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WILDLIFE RESEARCH REPORT

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ABSTRACT

The pinyon-juniper (PJ) habitat type has been expanding in the western United States and managers often rely on mechanical methods of thinning or removing pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) trees in order to improve habitat for big game. Three available thinning methods are ship anchor chaining (CHAIN), roller chopping (ROLLER), and mastication (MAST), which differ in cost, type of woody debris produced, and soil disturbance. Understory responses and cost-effectiveness of these 3 removal methods were compared beginning in 2011 at two locations in the Magnolia region of the Piceance Basin, Rio Blanco County, Colorado. The North Magnolia site (n=4 sampling blocks) had higher control plot tree density, lower tree basal area, and higher shrub cover than the South Magnolia site (n=3). Two years post-treatment, the responses of desirable perennials was similar among mechanical treatment types, with all treatments producing 10-15 higher grass biomass, 2-3 times higher grass cover, and higher shrub biomass (non-significant trend) than control plots. Responses of annual plants differed by mechanical treatment, with ROLLER producing the greatest response in annuals (both native and exotic), followed by CHAIN, followed by MAST. This may have been related to the fact that ROLLER produced more bare ground (22%) than CHAIN (14%) or MAST (11%) in the first post-treatment year. Seeding within treatments increased the density of desirable shrubs at South Magnolia, but not North Magnolia. At South Magnolia, seeding was similarly effective in all treatment types, even though for CHAIN and ROLLER, most shrubs were seeded using a seed dribbler mounted to the bulldozers during treatment, while in MAST all seed was broadcast prior to treatment. Bitterbrush (*Purshia tridentata*) was the most common species in seeded plots at South Magnolia. Seeding native annual forbs appeared to be most effective in MAST, possibly due to enhanced germination conditions due to masticated material. Both CHAIN and MAST may be cost-effective treatments, depending on

project size, species desired to be seeded, and risk of invasion by non-natives. ROLLER appears to be a less desirable treatment due to high mobilization costs and higher risk of invasion by exotics, including cheatgrass (*Bromus tectorum*). Differences in responses of exotics between North Magnolia and South Magnolia were as great or greater than those due to differences in treatment type, indicating a need for greater understanding of the site conditions which promote invasion by exotics.

WILDLIFE RESEARCH REPORT

EXAMINING THE EFFECTIVENESS OF MECHANICAL TREATMENTS AS A RESTORATION TECHNIQUE FOR MULE DEER HABITAT

DANIELLE B. JOHNSTON

PROJECT OBJECTIVES

1. Assess response of desirable shrubs, grasses, and forbs to removal of pinyon and juniper trees via three different mechanical treatments: ship anchor chaining (with two passes), roller chopping, and mastication (i.e. mulching or 'hydro-axing').
2. Assess differences among these 3 treatment types in the response of undesirable annual plants, including cheatgrass (*Bromus tectorum*).
3. Summarize differences in responses to the 3 treatment types in two stands differing in initial tree density and understory characteristics.
4. Compare cost-effectiveness of the 3 mechanical treatments.
5. Examine cost-effectiveness of seeding desired species in the 3 mechanical treatments, with a focus on these palatable shrubs: chokecherry (*Prunus virginiana*), Saskatoon serviceberry (*Amelanchier alnifolia*), Utah serviceberry (*Amelanchier utahensis*), mountain mahogany (*Cercocarpus montanus*), bitterbrush (*Purshia tridentata*), and winterfat (*Kraschenninnikovia lanata*).

SEGMENT OBJECTIVES

1. For the second post-treatment year, analyze differences in shrub, grass, and forb cover and biomass due to seeding and due to type of mechanical treatment.
2. Synthesize results between first and second post-treatment years.
3. Draw preliminary conclusions regarding mechanical treatments and seeding efforts.

INTRODUCTION

Pinyon-juniper (PJ) woodlands play an important role in mule deer ecology. Pinyon pine (*Pinus edulis*), Utah juniper (*Juniperus osteosperma*) and the associated understory shrub species such as mountain mahogany (*Cercocarpus montanus*), antelope bitterbrush (*Purshia tridentata*) and big sagebrush (*Artemisia tridentata*) are key to winter survival (Hansen and Dearden 1975). Deer strongly select for this habitat type because of the escape and thermal cover provided by pinyon and juniper trees (Anderson et al. 2013). However, PJ habitats occasionally lack understory and may provide very little forage (Bender et al. 2007). It has been shown that increasing nutrition in poor quality PJ winter range can increase deer populations in western Colorado (Bishop 2007). Therefore, creating patches of habitat types with higher nutritional value within PJ stands is a desirable management objective for mule deer.

