fuel loads and alter vegetation communities. In low elevation Wyoming big sagebrush communities that have degraded understories, but have not yet converted to dense stands of cheatgrass, land managers sometimes implement treatments such as prescribed fire, mowing, and tebuthiuron herbicide treatments to reduce sagebrush, and increase understory bunchgrass and forb cover (Davies et al. 2012; Olson and Whitson 2002; McDaniel et al. 2005). A high proportion of understory bunchgrass and forb cover can increase a community's resistance to cheatgrass dominance and resilience to disturbances such as wildfire (Chambers et al. 2014).

The Sagebrush Steppe Treatment Evaluation Project (SageSTEP) was established to evaluate the changes in vegetation and fuel loads after several types of woody plant reduction treatments in low elevation Wyoming big sagebrush communities and in pinyon-juniper woodlands (McIver et al. 2014). There is currently a lack of knowledge of how post-treatment fuel loads change over the longer term. Land managers, fire behavior specialists and researchers use fuel loading data to predict fire behavior and effects using various modeling programs. Although there are some fuel loading data available to land managers working in the Intermountain West, there are very few published fuels guides (Bourne and Bunting 2011; Shinneman et al. 2015) detailing fuel loads of areas of the Intermountain West which have been treated with woody plant reduction treatments. Furthermore, there are no published fuels guides that quantify fuel loads in areas where sagebrush or pinyon-juniper woodlands were treated more than three years prior. This is important information because woody plant reduction treatments, such as mowed sagebrush fuel breaks, have been implemented on regional scales across the Intermountain West (Shinneman et al. 2018). Furthermore, some dead fuel types such as tree litter and duff will decompose over time, and live fuels such as shrubs and grasses will continue to increase past three years post-treatment (Williams et al. 2017). Over time, pinyon and juniper trees will also increase on treated sites.

The purpose of this thesis chapter is to provide land managers, fire behavior specialists and researchers with fuel loading data at 10 years after woody plant reduction treatments in the Intermountain West. This data will be published in the form of a fuel loading guide with a similar format to Bourne and Bunting (2011) and the Natural Fuels Photo Series (Ottmar et al. 2007). This fuels guide is intended to help users quantify fuel loads at 10 years post-treatment and can be used to compare the effects of treatments to each and to an untreated control. In addition, this fuels guide can be used to compare the effects of treating pinyon-juniper woodlands during different phases of woodland development.

Methods and Materials

Data from 16 of the SageSTEP study sites were used to create this fuels guide (Figures 2.2, 2.3, 2.4, 2.5). Sagebrush study sites were at least 80.9 ha with 160 subplots, and woodland study sites ranged from 10.1-20.2 ha with 45-60 subplots (Bourne and Bunting 2011). Each subplot was 30 m by 33 m, and contained six transects, 5 of which were used for vegetation and woody fuels sampling. The sixth transect was used for herbaceous fuel sampling, and the location of this transect varied between two locations in subsequent years due to destructive sampling. Transects were set up parallel to each other and were 30 m in length.

For the purpose of organizing the fuels guide, subplots at sagebrush sites were categorized into four descriptive groups based on pre-treatment shrub and grass cover:

- Group 1 consists of subplots with 0-25% pre-treatment shrub cover and 0-25% pre-treatment total grass cover,
- Group 2 consists of subplots with 0-25% pre-treatment shrub cover and >25% pre-treatment total grass cover,
- Group 3 consists of subplots with >25% pre-treatment shrub cover and 0-25% pre-treatment total grass cover,
- Group 4 consists of subplots with >25% pre-treatment shrub cover and >25% pre-treatment total grass cover.

This grouping system was created by Stebleton and Bunting (2009) to allow users to quickly assign a group to a user's pre-treatment study site based on ocular estimates of grass and shrub cover. This system was continued in Bourne and Bunting (2011) and was continued for this 10-year post-treatment guide so that users can compare the three fuels guides. For all sagebrush steppe study sites, the dominant shrub is Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*), and the precipitation zone is 25.4-30.5 cm (10-12 in).

Four treatments were implemented at the sagebrush study sites: untreated control, prescribed burn, mechanical mowing, and tebuthiuron herbicide treatment. The intent of these treatments was to reduce sagebrush cover and promote understory grasses and forbs. Prescribed fire treatments were implemented in the fall by federal agencies, with the intent of broadcast burning 100% of each subplot. At many sites, 20-90% of each subplot was burned due to environmental conditions at the time of burning such as fuel moisture and wind. Follow-up burns were implemented at the sampling plot scale. The objective of mechanical mowing and herbicide treatments was to reduce sagebrush cover by 50% (Bourne and Bunting 2011). The mowing treatment reduced sagebrush height to 31-38 cm from a pre-treatment mean height of 68 cm. The tebuthiuron herbicide treatment was aerially applied in the form of pellets at a rate of 1.1-1.7 kg/ha (Bourne and Bunting 2011), and resulted in a high variability of sagebrush mortality among subplots at the same site.

Subplots at the woodland sites are organized by three woodland development phases as defined by Miller et al. (2005), and by region (Pinyon-Juniper, Utah Juniper, and Western Juniper). In Phase I, trees are present on the site, but the shrub and herbaceous components drive the ecological processes occurring on the site (hydrology, and nutrient and energy cycling). In Phase II, trees co-dominate the site with the shrub and herbaceous components, and all three influence ecological processes occurring on the site. In Phase III, trees dominate the ecological processes on the site, and shrubs, grasses, and forbs have declined in cover and density. Subplots were assigned to a woodland development phase prior to treatment, and subplots are still grouped by pre-treatment woodland phase in this guide so that users can assess the influence that pre-treatment phase has on 10-year post-treatment changes in vegetation and fuels. The Pinyon-Juniper study sites are located in Nevada (Figure 2.3), and the dominant tree species are Utah Juniper (*Juniperus osteosperma*) and single-leaf pinyon-pine (*Pinus monophylla*). The Utah Juniper study sites are located in Utah (Figure 2.4), and the dominant tree species are Utah Juniper (*Juniperus osteosperma*) and Colorado pinyon-pine (*Pinus edulis*). The Western Juniper study sites are located in Oregon and California (Figure 2.5), and the dominant tree species is Western Juniper (*Juniperus occidentalis*). All woodland sites are the in the 30.5-35.6 (12-14 in) precipitation zone.

The woodland data are also grouped by treatment. Three treatments—untreated control, prescribed fire, mechanical cutting—were implemented at all woodland sites, and an additional mechanical mastication treatment was implemented at the study sites in the Utah Juniper region. Prescribed fires were implemented in the fall and were intended to burn 100% of the area of each subplot, but the percentage of each subplot burned was highly variable. Surviving trees were individually burned in a follow-up treatment. Both mechanical treatments (cutting and mastication) targeted all trees greater than 0.5 m in height.

This chapter provides statistics on canopy cover, height, density, fuel load, and bulk density of several fuel load components and functional groups. Mean, 10th percentile, and 90th percentile statistics are provided to demonstrate the average and range of variability. Minimum and maximum were not used because these values were often extreme. Plant species codes, common names, and scientific names according to the USDA Plants Database (USDA, NRCS 2019) are available in Appendix I (Table 2.48). The published fuels guide will photographs with each region/phase/treatment category so that there are two photographic examples that accompany each table of summarized data. A table with the previously mentioned statistics was created for each region/phase/treatment grouping (see Tables 2.3-2.45).

Trees

Height, longest canopy diameter, and perpendicular canopy diameter were measured in the field for all trees 0.5 m in height. To estimate tree cover, the area of each tree greater than 0.5 m was estimated from canopy diameter measurements, and tree canopy area was divided by the area of subplot. All trees greater than 0.5 m in height were counted within the subplot for tree density measurements. Trees less than 0.5 m in height were measured using three belt transects 2 m wide along transects 2, 4, and 6 (Figure 2.1). Tree fuel loads were estimated using allometric equations developed Sabin (2008) and Tausch (2008).

Shrubs

Shrub cover was estimated from 300 points collected using line-point intercept (Bonham 1989) along five transects (Table 2.1). Densities of common shrubs were estimated by counting shrubs within three belt transects 2 m wide along transects 2, 4, and 6 (Figure 2.1). The process of estimating shrub fuel loads involved destructive sampling and the development of allometric relationships (Stebleton and Bunting 2009). At each study site in 2007, height, longest canopy diameter, and perpendicular canopy diameter were measured for each common species of shrub found outside of subplots. Shrub canopy volume was estimate using the height and canopy diameter measurements. These shrubs were then destructively sampled, oven-dried at 50°C for 48 hours and weighed to determine fuel load. Site- and species-specific regression equations were developed using height, canopy dimensions, and shrub volume as covariates (Rittenhouse and Sneva 1977; Stebleton and Bunting 2009). At 10 years post-treatment, shrub volume measurements were collected for shrubs taller than 15 cm within five nested-circular frames with a radius of 1, 2, or 3 m so that at least 10 shrubs of each common species were measured per sampling plot (Bonham 1989; Young et al. 2015). Then the site-specific allometric equations were used to estimate shrub fuel loads from shrub volume data. R^2 values for these equations are available in Stebleton and Bunting (2009) and Bourne and Bunting (2011). At 10 years post-treatment, standing dead shrubs fuels were sampled as downed woody debris.

Herbaceous Fuels

For each subplot, canopy cover of perennial grass, annual grass, forbs, and interspace litter were derived from 300 points per subplot (5 transects with 60 points per transect) using the line-point intercept method (Bonham 1989; Table 2.1). Herbaceous fuel loads were estimated from destructive sampling that occurred along the herbaceous fuels transect. All live herbaceous material, standing dead herbaceous material, and interspace litter were collected from a 0.5 by 0.5 m quadrat (Bonham 1989) at 15 sampling locations in woodland sites, and 8 sampling locations in the sagebrush sites. Heights of the tallest grass and forb within the quadrat were recorded prior to clipping. All herbaceous vegetation within 0.01 m of the ground was removed and sorted as live herbaceous, standing dead herbaceous, and interspace litter. Samples were oven-dried at 50°C for 48 hours and weighed. Bulk density was calculated by dividing the total fuel load by the landscape average of all grass and forb heights.

Down woody debris

Down woody debris fuel loads were sampled using a modified planar-intercept method (Brown et al. 1982). Down woody debris of the 10- and 100-hr time lag fuel moisture classes were tallied along 3 transects for a total of 90 m in each subplot (Table 2.1). Standing dead shrubs were sampled as down woody debris. Down woody debris of the 1000-hr time lag fuel moisture classes were tallied along 5 transects for a total of 150 m in each subplot. When sampling 1000-hr fuels, a decay class (sound or rotten) and the diameter of down woody fuel where the fuel intersected the transect were recorded for each fuel (Brown 1974). Equations developed by Brown (1974) were used to estimate fuel load by time lag fuel moisture class from the sampled woody fuel data.

For all treatments except the mastication treatment, 1-hr down woody debris fuel loads were not sampled. In the mastication treatment, 1-hr and 10-hr fuels were collected within 0.25 m by 0.25 m quadrats placed every other meter along two 30 m transects (30 quadrats per subplot), but 100- and 1000-hr fuels were sampled in the same manner as described in the previous paragraph. The method for sampling 1- and 10-hr fuels in the mastication treatment is not the same as the method used in the two years post-treatment fuels guide (Bourne and Bunting 2011), so be cautious when comparing these masticated fuels between the two fuels guides.

Litter, Duff, and Bare Ground

Within each sampling plot, duff and tree litter were collected from six, 0.25 x 0.25 m quadrats placed at one-third the distance from the bole of the tree (standing live, cut, masticated, or standing dead) to the edge of the tree canopy. Selected trees were those that were greater than 2 m in crown diameter rooted within the subplot. Sub-samples of the litter and duff were oven-dried at 50°C for 48 hours and weighed. Depth of tree litter and duff was not measured at 10 years post-treatment, so it was not possible to estimate tree litter and duff bulk density in this fuels guide. Cover and fuel load of interspace litter was estimated using methods described in the Herbaceous Fuels.

Bare ground cover for each subplot was derived from 300 points per subplot (5 transects with 60 points per transect) using the line-point intercept method (Bonham 1989; Table 2.1). Bare ground cover (%) is the only measure of fuel continuity.

Figures and Tables

Subplot Layout and Methods

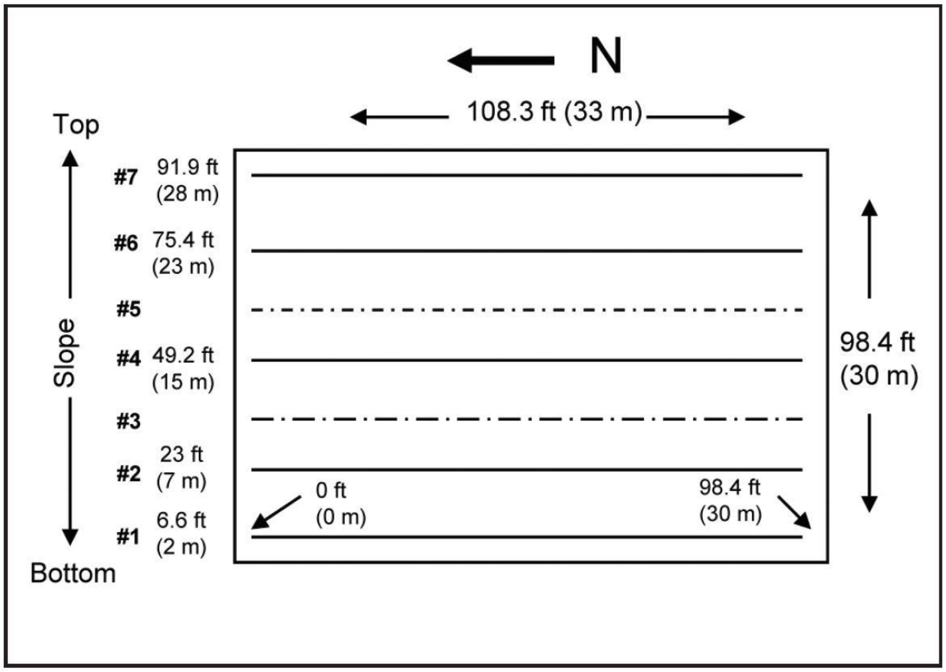

Figure 2.1. Layout of transects within a subplot. Adapted from Bourne and Bunting (2011). Herbaceous fuels were sampled along transects 3 and 5 in subsequent years. Grass, bare ground, and shrub cover were sampled along transects 1, 2, 4, 6, and 7. Shrub height and volume were sampled along transect 6, and shrub density was sampled along transects 2, 4, and 6. Down woody debris of the 10-hr and 100-hr classes were sampled along transects 2, 4, and 6, and the 1000-hr was sampled along transects 1, 2, 4, 6, and 7. In the mastication treatment, 1-hr and 10-hr fuels were sampled along transects 2 and 6.

Table 2.1. Summary of methods. Adapted from Bourne and Bunting (2011).

Stratum	Variable	Method	Transect #
Trees	Cover	Canopy Area/Plot Area (Young et al. 2015)	NA
	Density	Belt Transect (Krebs 1989; Salzer 1994)	2, 4, 6
		Census Data	NA
	Height	Census Data	NA
	Fuel Load & Bulk Density	Allometric Equations (Sabin 2008; Tausch 2008)	NA
			NA
Shrubs	Cover	Line Point Intercept (Bonham 1989)	1, 2, 4, 6, 7
	Height	Nested circular frame (Bonham 1989)	4
	Density	Belt Transect (Krebs 1989; Salzer 1994)	2, 4, 6
		Nested circular frame (Bonham 1989)	4
	Fuel Load & Bulk Density	Harvest (Pechanec & Pickford 1937; Riser 1984)	NA
		50 x 50 cm quadrat (Bonham 1989)	4
Herbaceous	Cover	Line-Point Intercept (Bonham 1989)	1, 2, 4, 6, 7
	Height	50 x 50 cm quadrat (Bonham 1989)	3 in 2016 & 2018; 5 in 2017
	Fuel Load & Bulk Density	Harvest (Pechanec & Pickford 1937; Riser 1984)	3 in 2016 & 2018; 5 in 2017
		50 x 50 cm quadrat (Bonham 1989)	3 in 2016 & 2018; 5 in 2017
Masticated Down Woody Debris	1-hr Fuel Load	25 x 25 cm quadrat (Young et al. 2015)	2, 6
	10-hr Fuel Load	25 x 25 cm quadrat (Young et al. 2015)	2, 6
	100-hr Fuel Load	Planar Intercept (Brown et al. 1982)	2, 4, 6
	1000-hr Fuel Load	Planar Intercept (Brown et al. 1982)	1, 2, 4, 6, 7
Down Woody Debris	10-hr Fuel Load	Planar Intercept (Brown et al. 1982)	2, 4, 6
	100-hr Fuel Load	Planar Intercept (Brown et al. 1982)	2, 4, 6
	1000-hr Fuel Load	Planar Intercept (Brown et al. 1982)	1, 2, 4, 6, 7
Litter & Duff	Cover	Line Point Intercept (Bonham 1989)	1, 2, 4, 6, 7
	Interspace Litter Fuel Load	Harvest (Pechanec & Pickford 1937; Riser 1984)	3 in 2016 & 2018; 5 in 2017
		50 x 50 cm quadrat (Bonham 1989)	3 in 2016 & 2018; 5 in 2017
	Tree Litter & Duff Fuel Load	Harvest (Pechanec & Pickford 1937; Riser 1984)	NA
		50 x 50 cm quadrat (Bonham 1989)	NA

Sagebrush Steppe

Figure 2.2. Map of Sagebrush Steppe study sites.

Sagebrush Steppe Treatments: Group 1

Table 2.2. Summarized data for Group 1 (0-25% pre-treatment shrub cover and 0-25% pre-treatment grass cover) of the Sagebrush Steppe Control treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	13	18	21
		CHVI8	0	<1	2
	Herbaceous	Perennial Grass	7	15	25
		Annual Grass	1	10	20
		Forb	1	5	11
	Litter & Duff	Interspace Litter	9	13	15
	Bare Ground	Bare Ground	35	41	50
Density (#/acre)	Shrub	ARTRW8	1789	2802	3824
		CHVI8	0	284	720
Height (in)	Shrub	ARTRW8	15	21	26
		CHVI8	12	12	12
	Herbaceous	Grass	5	7	9
		Forb	2	3	4
Fuel Loading (tons/acre)	Shrub	ARTRW8	0.63	2.21	4.47
		CHVI8	0	<0.01	0.01
	Herbaceous	Live	0.06	0.08	0.11
		Dead	0.02	0.04	0.05
	Down Woody Debris	10-hr	0.28	0.42	0.59
		100-hr	0.37	0.61	1.00
		1000-hr sound	0	0.16	0.59
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.07	0.21	0.45
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0.0175	0.0303	0.0498
		CHVI8	0	0.0003	0.0007
	Herbaceous	Live + Dead	0.0066	0.0102	0.0157

Table 2.3. Summarized data for Group 1 (0-25% pre-treatment shrub cover and 0-25% pre-treatment grass cover) of the Sagebrush Steppe Prescribed Fire treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	0	2	4
		CHVI8	0	2	4
	Herbaceous	Perennial Grass	2	16	33
		Annual Grass	29	47	61
		Forb	3	8	16
	Litter & Duff	Interspace Litter	9	13	16
	Bare Ground	Bare Ground	12	17	23
Density (#/acre)	Shrub	ARTRW8	0	264	802
		CHVI8	0	315	611
Height (in)	Shrub	ARTRW8	17	23	30
		CHVI8		NA	
	Herbaceous	Grass	9	10	11
		Forb	3	7	11
Fuel Loading (tons/acre)	Shrub	ARTRW8	0	0.07	0.15
		CHVI8		NA	
	Herbaceous	Live	0.17	0.23	0.29
		Dead	0.05	0.10	0.22
	Down Woody Debris	10-hr	0.06	0.19	0.33
		100-hr	0.10	0.22	0.41
		1000-hr sound		0	
		1000-hr rotten			
	Litter & Duff	Interspace Litter	0.08	0.13	0.19
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0	0.0016	0.0039
		CHVI8		NA	
	Herbaceous	Live + Dead	0.0134	0.0187	0.0269

Table 2.4. Summarized data for Group 1 (0-25% pre-treatment shrub cover and 0-25% pre-treatment grass cover) of the Sagebrush Steppe Mowing treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	9	13	17
		CHVI8	0	<1	<1
	Herbaceous	Perennial Grass	8	18	34
		Annual Grass	3	17	31
		Forb	1	5	12
	Litter & Duff	Interspace Litter	12	15	18
	Bare Ground	Bare Ground	26	34	45
Density (#/acre)	Shrub	ARTRW8	1903	2352	2825
		CHVI8	0	39	113
Height (in)	Shrub	ARTRW8	13	18	23
		CHVI8	15	15	15
	Herbaceous	Grass	7	7	9
		Forb	3	3	4
Fuel Loading (tons/acre)	Shrub	ARTRW8	0.35	1.04	2.20
		CHVI8	0	0.02	0.05
	Herbaceous	Live	0.08	0.13	0.18
		Dead	0.02	0.04	0.06
	Down Woody Debris	10-hr	0.45	0.66	0.84
		100-hr	0.35	0.73	1.17
		1000-hr sound	0	0.30	0.59
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.13	0.22	0.32
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0.0118	0.0216	0.0321
		CHVI8	0	0.0007	0.0018
	Herbaceous	Live + Dead	0.0087	0.0124	0.0164

Table 2.5. Summarized data for Group 1 (0-25% pre-treatment shrub cover and 0-25% pre-treatment grass cover) of the Sagebrush Steppe Tebuthiuron treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	5	14	23
		CHVI8		0	
	Herbaceous	Perennial Grass	4	19	36
		Annual Grass	18	40	64
		Forb	2	9	15
	Litter & Duff	Interspace Litter	6	9	12
	Bare Ground	Bare Ground	5	19	35
Density (#/acre)	Shrub	ARTRW8	868	1830	2498
		CHVI8	0	6	23
Height (in)	Shrub	ARTRW8	19	22	26
		CHVI8		NA	
	Herbaceous	Grass	7	10	12
		Forb	3	5	7
Fuel Loading (tons/acre)	Shrub	ARTRW8	0.28	1.38	2.69
		CHVI8		NA	
	Herbaceous	Live	0.11	0.20	0.28
		Dead	0.02	0.06	0.13
	Down Woody Debris	10-hr	0.42	0.57	0.74
		100-hr	0.44	0.99	1.96
		1000-hr sound	0	0.79	2.13
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.07	0.23	0.46
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0.0055	0.0192	0.0312
		CHVI8		NA	
	Herbaceous	Live + Dead	0.0082	0.0145	0.0245

Sagebrush Steppe Treatments: Group 2

Table 2.6. Summarized data for Group 2 (0-25% pre-treatment shrub cover and >25% pre-treatment grass cover) of the Sagebrush Steppe Control treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	12	17	26
		CHVI8	0	<1	1
	Herbaceous	Perennial Grass	17	31	42
		Annual Grass	10	26	42
		Forb	2	11	25
	Litter & Duff	Interspace Litter	5	10	15
	Bare Ground	Bare Ground	2	14	34
Density (#/acre)	Shrub	ARTRW8	1204	1873	3111
		CHVI8	0	190	409
Height (in)	Shrub	ARTRW8	19	26	34
		CHVI8	10	10	11
	Herbaceous	Grass	7	9	12
		Forb	3	5	8
Fuel Loading (tons/acre)	Shrub	ARTRW8	0.77	2.00	4.31
		CHVI8	NA		
	Herbaceous	Live	0.09	0.21	0.37
		Dead	0.03	0.16	0.27
	Down Woody Debris	10-hr	0.17	0.36	0.65
		100-hr	0.30	0.65	1.23
		1000-hr sound	0	0.30	0.62
		1000-hr rotten	0		
	Litter & Duff	Interspace Litter	0.09	0.19	0.37
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0.0091	0.0196	0.0337
		CHVI8	NA		
	Herbaceous	Live + Dead	0.0118	0.0205	0.0272

Table 2.7. Summarized data for Group 2 (0-25% pre-treatment shrub cover and >25% pre-treatment grass cover) of the Sagebrush Steppe Prescribed Fire treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	0	2	5
		CHVI8	0	<1	1
	Herbaceous	Perennial Grass	23	33	49
		Annual Grass	15	39	63
		Forb	<1	9	22
	Litter & Duff	Interspace Litter	7	10	14
	Bare Ground	Bare Ground	6	14	21
Density (#/acre)	Shrub	ARTRW8	0	402	1113
		CHVI8	0	45	132
Height (in)	Shrub	ARTRW8	21	24	28
		CHVI8	NA	12	NA
	Herbaceous	Grass	8	11	14
		Forb	2	6	13
Fuel Loading (tons/acre)	Shrub	ARTRW8	0	0.17	0.47
		CHVI8	NA		
	Herbaceous	Live	0.18	0.35	0.60
		Dead	0.05	0.26	0.64
	Down Woody Debris	10-hr	0.10	0.25	0.43
		100-hr	0.05	0.39	1.06
		1000-hr sound	0	0.07	0.20
		1000-hr rotten	0		
	Litter & Duff	Interspace Litter	0.08	0.15	0.20
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0	0.0028	0.0078
		CHVI8	NA		
	Herbaceous	Live + Dead	0.0183	0.0283	0.0432

Table 2.8. Summarized data for Group 2 (0-25% pre-treatment shrub cover and >25% pre-treatment grass cover) of the Sagebrush Steppe Mowing treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	4	8	13
		CHVI8	0	<1	1
	Herbaceous	Perennial Grass	16	30	43
		Annual Grass	7	34	55
		Forb	2	9	20
	Litter & Duff	Interspace Litter	4	11	17
	Bare Ground	Bare Ground	3	10	26
Density (#/acre)	Shrub	ARTRW8	636	1503	2725
		CHVI8	0	101	431
Height (in)	Shrub	ARTRW8	16	20	25
		CHVI8	NA	10	NA
	Herbaceous	Grass	7	10	14
		Forb	2	4	8
Fuel Loading (tons/acre)	Shrub	ARTRW8	0.13	0.65	1.48
		CHVI8	0	<0.01	0
	Herbaceous	Live	0.14	0.26	0.39
		Dead	0.04	0.17	0.25
	Down Woody Debris	10-hr	0.25	0.56	0.90
		100-hr	0.25	0.93	1.77
		1000-hr sound	0	0.17	0.37
		1000-hr rotten	0	0.01	0
	Litter & Duff	Interspace Litter	0.06	0.30	0.56
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0.0026	0.0112	0.0181
		CHVI8	0	0.0001	0
	Herbaceous	Live + Dead	0.0125	0.0240	0.0375

Table 2.9. Summarized data for Group 2 (0-25% pre-treatment shrub cover and >25% pre-treatment grass cover) of the Sagebrush Steppe Tebuthiuron treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	<1	6	16
		CHVI8	0	<1	<1
	Herbaceous	Perennial Grass	7	21	34
		Annual Grass	8	44	79
		Forb	3	12	22
	Litter & Duff	Interspace Litter	5	9	14
	Bare Ground	Bare Ground	2	11	31
Density (#/acre)	Shrub	ARTRW8	82	755	1926
		CHVI8	0	68	191
Height (in)	Shrub	ARTRW8	17	24	32
		CHVI8	12	15	19
	Herbaceous	Grass	7	11	14
		Forb	2	5	9
Fuel Loading (tons/acre)	Shrub	ARTRW8	0	0.62	1.86
		CHVI8		NA	
	Herbaceous	Live	0.15	0.28	0.42
		Dead	0.03	0.13	0.26
	Down Woody Debris	10-hr	0.32	0.62	1.13
		100-hr	0.29	1.15	2.13
		1000-hr sound	0	0.46	1.02
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.06	0.15	0.23
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	<0.0001	0.0077	0.0195
		CHVI8		NA	
	Herbaceous	Live + Dead	0.0143	0.0214	0.0290

Sagebrush Steppe Treatments: Group 3

Table 2.10. Summarized data for Group 3 (>25% pre-treatment shrub cover and 0-25% pre-treatment grass cover) of the Sagebrush Steppe Control treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	21	42	50
		CHVI8		0	
	Herbaceous	Perennial Grass	8	16	24
		Annual Grass	0	4	15
		Forb	<1	2	3
	Litter & Duff	Interspace Litter	7	11	15
	Bare Ground	Bare Ground	20	27	39
Density (#/acre)	Shrub	ARTRW8	1812	7579	12229
		CHVI8	0	6	14
Height (in)	Shrub	ARTRW8	16	19	21
		CHVI8		NA	
	Herbaceous	Grass	5	6	7
		Forb	<1	2	3
Fuel Loading (tons/acre)	Shrub	ARTRW8	1.26	3.74	6.68
		CHVI8		NA	
	Herbaceous	Live	0.03	0.06	0.09
		Dead	<0.01	0.02	0.03
	Down Woody Debris	10-hr	0.51	0.75	1.04
		100-hr	0.79	1.05	1.44
		1000-hr sound	0.10	0.35	0.59
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.09	0.13	0.17
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0.0207	0.0508	0.0833
		CHVI8		NA	
	Herbaceous	Live + Dead	0.0031	0.0070	0.0108

Table 2.11. Summarized data for Group 3 (>25% pre-treatment shrub cover and 0-25% pre-treatment grass cover) of the Sagebrush Steppe Prescribed Fire treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	0	13	37
		CHVI8	0	<1	2
	Herbaceous	Perennial Grass	10	20	33
		Annual Grass	13	48	71
		Forb	<1	5	8
	Litter & Duff	Interspace Litter	4	8	12
	Bare Ground	Bare Ground	1	12	21
Density (#/acre)	Shrub	ARTRW8	0	2209	6563
		CHVI8	0	123	493
Height (in)	Shrub	ARTRW8	13	19	25
		CHVI8	11	12	13
	Herbaceous	Grass	7	10	13
		Forb	3	6	10
Fuel Loading (tons/acre)	Shrub	ARTRW8	0	1.59	4.46
		CHVI8		NA	
	Herbaceous	Live	0.11	0.30	0.63
		Dead	0.03	0.11	0.28
	Down Woody Debris	10-hr	0.04	0.20	0.47
		100-hr	0	0.35	0.82
		1000-hr sound	0	0.27	0.57
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.14	0.34	0.52
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0	0.0190	0.0567
		CHVI8		NA	
	Herbaceous	Live + Dead	0.0106	0.0210	0.0354

Table 2.12. Summarized data for Group 3 (>25% pre-treatment shrub cover and 0-25% pre-treatment grass cover) of the Sagebrush Steppe Mowing treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	17	19	22
		CHVI8	0	4	8
	Herbaceous	Perennial Grass	8	14	23
		Annual Grass	6	30	63
		Forb	1	13	27
	Litter & Duff	Interspace Litter	10	13	17
	Bare Ground	Bare Ground	3	17	28
Density (#/acre)	Shrub	ARTRW8	2316	3581	5064
		CHVI8	91	1007	2544
Height (in)	Shrub	ARTRW8	16	19	22
		CHVI8	10	13	15
	Herbaceous	Grass	7	9	10
		Forb	1	3	4
Fuel Loading (tons/acre)	Shrub	ARTRW8	1.44	2.08	2.78
		CHVI8	NA		
	Herbaceous	Live	0.10	0.14	0.18
		Dead	0.01	0.03	0.07
	Down Woody Debris	10-hr	0.50	0.88	1.21
		100-hr	0.57	1.94	3.62
		1000-hr sound	0.05	0.86	2.27
		1000-hr rotten	0		
	Litter & Duff	Interspace Litter	0.21	0.43	0.61
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0.0188	0.0309	0.0473
		CHVI8	NA		
	Herbaceous	Live + Dead	0.0070	0.0116	0.0168

Table 2.13. Summarized data for Group 3 (>25% pre-treatment shrub cover and 0-25% pre-treatment grass cover) of the Sagebrush Steppe Tebuthiuron treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	12	21	28
		CHVI8	0	<1	<1
	Herbaceous	Perennial Grass	5	19	33
		Annual Grass	9	38	68
		Forb	1	3	7
	Litter & Duff	Interspace Litter	7	11	15
	Bare Ground	Bare Ground	4	16	32
Density (#/acre)	Shrub	ARTRW8	1585	3515	6631
		CHVI8	0	25	68
Height (in)	Shrub	ARTRW8	19	24	29
		CHVI8	NA	34	NA
	Herbaceous	Grass	7	10	13
		Forb	1	5	9
Fuel Loading (tons/acre)	Shrub	ARTRW8	0.51	1.76	3.93
		CHVI8		NA	
	Herbaceous	Live	0.04	0.19	0.33
		Dead	<0.01	0.08	0.13
	Down Woody Debris	10-hr	0.20	0.55	0.85
		100-hr	0.23	1.13	3.18
		1000-hr sound	0	0.86	1.83
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.05	0.22	0.46
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0.0074	0.0256	0.0470
		CHVI8		NA	
	Herbaceous	Live + Dead	0.0064	0.0132	0.0199

Sagebrush Steppe Treatments: Group 4

Table 2.14. Summarized data for Group 4 (>25% pre-treatment shrub cover and >25% pre-treatment grass cover) of the Sagebrush Steppe Control treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	21	25	30
		CHVI8	0	<1	<1
	Herbaceous	Perennial Grass	9	24	41
		Annual Grass	18	42	64
		Forb	5	13	24
	Litter & Duff	Interspace Litter	4	7	10
	Bare Ground	Bare Ground	3	8	15
Density (#/acre)	Shrub	ARTRW8	1522	2856	4583
		CHVI8	0	151	91
Height (in)	Shrub	ARTRW8	18	26	38
		CHVI8	16	16	16
	Herbaceous	Grass	7	10	13
		Forb	3	5	7
Fuel Loading (tons/acre)	Shrub	ARTRW8	1.11	2.67	4.80
		CHVI8	NA		
	Herbaceous	Live	0.10	0.16	0.25
		Dead	<0.01	0.09	0.20
	Down Woody Debris	10-hr	0.22	0.69	1.42
		100-hr	0.46	1.11	2.13
		1000-hr sound	0	0.40	0.96
		1000-hr rotten	0	0.04	0.17
	Litter & Duff	Interspace Litter	0.07	0.15	0.24
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0.0098	0.0363	0.0721
		CHVI8	NA		
	Herbaceous	Live + Dead	0.0053	0.0156	0.0307

Table 2.15. Summarized data for Group 4 (>25% pre-treatment shrub cover and >25% pre-treatment grass cover) of the Sagebrush Steppe Prescribed Fire treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	0	9	20
		CHVI8	0	<1	2
	Herbaceous	Perennial Grass	10	26	46
		Annual Grass	15	42	60
		Forb	0	13	30
	Litter & Duff	Interspace Litter	5	8	13
	Bare Ground	Bare Ground	3	10	23
Density (#/acre)	Shrub	ARTRW8	0	2510	6927
		CHVI8	0	114	341
Height (in)	Shrub	ARTRW8	13	17	20
		CHVI8	13	15	18
	Herbaceous	Grass	6	10	13
		Forb	2	6	11
Fuel Loading (tons/acre)	Shrub	ARTRW8	0	0.76	1.74
		CHVI8	NA		
	Herbaceous	Live	0.13	0.24	0.32
		Dead	0.03	0.11	0.19
	Down Woody Debris	10-hr	0.07	0.30	0.72
		100-hr	0.05	0.48	1.18
		1000-hr sound	0	0.05	0.28
		1000-hr rotten	0		
	Litter & Duff	Interspace Litter	0.06	0.12	0.19
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0	0.0146	0.0343
		CHVI8	NA		
	Herbaceous	Live + Dead	0.0125	0.0207	0.0296

Table 2.16. Summarized data for Group 4 (>25% pre-treatment shrub cover and >25% pre-treatment grass cover) of the Sagebrush Steppe Mowing treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	5	16	24
		CHVI8	0	<1	2
	Herbaceous	Perennial Grass	16	32	43
		Annual Grass	6	26	38
		Forb	0.3	9	21
	Litter & Duff	Interspace Litter	6	11	17
	Bare Ground	Bare Ground	2	12	23
Density (#/acre)	Shrub	ARTRW8	1260	2842	4247
		CHVI8	0	169	500
Height (in)	Shrub	ARTRW8	14	18	22
		CHVI8	8	13	16
	Herbaceous	Grass	8	10	14
		Forb	2	4	5
Fuel Loading (tons/acre)	Shrub	ARTRW8	0.21	1.23	2.17
		CHVI8	NA		
	Herbaceous	Live	0.07	0.19	0.26
		Dead	0.02	0.12	0.33
	Down Woody Debris	10-hr	0.37	0.82	1.34
		100-hr	0.66	1.89	3.69
		1000-hr sound	0	0.72	1.24
		1000-hr rotten	0	0.16	0
	Litter & Duff	Interspace Litter	0.09	0.20	0.33
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0.0049	0.0249	0.0450
		CHVI8	NA		
	Herbaceous	Live + Dead	0.0053	0.0175	0.0305

Table 2.17. Summarized data for Group 4 (>25% pre-treatment shrub cover and >25% pre-treatment grass cover) of the Sagebrush Steppe Tebuthiuron treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Shrub	ARTRW8	4	25	46
		CHVI8	0	<1	2
	Herbaceous	Perennial Grass	18	34	46
		Annual Grass	7	36	74
		Forb	1	9	25
	Litter & Duff	Interspace Litter	2	5	9
	Bare Ground	Bare Ground	2	5	10
Density (#/acre)	Shrub	ARTRW8	1011	2951	5098
		CHVI8	0	219	636
Height (in)	Shrub	ARTRW8	18	27	34
		CHVI8	12	13	15
	Herbaceous	Grass	5	10	15
		Forb	2	4	6
Fuel Loading (tons/acre)	Shrub	ARTRW8	0.20	1.91	4.46
		CHVI8		NA	
	Herbaceous	Live	0.08	0.23	0.42
		Dead	0.01	0.14	0.33
	Down Woody Debris	10-hr	0.20	0.68	1.39
		100-hr	0.15	1.25	2.68
		1000-hr sound	0	0.29	0.80
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.05	0.14	0.22
Bulk Density (lbs/ft^3)	Shrub	ARTRW8	0.0037	0.0218	0.0441
		CHVI8		NA	
	Herbaceous	Live + Dead	0.0113	0.0218	0.0307

Pinyon-Juniper Region

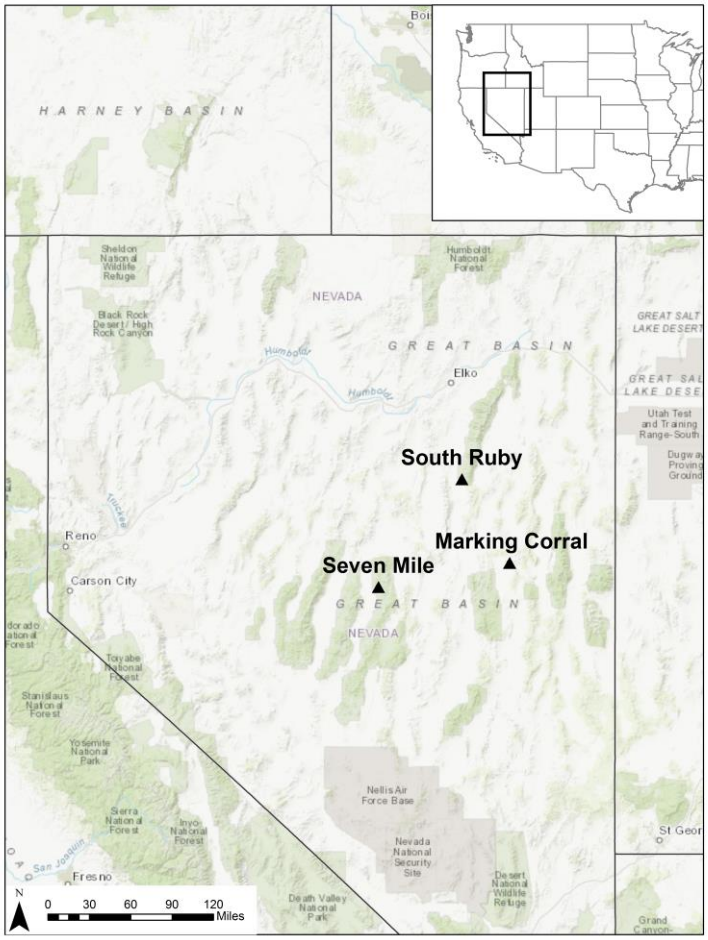

Figure 2.3. Map of study sites in the Pinyon-Juniper region.

Pinyon-Juniper Treatments: Phase I

Table 2.18. Summarized data for Phase I of the Pinyon-Juniper Control treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIMO	3	8	13
	Shrub	Total	11	19	25
	Herbaceous	Perennial Grass	6	17	29
		Annual Grass	0	<1	<1
		Forb	5	11	16
	Litter & Duff	Interspace Litter	9	11	14
	Bare Ground	Bare Ground	22	30	38
Density (#/acre)	Tree	JUOS & PIMO < 1.6 ft tall	23	41	68
		JUOS & PIMO > 1.6 ft tall	59	95	125
	Shrub	Total	1990	5235	7655
Height (ft)	Tree	JUOS & PIMO	2	7	13
		JUOS & PIMO Canopy Base	<1	<1	1
Height (in)	Shrub	Total	13	15	17
	Herbaceous	Grass	5	10	16
		Forb	2	3	5
Fuel Loading (tons/acre)	Tree	JUOS & PIMO	0.81	3.02	5.06
	Shrub	Total	0.81	2.26	4.05
	Herbaceous	Live	0.03	0.05	0.08
		Dead	<0.01	<0.01	0.02
	Down Woody Debris	10-hr	0.08	0.44	0.93
		100-hr	0.12	1.27	2.80
		1000-hr sound	0	0.06	0.19
		1000-hr rotten	0	0.25	0.76
	Litter & Duff	Interspace Litter	0.12	0.19	0.27
		Tree Litter + Duff	0.58	1.37	2.55
Bulk Density (lbs/ft^3)	Tree	JUOS & PIMO Canopy	0.0025	0.0059	0.0094
	Shrub	Total	0.0166	0.0372	0.0589
	Herbaceous	Live + Dead	0.0030	0.0088	0.0141

Table 2.19. Summarized data for Phase II of the Pinyon-Juniper Prescribed Fire treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIMO	0	1	4
	Shrub	Total	10	17	27
	Herbaceous	Perennial Grass	13	27	38
		Annual Grass	0	21	42
		Forb	12	17	20
	Litter & Duff	Interspace Litter	6	12	19
	Bare Ground	Bare Ground	2	19	44
Density (#/acre)	Tree	JUOS & PIMO < 1.6 ft tall	0	10	41
		JUOS & PIMO > 1.6 ft tall	0	9	21
	Shrub	Total	2311	3573	5400
Height (ft)	Tree	JUOS & PIMO	3	8	14
		JUOS & PIMO Canopy Base	<1	<1	1
Height (in)	Shrub	Total	12	16	20
	Herbaceous	Grass	4	10	16
		Forb	2	5	9
Fuel Loading (tons/acre)	Tree	JUOS & PIMO	0	0.51	1.19
	Shrub	Total	0.18	0.70	1.17
	Herbaceous	Live	0.13	0.25	0.34
		Dead	<0.01	0.06	0.14
	Down Woody Debris	10-hr	0.27	0.35	0.48
		100-hr	0.31	1.12	2.40
		1000-hr sound	0.11	0.87	2.62
		1000-hr rotten	0	0.03	0.06
	Litter & Duff	Interspace Litter	0.06	0.17	0.39
		Tree Litter + Duff	0	0.23	0.70
Bulk Density (lbs/ft^3)	Tree	JUOS & PIMO Canopy	0	0.0009	0.0028
	Shrub	Total	0.0062	0.0155	0.0262
	Herbaceous	Live + Dead	0.0136	0.0301	0.0361

Table 2.20. Summarized data for Phase I of the Pinyon-Juniper Cutting treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIMO	<1	<1	<1
	Shrub	Total	22	28	37
	Herbaceous	Perennial Grass	23	29	35
		Annual Grass	0	7	21
		Forb	10	16	24
	Litter & Duff	Interspace Litter	4	10	15
	Bare Ground	Bare Ground	6	16	33
Density (#/acre)	Tree	JUOS & PIMO < 1.6 ft tall	2	69	176
		JUOS & PIMO > 1.6 ft tall	12	38	60
	Shrub	Total	3226	5021	6138
Height (ft)	Tree	JUOS & PIMO	2	3	5
		JUOS & PIMO Canopy Base	<1	<1	<1
Height (in)	Shrub	Total	13	19	28
	Herbaceous	Grass	8	10	12
		Forb	2	6	9
Fuel Loading (tons/acre)	Tree	JUOS & PIMO	0.01	0.04	0.10
	Shrub	Total	1.27	2.96	5.03
	Herbaceous	Live	0.12	0.24	0.35
		Dead	0.02	0.05	0.13
	Down Woody Debris	10-hr	0.12	0.50	1.24
		100-hr	0.64	1.38	2.79
		1000-hr sound	0.31	1.78	2.45
		1000-hr rotten	0	0.29	0.62
	Litter & Duff	Interspace Litter	0.10	0.25	0.38
		Tree Litter + Duff	<0.01	0.10	0.24
Bulk Density (lbs/ft^3)	Tree	JUOS & PIMO Canopy	<0.0001	0.0003	0.0008
	Shrub	Total	0.0112	0.0401	0.0745
	Herbaceous	Live + Dead	0.0059	0.0218	0.0368

Pinyon-Juniper Treatments: Phase II

Table 2.21. Summarized data for Phase II of the Pinyon-Juniper Control treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIMO	12	35	62
	Shrub	Total	4	10	18
	Herbaceous	Perennial Grass	3	7	11
		Annual Grass		0	
		Forb	2	7	11
	Litter & Duff	Interspace Litter	5	11	14
	Bare Ground	Bare Ground	24	32	43
Density (#/acre)	Tree	JUOS & PIMO < 1.6 ft tall	0	78	180
		JUOS & PIMO > 1.6 ft tall	107	220	330
	Shrub	Total	679	3253	6178
Height (ft)	Tree	JUOS & PIMO	3	10	16
		JUOS & PIMO Canopy Base	<1	<1	2
Height (in)	Shrub	Total	10	13	18
	Herbaceous	Grass	4	6	8
		Forb	2	3	5
Fuel Loading (tons/acre)	Tree	JUOS & PIMO	5.08	15.87	29.36
	Shrub	Total	0.33	0.76	1.12
	Herbaceous	Live	0.01	0.05	0.08
		Dead	0	<0.01	0.02
	Down Woody Debris	10-hr	0.22	0.41	0.60
		100-hr	0.24	0.87	1.72
		1000-hr sound	0	0.51	1.37
		1000-hr rotten	0	0.08	0.27
	Litter & Duff	Interspace Litter	0.09	0.21	0.39
		Tree Litter + Duff	2.76	10.19	19.25
Bulk Density (lbs/ft^3)	Tree	JUOS & PIMO Canopy	0.0087	0.0206	0.0365
	Shrub	Total	0.0060	0.0169	0.0297
	Herbaceous	Live + Dead	0.0030	0.0105	0.0166

Table 2.22. Summarized data for Phase II of the Pinyon-Juniper Prescribed Fire treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIMO	0	3	7
	Shrub	Total	6	12	22
	Herbaceous	Perennial Grass	16	31	47
		Annual Grass	0	26	53
		Forb	6	13	24
	Litter & Duff	Interspace Litter	7	11	17
	Bare Ground	Bare Ground	5	18	40
Density (#/acre)	Tree	JUOS & PIMO < 1.6 ft tall	0	21	56
		JUOS & PIMO > 1.6 ft tall	0	36	64
	Shrub	Total	832	2703	4935
Height (ft)	Tree	JUOS & PIMO	2	7	15
		JUOS & PIMO Canopy Base	<1	<1	2
Height (in)	Shrub	Total	11	15	20
	Herbaceous	Grass	4	10	17
		Forb	2	3	7
Fuel Loading (tons/acre)	Tree	JUOS & PIMO	0	1.27	3.25
	Shrub	Total	0.10	0.63	1.13
	Herbaceous	Live	0.11	0.21	0.32
		Dead	<0.01	0.04	0.08
	Down Woody Debris	10-hr	0.16	0.44	0.82
		100-hr	0.27	0.87	1.71
		1000-hr sound	0	1.42	3.71
		1000-hr rotten	0	0.06	0.14
	Litter & Duff	Interspace Litter	0.05	0.25	0.61
		Tree Litter + Duff	0	0.64	0.61
Bulk Density (lbs/ft^3)	Tree	JUOS & PIMO Canopy	0	0.0021	0.0052
	Shrub	Total	0.0021	0.0151	0.0469
	Herbaceous	Live + Dead	0.0145	0.0241	0.0393

Table 2.23. Summarized data for Phase II of the Pinyon-Juniper Cutting treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIMO	0	<1	1
	Shrub	Total	15	22	29
	Herbaceous	Perennial Grass	15	25	36
		Annual Grass	0	13	28
		Forb	6	12	21
	Litter & Duff	Interspace Litter	8	12	16
	Bare Ground	Bare Ground	6	18	31
Density (#/acre)	Tree	JUOS & PIMO < 1.6 ft tall	0	87	203
		JUOS & PIMO > 1.6 ft tall	16	67	115
	Shrub	Total	2327	4422	7948
Height (ft)	Tree	JUOS & PIMO	2	3	5
		JUOS & PIMO Canopy Base	<1	<1	1
Height (in)	Shrub	Total	14	18	23
	Herbaceous	Grass	6	11	17
		Forb	2	4	7
Fuel Loading (tons/acre)	Tree	JUOS & PIMO	<0.01	0.08	0.21
	Shrub	Total	0.82	2.23	3.82
	Herbaceous	Live	0.07	0.17	0.38
		Dead	<0.01	0.03	0.07
	Down Woody Debris	10-hr	0.21	0.68	1.48
		100-hr	0.57	2.12	4.82
		1000-hr sound	1.15	3.20	5.84
		1000-hr rotten	0	0.20	0.60
	Litter & Duff	Interspace Litter	0.07	0.30	0.64
		Tree Litter + Duff	<0.01	0.41	0.88
Bulk Density (lbs/ft^3)	Tree	JUOS & PIMO Canopy	<0.0001	0.0006	0.0013
	Shrub	Total	0.0105	0.0336	0.0517
	Herbaceous	Live + Dead	0.0064	0.0191	0.0356

Pinyon-Juniper Treatments: Phase III

Table 2.24. Summarized data for Phase III of the Pinyon-Juniper Control treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIMO	32	47	64
	Shrub	Total	<1	5	11
	Herbaceous	Perennial Grass	<1	6	10
		Annual Grass	0	<1	0
		Forb	<1	2	4
	Litter & Duff	Interspace Litter	7	9	13
	Bare Ground	Bare Ground	24	32	43
Density (#/acre)	Tree	JUOS & PIMO < 1.6 ft tall	68	183	414
		JUOS & PIMO > 1.6 ft tall	173	275	357
	Shrub	Total	522	1776	3997
Height (ft)	Tree	JUOS & PIMO	4	12	19
		JUOS & PIMO Canopy Base	<1	1	2
Height (in)	Shrub	Total	12	15	18
	Herbaceous	Grass	<1	6	13
		Forb	1	3	4
Fuel Loading (tons/acre)	Tree	JUOS & PIMO	14.74	24.14	31.93
	Shrub	Total	0.07	0.41	1.25
	Herbaceous	Live	<0.01	0.03	0.08
		Dead	0	<0.01	0.01
	Down Woody Debris	10-hr	0.30	0.68	1.12
		100-hr	0.10	0.88	1.48
		1000-hr sound	0	0.67	2.21
		1000-hr rotten	0	0.49	1.45
	Litter & Duff	Interspace Litter	0.12	0.28	0.44
		Tree Litter + Duff	10.16	17.53	29.37
Bulk Density (lbs/ft^3)	Tree	JUOS & PIMO Canopy	0.0166	0.0253	0.0344
	Shrub	Total	0.0010	0.0085	0.0295
	Herbaceous	Live + Dead	0.0013	0.0168	0.0597

Table 2.25. Summarized data for Phase III of the Pinyon-Juniper Prescribed Fire treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIMO	5	12	20
	Shrub	Total	1	6	9
	Herbaceous	Perennial Grass	5	16	29
		Annual Grass	0	28	64
		Forb	1	11	18
	Litter & Duff	Interspace Litter	7	18	29
	Bare Ground	Bare Ground	4	17	31
Density (#/acre)	Tree	JUOS & PIMO < 1.6 ft tall	0	32	90
		JUOS & PIMO > 1.6 ft tall	18	63	96
	Shrub	Total	113	1723	3563
Height (ft)	Tree	JUOS & PIMO	4	12	20
		JUOS & PIMO Canopy Base	<1	2	4
Height (in)	Shrub	Total	11	18	29
	Herbaceous	Grass	6	10	15
		Forb	1	5	7
Fuel Loading (tons/acre)	Tree	JUOS & PIMO	2.41	6.10	10.12
	Shrub	Total	<0.01	0.39	0.78
	Herbaceous	Live	0.07	0.18	0.36
		Dead	<0.01	0.08	0.18
	Down Woody Debris	10-hr	0.24	0.51	0.80
		100-hr	0.64	1.37	2.29
		1000-hr sound	0.59	6.21	14.16
		1000-hr rotten	0	0.53	0.07
	Litter & Duff	Interspace Litter	0.12	0.35	0.66
		Tree Litter + Duff	0.60	3.03	5.68
Bulk Density (lbs/ft^3)	Tree	JUOS & PIMO Canopy	0.0025	0.0065	0.0109
	Shrub	Total	<0.0001	0.0076	0.0196
	Herbaceous	Live + Dead	0.0100	0.0215	0.0335

Table 2.26. Summarized data for Phase III of the Pinyon-Juniper Cutting treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIMO	0	2	6
	Shrub	Total	8	16	25
	Herbaceous	Perennial Grass	15	24	38
		Annual Grass	0	22	43
		Forb	3	9	15
	Litter & Duff	Interspace Litter	7	12	16
	Bare Ground	Bare Ground	2	11	27
Density (#/acre)	Tree	JUOS & PIMO < 1.6 ft tall	0	69	189
		JUOS & PIMO > 1.6 ft tall	17	58	118
	Shrub	Total	654	2645	4766
Height (ft)	Tree	JUOS & PIMO	2	4	7
		JUOS & PIMO Canopy Base	<1	<1	<1
Height (in)	Shrub	Total	12	21	34
	Herbaceous	Grass	6	11	14
		Forb	2	5	9
Fuel Loading (tons/acre)	Tree	JUOS & PIMO	<0.01	0.78	2.93
	Shrub	Total	0.30	1.51	3.60
	Herbaceous	Live	0.05	0.29	0.54
		Dead	0.02	0.14	0.32
	Down Woody Debris	10-hr	0.37	1.03	1.43
		100-hr	1.39	4.35	5.10
		1000-hr sound	3.67	11.44	22.55
		1000-hr rotten	0	0.03	0.14
	Litter & Duff	Interspace Litter	0.37	0.57	0.94
		Tree Litter + Duff	<0.01	2.25	6.82
Bulk Density (lbs/ft^3)	Tree	JUOS & PIMO Canopy	<0.0001	0.0019	0.0069
	Shrub	Total	0.0072	0.0222	0.0540
	Herbaceous	Live + Dead	0.0132	0.0295	0.0457

Utah Juniper Treatments

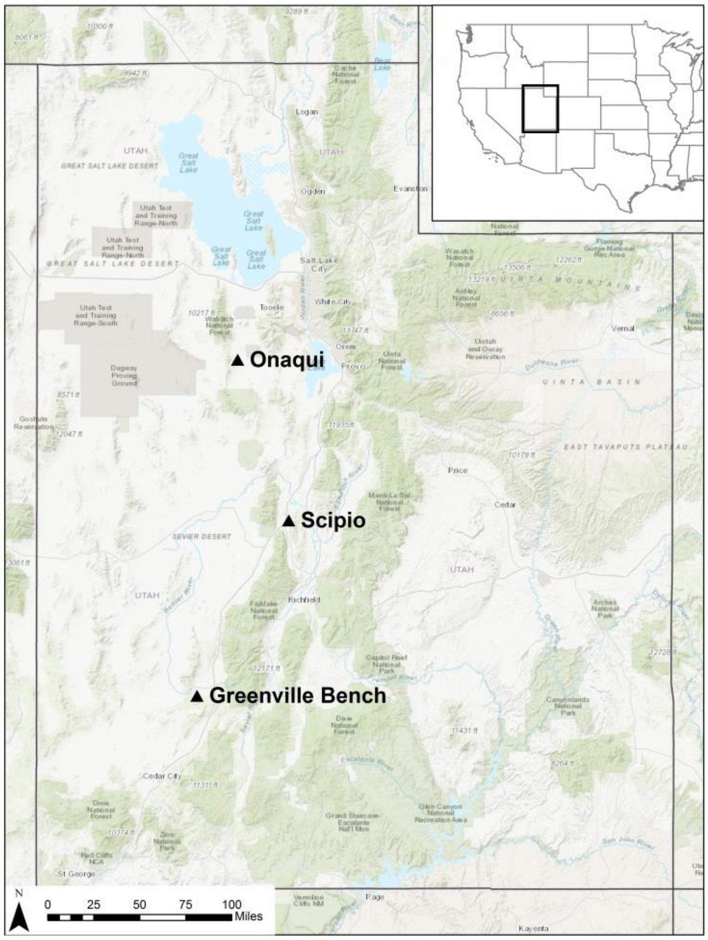

Figure 2.4. Map of study sites in the Utah Juniper Region.

Utah Juniper Treatments: Phase I

Table 2.27. Summarized data for Phase I of the Utah Juniper Control treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIED	6	10	16
	Shrub	Total	11	18	26
	Herbaceous	Perennial Grass	10	18	26
		Annual Grass	<1	9	21
		Forb	1	23	40
	Litter & Duff	Interspace Litter	5	10	15
	Bare Ground	Bare Ground	12	22	33
Density (#/acre)	Tree	JUOS & PIED < 1.6 ft tall	0	29	90
		JUOS & PIED > 1.6 ft tall	35	83	121
	Shrub	Total	2156	4856	7941
Height (ft)	Tree	JUOS & PIED	2	7	13
		JUOS & PIED Canopy Base	<1	<1	1
Height (in)	Shrub	Total	13	16	20
	Herbaceous	Grass	5	9	14
		Forb	3	4	5
Fuel Loading (tons/acre)	Tree	JUOS & PIED	1.73	4.04	6.91
	Shrub	Total	1.01	1.99	3.78
	Herbaceous	Live	0.06	0.13	0.25
		Dead	0	0.02	0.04
	Down Woody Debris	10-hr	0.16	0.52	0.85
		100-hr	0.30	1.15	2.22
		1000-hr sound	0	0.46	2.02
		1000-hr rotten	0	0.20	0.48
	Litter & Duff	Interspace Litter	0.05	0.17	0.30
		Tree Litter + Duff	1.32	3.08	5.13
Bulk Density (lbs/ft^3)	Tree	JUOS & PIED Canopy	0.0038	0.0072	0.0127
	Shrub	Total	0.0230	0.0348	0.0439
	Herbaceous	Live + Dead	0.0071	0.0153	0.0287

Table 2.28. Summarized data for Phase I of the Utah Juniper Prescribed Fire treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIED	0	<1	2
	Shrub	Total	2	12	22
	Herbaceous	Perennial Grass	12	34	48
		Annual Grass	8	19	33
		Forb	6	26	53
	Litter & Duff	Interspace Litter	7	10	17
	Bare Ground	Bare Ground	8	15	24
Density (#/acre)	Tree	JUOS & PIED < 1.6 ft tall	0	4	20
		JUOS & PIED > 1.6 ft tall	0	3	8
	Shrub	Total	755	5911	13020
Height (ft)	Tree	JUOS & PIED	3	8	14
		JUOS & PIED Canopy Base	<1	<1	2
Height (in)	Shrub	Total	11	14	15
	Herbaceous	Grass	7	9	11
		Forb	1	5	10
Fuel Loading (tons/acre)	Tree	JUOS & PIED	0	0.26	0.91
	Shrub	Total	0.07	0.64	1.77
	Herbaceous	Live	0.20	0.34	0.52
		Dead	<0.01	0.04	0.07
	Down Woody Debris	10-hr	0.18	0.36	0.51
		100-hr	0.10	0.57	0.93
		1000-hr sound	0	0.21	0.46
		1000-hr rotten	0	0.08	0.23
	Litter & Duff	Interspace Litter	0.08	0.17	0.27
		Tree Litter + Duff	0	0.07	0.27
Bulk Density (lbs/ft^3)	Tree	JUOS & PIED Canopy	0	0.0003	0.0012
	Shrub	Total	0.0007	0.0134	0.0270
	Herbaceous	Live + Dead	0.0178	0.0320	0.0525

Table 2.29. Summarized data for Phase I of the Utah Juniper Cutting treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIED	0	<1	1
	Shrub	Total	19	24	31
	Herbaceous	Perennial Grass	19	26	39
		Annual Grass	2	16	36
		Forb	2	19	47
	Litter & Duff	Interspace Litter	8	10	14
	Bare Ground	Bare Ground	7	17	28
Density (#/acre)	Tree	JUOS & PIED < 1.6 ft tall	0	33	90
		JUOS & PIED > 1.6 ft tall	4	26	74
	Shrub	Total	3058	7252	12073
Height (ft)	Tree	JUOS & PIED	2	4	6
		JUOS & PIED Canopy Base	<1	<1	<1
Height (in)	Shrub	Total	12	16	23
	Herbaceous	Grass	8	10	15
		Forb	3	4	5
Fuel Loading (tons/acre)	Tree	JUOS & PIED	<0.01	0.06	0.14
	Shrub	Total	0.86	2.46	4.31
	Herbaceous	Live	0.08	0.16	0.35
		Dead	0.00	0.04	0.10
	Down Woody Debris	10-hr	0.12	0.60	1.37
		100-hr	0.39	1.12	2.07
		1000-hr sound	0	0.73	1.56
		1000-hr rotten	0	0.08	0.22
	Litter & Duff	Interspace Litter	0.09	0.20	0.33
		Tree Litter + Duff	<0.01	0.04	0.08
Bulk Density (lbs/ft^3)	Tree	JUOS & PIED Canopy	<0.0001	0.0004	0.0011
	Shrub	Total	0.0178	0.0434	0.0746
	Herbaceous	Live + Dead	0.0106	0.0174	0.0301

Table 2.30. Summarized data for Phase I of the Utah Juniper Mastication treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIED	<1	<1	1
	Shrub	Total	11	14	18
	Herbaceous	Perennial Grass	28	36	48
		Annual Grass	0	9	23
		Forb	3	10	19
	Litter & Duff	Interspace Litter	7	11	15
	Bare Ground	Bare Ground	12	22	31
Density (#/acre)	Tree	JUOS & PIED < 1.6 ft tall	0	32	83
		JUOS & PIED > 1.6 ft tall	5	32	69
	Shrub	Total	2817	4374	6587
Height (ft)	Tree	JUOS & PIED	2	3	5
		JUOS & PIED Canopy Base	<1	<1	1
Height (in)	Shrub	Total	11	14	16
	Herbaceous	Grass	6	10	12
		Forb	3	3	4
Fuel Loading (tons/acre)	Tree	JUOS & PIED	<0.01	0.04	0.12
	Shrub	Total	0.47	1.01	1.77
	Herbaceous	Live	0.12	0.27	0.47
		Dead	0.02	0.07	0.16
	Down Woody Debris	*1-hr	0.01	0.44	0.83
		*10-hr	0.14	1.12	2.47
		100-hr	0.14	1.10	1.95
		1000-hr sound	0	0.26	0.70
		1000-hr rotten	0	0.10	0.32
	Litter & Duff	Interspace Litter	0.07	0.19	0.35
		Tree Litter + Duff	<0.01	0.06	0.21
Bulk Density (lbs/ft^3)	Tree	JUOS & PIED Canopy	<0.0001	0.0004	0.0011
	Shrub	Total	0.0121	0.0238	0.0395
	Herbaceous	Live + Dead	0.0159	0.0323	0.0422

Utah Juniper Treatments: Phase II

Table 2.31. Summarized data for Phase II of the Utah Juniper Control treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIED	16	22	32
	Shrub	Total	4	10	20
	Herbaceous	Perennial Grass	7	14	23
		Annual Grass	<1	5	13
		Forb	3	20	35
	Litter & Duff	Interspace Litter	5	10	17
	Bare Ground	Bare Ground	12	26	40
Density (#/acre)	Tree	JUOS & PIED < 1.6 ft tall	0	70	146
		JUOS & PIED > 1.6 ft tall	55	118	189
	Shrub	Total	1439	3251	5805
Height (ft)	Tree	JUOS & PIED	3	9	15
		JUOS & PIED Canopy Base	<1	<1	2
Height (in)	Shrub	Total	10	15	20
	Herbaceous	Grass	4	7	11
		Forb	2	3	5
Fuel Loading (tons/acre)	Tree	JUOS & PIED	6.28	9.83	14.44
	Shrub	Total	0.08	0.73	1.79
	Herbaceous	Live	0.02	0.07	0.15
		Dead	0	0.02	0.04
	Down Woody Debris	10-hr	0.15	0.41	0.96
		100-hr	0.18	0.78	1.92
		1000-hr sound	0	0.18	0.42
		1000-hr rotten	0	0.07	0.22
	Litter & Duff	Interspace Litter	0.07	0.25	0.48
		Tree Litter + Duff	3.90	7.90	11.71
Bulk Density (lbs/ft^3)	Tree	JUOS & PIED Canopy	0.0089	0.0131	0.0186
	Shrub	Total	0.0021	0.0144	0.0318
	Herbaceous	Live + Dead	0.0050	0.0108	0.0178

Table 2.32. Summarized data for Phase II of the Utah Juniper Prescribed Fire treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIED	0	1	3
	Shrub	Total	3	11	18
	Herbaceous	Perennial Grass	20	33	47
		Annual Grass	11	21	29
		Forb	4	29	56
	Litter & Duff	Interspace Litter	4	9	14
	Bare Ground	Bare Ground	8	15	25
Density (#/acre)	Tree	JUOS & PIED < 1.6 ft tall	0	18	45
		JUOS & PIED > 1.6 ft tall	0	9	21
	Shrub	Total	1259	4419	8836
Height (ft)	Tree	JUOS & PIED	2	8	14
		JUOS & PIED Canopy Base	<1	1	2
Height (in)	Shrub	Total	10	14	20
	Herbaceous	Grass	8	11	15
		Forb	2	5	5
Fuel Loading (tons/acre)	Tree	JUOS & PIED	0	0.57	1.41
	Shrub	Total	<0.01	0.46	1.63
	Herbaceous	Live	0.15	0.30	0.45
		Dead	0.01	0.06	0.09
	Down Woody Debris	10-hr	0.27	0.62	1.31
		100-hr	0.39	1.19	2.02
		1000-hr sound	0	0.61	1.48
		1000-hr rotten	0	0.06	0.22
	Litter & Duff	Interspace Litter	0.07	0.18	0.35
		Tree Litter + Duff	0	0.17	0.55
Bulk Density (lbs/ft^3)	Tree	JUOS & PIED Canopy	0	0.0009	0.0019
	Shrub	Total	0.0004	0.0107	0.0294
	Herbaceous	Live + Dead	0.0145	0.0278	0.0380

Table 2.33. Summarized data for Phase II of the Utah Juniper Cutting treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIED	<1	<1	1
	Shrub	Total	14	22	29
	Herbaceous	Perennial Grass	16	27	34
		Annual Grass	2	11	23
		Forb	2	19	39
	Litter & Duff	Interspace Litter	4	10	15
	Bare Ground	Bare Ground	9	18	29
Density (#/acre)	Tree	JUOS & PIED < 1.6 ft tall	0	59	142
		JUOS & PIED > 1.6 ft tall	15	42	71
	Shrub	Total	2289	5758	11540
Height (ft)	Tree	JUOS & PIED	2	4	5
		JUOS & PIED Canopy Base	<1	<1	<1
Height (in)	Shrub	Total	13	16	21
	Herbaceous	Grass	7	9	14
		Forb	2	5	8
Fuel Loading (tons/acre)	Tree	JUOS & PIED	0.03	0.10	0.27
	Shrub	Total	0.51	1.97	3.87
	Herbaceous	Live	0.12	0.21	0.31
		Dead	<0.01	0.04	0.07
	Down Woody Debris	10-hr	0.34	0.70	1.06
		100-hr	0.76	1.55	2.74
		1000-hr sound	0.13	1.81	3.62
		1000-hr rotten	0	0.10	0.21
	Litter & Duff	Interspace Litter	0.05	0.20	0.35
		Tree Litter + Duff	0.02	0.14	0.23
Bulk Density (lbs/ft^3)	Tree	JUOS & PIED Canopy	0.0003	0.0007	0.0017
	Shrub	Total	0.0153	0.0371	0.0599
	Herbaceous	Live + Dead	0.0108	0.0223	0.0365

Table 2.34. Summarized data for Phase II of the Utah Juniper Mastication treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIED	<1	<1	2
	Shrub	Total	8	15	20
	Herbaceous	Perennial Grass	22	30	38
		Annual Grass	<1	10	21
		Forb	2	14	26
	Litter & Duff	Interspace Litter	7	12	18
	Bare Ground	Bare Ground	14	21	29
Density (#/acre)	Tree	JUOS & PIED < 1.6 ft tall	0	31	68
		JUOS & PIED > 1.6 ft tall	8	49	82
	Shrub	Total	2754	4882	7673
Height (ft)	Tree	JUOS & PIED	2	3	5
		JUOS & PIED Canopy Base	<1	<1	<1
Height (in)	Shrub	Total	11	13	15
	Herbaceous	Grass	6	9	11
		Forb	2	3	5
Fuel Loading (tons/acre)	Tree	JUOS & PIED	<0.01	0.10	0.17
	Shrub	Total	0.17	0.92	1.78
	Herbaceous	Live	0.09	0.19	0.36
		Dead	0.01	0.03	0.07
	Down Woody Debris	*1-hr	0.26	0.76	1.51
		*10-hr	0.60	1.70	3.01
		100-hr	0.22	1.12	2.15
		1000-hr sound	0	0.51	1.24
		1000-hr rotten	0	0.57	0.84
	Litter & Duff	Interspace Litter	0.10	0.25	0.40
		Tree Litter + Duff	<0.01	0.17	0.37
Bulk Density (lbs/ft^3)	Tree	JUOS & PIED Canopy	<0.0001	0.0007	0.0013
	Shrub	Total	0.0073	0.0238	0.0421
	Herbaceous	Live + Dead	0.0105	0.0221	0.0367

Utah Juniper Treatments: Phase III

Table 2.35. Summarized data for Phase III of the Utah Juniper Control treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIED	28	39	53
	Shrub	Total	1	3	5
	Herbaceous	Perennial Grass	2	9	19
		Annual Grass	0	2	4
		Forb	1	13	22
	Litter & Duff	Interspace Litter	5	9	15
	Bare Ground	Bare Ground	23	31	38
Density (#/acre)	Tree	JUOS & PIED < 1.6 ft tall	9	84	171
		JUOS & PIED > 1.6 ft tall	106	189	310
	Shrub	Total	620	1746	3265
Height (ft)	Tree	JUOS & PIED	4	10	15
		JUOS & PIED Canopy Base	<1	1	2
Height (in)	Shrub	Total	12	15	19
	Herbaceous	Grass	4	5	6
		Forb	1	3	4
Fuel Loading (tons/acre)	Tree	JUOS & PIED	10.50	16.91	23.26
	Shrub	Total	0.03	0.24	0.48
	Herbaceous	Live	<0.01	0.08	0.08
		Dead	0	<0.01	0.02
	Down Woody Debris	10-hr	0.11	0.39	0.69
		100-hr	0.02	0.60	1.24
		1000-hr sound	0	0.14	0.42
		1000-hr rotten	0	0.28	0.84
	Litter & Duff	Interspace Litter	0.04	0.27	0.50
		Tree Litter + Duff	7.71	10.20	13.48
Bulk Density (lbs/ft^3)	Tree	JUOS & PIED Canopy	0.0155	0.0206	0.0262
	Shrub	Total	0.0011	0.0062	0.0105
	Herbaceous	Live + Dead	0.0009	0.0132	0.0185

Table 2.36. Summarized data for Phase III of the Utah Juniper Prescribed Fire treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIED	1	9	17
	Shrub	Total	2	6	9
	Herbaceous	Perennial Grass	10	25	36
		Annual Grass	9	25	46
		Forb	6	25	46
	Litter & Duff	Interspace Litter	6	10	14
	Bare Ground	Bare Ground	7	15	28
Density (#/acre)	Tree	JUOS & PIED < 1.6 ft tall	0	38	86
		JUOS & PIED > 1.6 ft tall	12	48	97
	Shrub	Total	994	3409	6345
Height (ft)	Tree	JUOS & PIED	4	11	16
		JUOS & PIED Canopy Base	<1	2	3
Height (in)	Shrub	Total	9	12	13
	Herbaceous	Grass	9	12	17
		Forb	3	5	8
Fuel Loading (tons/acre)	Tree	JUOS & PIED	0.64	3.79	7.01
	Shrub	Total	0	0.29	0.74
	Herbaceous	Live	0.08	0.22	0.36
		Dead	<0.01	0.05	0.11
	Down Woody Debris	10-hr	0.36	0.72	1.26
		100-hr	0.63	2.07	4.68
		1000-hr sound	0.27	0.94	1.97
		1000-hr rotten	0	0.05	0.16
	Litter & Duff	Interspace Litter	0.05	0.20	0.44
		Tree Litter + Duff	0.13	1.42	3.70
Bulk Density (lbs/ft^3)	Tree	JUOS & PIED Canopy	0.0007	0.0052	0.0091
	Shrub	Total	0	0.0046	0.0103
	Herbaceous	Live + Dead	0.0091	0.0186	0.0308

Table 2.37. Summarized data for Phase III of the Utah Juniper Cutting treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIED	<1	1	2
	Shrub	Total	5	11	18
	Herbaceous	Perennial Grass	26	33	42
		Annual Grass	1	15	29
		Forb	5	18	39
	Litter & Duff	Interspace Litter	4	9	14
	Bare Ground	Bare Ground	11	17	23
Density (#/acre)	Tree	JUOS & PIED < 1.6 ft tall	0	81	175
		JUOS & PIED > 1.6 ft tall	37	74	115
	Shrub	Total	1709	4265	8026
Height (ft)	Tree	JUOS & PIED	2	4	5
		JUOS & PIED Canopy Base	<1	<1	1
Height (in)	Shrub	Total	9	14	20
	Herbaceous	Grass	7	10	12
		Forb	4	5	6
Fuel Loading (tons/acre)	Tree	JUOS & PIED	0.07	0.19	0.38
	Shrub	Total	0	0.46	0.81
	Herbaceous	Live	0.13	0.34	0.63
		Dead	0.03	0.10	0.18
	Down Woody Debris	10-hr	0.42	0.95	1.40
		100-hr	1.29	2.34	3.71
		1000-hr sound	2.24	5.79	10.95
		1000-hr rotten	0	0.20	0.32
	Litter & Duff	Interspace Litter	0.09	0.18	0.28
		Tree Litter + Duff	0.02	0.22	0.67
Bulk Density (lbs/ft^3)	Tree	JUOS & PIED Canopy	0.0005	0.0013	0.0021
	Shrub	Total	0	0.0098	0.0210
	Herbaceous	Live + Dead	0.0162	0.0370	0.0610

Table 2.38. Summarized data for Phase III of the Utah Juniper Mastication treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOS & PIED	<1	<1	2
	Shrub	Total	4	11	18
	Herbaceous	Perennial Grass	17	25	34
		Annual Grass	2	16	31
		Forb	3	14	33
	Litter & Duff	Interspace Litter	4	10	16
	Bare Ground	Bare Ground	12	19	27
Density (#/acre)	Tree	JUOS & PIED < 1.6 ft tall	0	38	135
		JUOS & PIED > 1.6 ft tall	6	58	105
	Shrub	Total	1192	3448	5976
Height (ft)	Tree	JUOS & PIED	2	3	6
		JUOS & PIED Canopy Base	0	<1	<1
Height (in)	Shrub	Total	9	13	17
	Herbaceous	Grass	8	10	12
		Forb	2	4	6
Fuel Loading (tons/acre)	Tree	JUOS & PIED	0.01	0.14	0.37
	Shrub	Total	<0.01	0.60	1.47
	Herbaceous	Live	0.12	0.23	0.38
		Dead	0.01	0.04	0.07
	Down Woody Debris	*1-hr	0.16	1.31	2.45
		*10-hr	0.20	2.12	3.37
		100-hr	0.84	1.79	3.09
		1000-hr sound	0.15	1.74	5.10
		1000-hr rotten	0	0.48	1.94
	Litter & Duff	Interspace Litter	0.13	0.35	0.66
		Tree Litter + Duff	<0.01	0.28	0.94
Bulk Density (lbs/ft^3)	Tree	JUOS & PIED Canopy	<0.0001	0.0009	0.0023
	Shrub	Total	0.0006	0.0171	0.0342
	Herbaceous	Live + Dead	0.0124	0.0249	0.0410

Western Juniper Region

Figure 2.5. Map of study sites in the Western Juniper Region.

Western Juniper Treatments: Phase I

Table 2.39. Summarized data for Phase I of the Western Juniper Control treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOC	6	13	27
	Shrub	Total	2	10	20
	Herbaceous	Perennial Grass	23	42	61
		Annual Grass	0	8	20
		Forb	5	11	23
	Litter & Duff	Interspace Litter	3	8	12
	Bare Ground	Bare Ground	5	19	39
Density (#/acre)	Tree	JUOC < 1.6 ft tall	0	47	151
		JUOC > 1.6 ft tall	37	82	158
	Shrub	Total	569	1414	2658
Height (ft)	Tree	JUOC	2	10	23
		JUOC Canopy Base	0	<1	2
Height (in)	Shrub	Total	10	22	35
	Herbaceous	Grass	6	10	13
		Forb	2	4	7
Fuel Loading (tons/acre)	Tree	JUOC	2.87	6.93	12.05
	Shrub	Total	0	0.18	0.42
	Herbaceous	Live	0.07	0.16	0.33
		Dead	0.02	0.09	0.21
	Down Woody Debris	10-hr	0.29	0.68	1.20
		100-hr	0.20	0.80	1.67
		1000-hr sound	0	0.12	0.43
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.04	0.10	0.16
		Tree Litter + Duff	0.82	2.38	4.36
Bulk Density (lbs/ft^3)	Tree	JUOC Canopy	0.0029	0.0050	0.0086
	Shrub	Total	0	0.0039	0.0105
	Herbaceous	Live + Dead	0.0137	0.0189	0.0268

Table 2.40. Summarized data for Phase I of the Western Juniper Prescribed Fire treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOC	0	<1	<1
	Shrub	Total	3	12	24
	Herbaceous	Perennial Grass	33	43	58
		Annual Grass	<1	22	51
		Forb	2	22	40
	Litter & Duff	Interspace Litter	3	8	15
	Bare Ground	Bare Ground	2	14	32
Density (#/acre)	Tree	JUOC < 1.6 ft tall	0	4	2
		JUOC > 1.6 ft tall	0	2	8
	Shrub	Total	279	1964	3721
Height (ft)	Tree	JUOC	2	8	19
		JUOC Canopy Base	0	<1	1
Height (in)	Shrub	Total	10	20	31
	Herbaceous	Grass	7	9	11
		Forb	1	6	10
Fuel Loading (tons/acre)	Tree	JUOC	0	0.14	0.03
	Shrub	Total	0	0.19	0.54
	Herbaceous	Live	0.15	0.30	0.54
		Dead	0.01	0.16	0.40
	Down Woody Debris	10-hr	0.08	0.36	0.72
		100-hr	0.10	0.62	1.60
		1000-hr sound	0	3.57	6.45
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.05	0.13	0.24
		Tree Litter + Duff	0	0.02	0.04
Bulk Density (lbs/ft^3)	Tree	JUOC Canopy	0	0.0001	0.0001
	Shrub	Total	0	0.0073	0.0199
	Herbaceous	Live + Dead	0.0186	0.0338	0.0492

Table 2.41. Summarized data for Phase I of the Western Juniper Cutting treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOC	0	<1	1
	Shrub	Total	9	24	46
	Herbaceous	Perennial Grass	34	48	64
		Annual Grass	0	14	37
		Forb	1	11	31
	Litter & Duff	Interspace Litter	3	8	13
	Bare Ground	Bare Ground	2	14	30
Density (#/acre)	Tree	JUOC < 1.6 ft tall	0	45	146
		JUOC > 1.6 ft tall	0	50	100
	Shrub	Total	1000	2947	4530
Height (ft)	Tree	JUOC	2	3	4
		JUOC Canopy Base	0	<1	<1
Height (in)	Shrub	Total	15	24	36
	Herbaceous	Grass	8	11	16
		Forb	1	4	8
Fuel Loading (tons/acre)	Tree	JUOC	0.03	0.10	0.19
	Shrub	Total	0	1.20	2.96
	Herbaceous	Live	0.14	0.25	0.43
		Dead	0.07	0.15	0.29
	Down Woody Debris	10-hr	0.30	0.91	1.85
		100-hr	0.44	1.28	2.31
		1000-hr sound	0.21	3.02	6.95
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.08	0.20	0.36
		Tree Litter + Duff	0	0.04	0.06
Bulk Density (lbs/ft^3)	Tree	JUOC Canopy	0	0.0006	0.0011
	Shrub	Total	0	0.0213	0.0429
	Herbaceous	Live + Dead	0.0217	0.0320	0.0452

Western Juniper Treatments: Phase II

Table 2.42. Summarized data for Phase II of the Western Juniper Control treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOC	17	26	36
	Shrub	Total	1	9	17
	Herbaceous	Perennial Grass	18	38	65
		Annual Grass	0	4	11
		Forb	4	14	23
	Litter & Duff	Interspace Litter	3	7	11
	Bare Ground	Bare Ground	4	18	46
Density (#/acre)	Tree	JUOC < 1.6 ft tall	0	71	207
		JUOC > 1.6 ft tall	56	96	161
	Shrub	Total	488	1403	2621
Height (ft)	Tree	JUOC	2	14	30
		JUOC Canopy Base	0	2	5
Height (in)	Shrub	Total	15	24	33
	Herbaceous	Grass	6	8	12
		Forb	1	5	10
Fuel Loading (tons/acre)	Tree	JUOC	9.52	14.44	20.16
	Shrub	Total	0	0.19	0.45
	Herbaceous	Live	0.04	0.13	0.32
		Dead	0.01	0.05	0.12
	Down Woody Debris	10-hr	0.31	0.69	1.30
		100-hr	0.13	0.76	1.34
		1000-hr sound	0	0.56	1.54
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.04	0.13	0.31
		Tree Litter + Duff	1.45	3.39	5.89
Bulk Density (lbs/ft^3)	Tree	JUOC Canopy	0.0052	0.0080	0.0113
	Shrub	Total	0	0.0030	0.0066
	Herbaceous	Live + Dead	0.0058	0.0144	0.0235

Table 2.43. Summarized data for Phase II of the Western Juniper Prescribed Fire treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOC	0	1	3
	Shrub	Total	3	11	21
	Herbaceous	Perennial Grass	29	43	55
		Annual Grass	4	29	61
		Forb	2	21	41
	Litter & Duff	Interspace Litter	1	8	16
	Bare Ground	Bare Ground	1	12	24
Density (#/acre)	Tree	JUOC < 1.6 ft tall	0	6	23
		JUOC > 1.6 ft tall	0	10	31
	Shrub	Total	434	1374	2750
Height (ft)	Tree	JUOC	2	7	13
		JUOC Canopy Base	0	<1	2
Height (in)	Shrub	Total	11	19	26
	Herbaceous	Grass	7	10	15
		Forb	2	6	10
Fuel Loading (tons/acre)	Tree	JUOC	0	0.49	0.92
	Shrub	Total	0	0.17	0.55
	Herbaceous	Live	0.19	0.32	0.49
		Dead	0.03	0.18	0.41
	Down Woody Debris	10-hr	0.12	0.40	0.99
		100-hr	0.18	0.92	1.67
		1000-hr sound	0.64	2.48	4.97
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.04	0.13	0.22
		Tree Litter + Duff	0	0.08	0.26
Bulk Density (lbs/ft^3)	Tree	JUOC Canopy	0	0.0004	0.0012
	Shrub	Total	0	0.0038	0.0091
	Herbaceous	Live + Dead	0.0200	0.0374	0.0594

Table 2.44. Summarized data for Phase II of the Western Juniper Cutting treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOC	<1	<1	2
	Shrub	Total	7	24	44
	Herbaceous	Perennial Grass	41	50	62
		Annual Grass	<1	15	38
		Forb	2	18	37
	Litter & Duff	Interspace Litter	3	6	10
	Bare Ground	Bare Ground	<1	8	20
Density (#/acre)	Tree	JUOC < 1.6 ft tall	0	65	157
		JUOC > 1.6 ft tall	8	65	123
	Shrub	Total	944	2364	3867
Height (ft)	Tree	JUOC	2	3	5
		JUOC Canopy Base	0	<1	<1
Height (in)	Shrub	Total	17	27	33
	Herbaceous	Grass	8	12	15
		Forb	2	7	10
Fuel Loading (tons/acre)	Tree	JUOC	0.02	0.13	0.29
	Shrub	Total	0	1.56	3.99
	Herbaceous	Live	0.14	0.25	0.37
		Dead	0.04	0.16	0.32
	Down Woody Debris	10-hr	0.70	1.13	1.95
		100-hr	1.18	2.38	3.64
		1000-hr sound	2.30	6.96	11.25
		1000-hr rotten	0		
	Litter & Duff	Interspace Litter	0.08	0.25	0.41
		Tree Litter + Duff	0.02	0.25	0.84
Bulk Density (lbs/ft^3)	Tree	JUOC Canopy	0.0001	0.0008	0.0014
	Shrub	Total	0	0.0204	0.0443
	Herbaceous	Live + Dead	0.0110	0.0267	0.0447

Western Juniper Treatments: Phase III

Table 2.45. Summarized data for Phase III of the Western Juniper Control treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOC	26	37	45
	Shrub	Total	<1	5	8
	Herbaceous	Perennial Grass	19	38	55
		Annual Grass	0	3	7
		Forb	3	12	20
	Litter & Duff	Interspace Litter	5	8	11
	Bare Ground	Bare Ground	6	17	34
Density (#/acre)	Tree	JUOC < 1.6 ft tall	2	47	88
		JUOC > 1.6 ft tall	83	115	149
	Shrub	Total	232	693	1155
Height (ft)	Tree	JUOC	6	22	35
		JUOC Canopy Base	<1	5	10
Height (in)	Shrub	Total	20	24	29
	Herbaceous	Grass	5	7	9
		Forb	2	5	8
Fuel Loading (tons/acre)	Tree	JUOC	15.73	21.89	28.60
	Shrub	Total	0	0.08	0.22
	Herbaceous	Live	0.04	0.10	0.14
		Dead	0.00	0.03	0.07
	Down Woody Debris	10-hr	0.23	0.41	0.56
		100-hr	0.11	0.62	1.62
		1000-hr sound	0	0.21	0.38
		1000-hr rotten	0		
	Litter & Duff	Interspace Litter	0.06	0.15	0.34
		Tree Litter + Duff	1.23	2.97	4.26
Bulk Density (lbs/ft^3)	Tree	JUOC Canopy	0.0069	0.0095	0.0119
	Shrub	Total	0	0.0012	0.0026
	Herbaceous	Live + Dead	0.0073	0.0125	0.0191

Table 2.46. Summarized data for Phase III of the Western Juniper Prescribed Fire treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOC	0	4	11
	Shrub	Total	5	13	25
	Herbaceous	Perennial Grass	33	43	54
		Annual Grass	8	21	29
		Forb	9	21	33
	Litter & Duff	Interspace Litter	3	7	14
	Bare Ground	Bare Ground	3	11	19
Density (#/acre)	Tree	JUOC < 1.6 ft tall	0	8	23
		JUOC > 1.6 ft tall	0	16	36
	Shrub	Total	519	1398	2513
Height (ft)	Tree	JUOC	2	12	26
		JUOC Canopy Base	0	2	5
Height (in)	Shrub	Total	12	23	31
	Herbaceous	Grass	6	11	15
		Forb	3	7	11
Fuel Loading (tons/acre)	Tree	JUOC	0	1.78	5.83
	Shrub	Total	0	0.51	1.98
	Herbaceous	Live	0.09	0.26	0.50
		Dead	0.01	0.14	0.25
	Down Woody Debris	10-hr	0.11	0.54	1.42
		100-hr	0.40	1.70	3.14
		1000-hr sound	1.19	8.26	16.71
		1000-hr rotten		0	
	Litter & Duff	Interspace Litter	0.07	0.14	0.23
		Tree Litter + Duff	0	0.23	0.53
Bulk Density (lbs/ft^3)	Tree	JUOC Canopy	0	0.0009	0.0025
	Shrub	Total	0	0.0070	0.0288
	Herbaceous	Live + Dead	0.0126	0.0248	0.0457

Table 2.47. Summarized data for Phase III of the Western Juniper Cutting treatment.

Variable	Category	Component	10th	Mean	90th
Total Cover (%)	Tree	JUOC	<1	1	2
	Shrub	Total	3	14	37
	Herbaceous	Perennial Grass	34	49	61
		Annual Grass	11	24	42
		Forb	4	11	17
	Litter & Duff	Interspace Litter	2	6	11
	Bare Ground	Bare Ground	<1	6	14
Density (#/acre)	Tree	JUOC < 1.6 ft tall	2	82	173
		JUOC > 1.6 ft tall	5	77	127
	Shrub	Total	357	2246	4600
Height (ft)	Tree	JUOC	2	3	6
		JUOC Canopy Base	0	<1	<1
Height (in)	Shrub	Total	10	26	39
	Herbaceous	Grass	9	11	14
		Forb	3	7	9
Fuel Loading (tons/acre)	Tree	JUOC	<0.01	0.23	0.42
	Shrub	Total	0	0.50	1.47
	Herbaceous	Live	0.13	0.25	0.31
		Dead	0.05	0.14	0.23
	Down Woody Debris	10-hr	1.06	2.06	3.62
		100-hr	1.79	3.35	5.27
		1000-hr sound	6.01	12.75	23.71
		1000-hr rotten	0		
	Litter & Duff	Interspace Litter	0.08	0.19	0.35
		Tree Litter + Duff	<0.01	0.75	1.39
Bulk Density (lbs/ft^3)	Tree	JUOC Canopy	<0.0001	0.0011	0.0017
	Shrub	Total	0	0.0054	0.0171
	Herbaceous	Live + Dead	0.0144	0.0255	0.0349

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Appendix I

Table A.1. Scientific names, common names, and USDA Plant Species Codes for species described in tables. Adapted from Bourne and Bunting (2011).

	USDA Code	Scientific Name	Common Name
Trees	CELE3	*Cercocarpus ledifolius*	curl-leaf mountain mahogany
	JUOC	*Juniperus occidentalis*	western juniper
	JUOS	*Juniperus osteosperma*	Utah juniper
	PIED	*Pinus edulis*	two-needle pinyon pine
	PIMO	*Pinus monophylla*	singleleaf pinyon pine
Shrubs	ARAR8	*Artemisia arbuscula*	low sagebrush
	ARNO4	*Artemisia nova*	black sagebrush
	ARTRV	*Artemisia tridentata ssp. vaseyana*	mountain big sagebrush
	ARTRW8	*Artemisia tridentata ssp. wyomingensis*	Wyoming big sagebrush
	CHVI8	*Chrysothamnus viscidiflorus*	yellow rabbitbrush
	PUTR2	*Purshia tridentata*	antelope bitterbrush