The PJ habitat type has increased in many parts of western North America over the past 100 years (Miller and Rose 1999, Schaffer et al. 2003, Bradley and Fleishman 2008). Disruption of natural fire regimes, overgrazing, and invasion by weedy species have led to a wide array of management problems. Of particular concern are overgrown stands of PJ that have allowed the overstory to shade out understory plant species. Fire is a natural remedy, however prescribed fire is often impractical because of the proximity to infrastructure and human activity, as well as the lack of continuous understory fuels. Alternatives to fire include mechanical treatments, which can open up the canopy and reduce competition

(Young et al. 2013). Mechanical treatments may also increase mule deer fawn survival in western Colorado (Bergman et al. 2014). Several different types of mechanical removal methods exist, and little information is available to determine which method is most desirable and cost-effective.

Mechanical treatments in PJ forests differ in the size of woody litter produced, in the degree of soil disturbance created, and in cost. Chaining is an inexpensive technique by which trees are removed by dragging a ship anchor chain between two bulldozers (Figure 1a). Trees are uprooted and left intact and the action of uprooting may create a great degree of soil disturbance (Cain 1972); Figure 1b). Roller chopping is a more expensive technique in which a heavy rotating drum with protruding steel plates is pulled behind a bulldozer (Figure 1c). The bulldozer knocks the trees over and the drum chops them into large pieces (Figure 1d). The action of the roller chopper creates soil disturbance, though to a lesser depth than does chaining. Mastication is a technique by which entire trees are mulched, typically using a rubber-tired industrial tractor (e.g. Hydro-ax© or Barko©) with front-end mounted rotary cutter or a drum-style mulcher (e.g. Fecon© or FAE©; Figure 1e). Fine woody debris is produced (Figure 1f), there is little ground disturbance, and the cost per area may be 5 to 10 times higher than that of chaining. Mastication is a relatively new method which has gained favor because of the lower degree of ground disturbance, but only recently has any research been done to understand the effect of mastication on plant communities (Ross et al. 2012b, Young et al. 2013, Provencher and Thompson 2014). Only one study (Provencher and Thompson 2014), and none on the Colorado Plateau, has made head-to-head comparisons of older mechanical removal methods with mastication.

Differences in the size of woody litter produced and the degree of soil disturbance may influence the germination and establishment of desirable understory species. For instance, the mulch layer produced by a mastication treatment may have positive or negative effects on germination; germination may be inhibited by lower light availability at the soil surface, or it may be enhanced by higher soil moisture. In chaining and roller chopping, the higher degree of soil disturbance may provide an opportunity for seeded species to establish, or it may become a liability by allowing invasion by weedy species. Finally, in a chaining treatment, the tree skeletons may offer a few years of protection from herbivory, which could play an important role in allowing shrubs to establish. These differences may affect the success of seeding attempts following mechanical tree removal, but such differences have yet to be examined. Finally, characteristics of the PJ forest stand, such as density, basal area, and understory seed bank, may influence which treatment produces the most desirable results.

Our study has three goals: to compare the desirability of vegetation produced by three types of mechanical treatment (ship anchor chaining, roller chopping, and mastication), to determine the usefulness of seeding within each of these three treatments, and to determine if these results differ between two PJ stands with differing basal areas and densities. Desirable vegetation in this context is native vegetation with a high proportion of ground cover consisting of broadleaf forbs and palatable shrubs. Undesirable vegetation includes cheatgrass (*Bromus tectorum*) and non-native annual forbs such as Russian thistle (*Salsola tragus*).

STUDY AREA

The Piceance Creek Basin, located in Rio Blanco and Garfield Counties of northwestern Colorado, serves as winter range for one of North America's largest migratory mule deer (*Odocoileus hemionus*) populations (White and Lubow 2002). The basin ranges in elevation from 1706 meters to 2743 meters with the highest points near the edges (Tiedeman 1978). This basin encompasses nearly 4143 square kilometers and is bordered from the north by the White River, from the south by the Roan Plateau, from the east by the Grand Hogback and from the west by the Cathedral Bluffs. Terrain varies from rugged badlands, abrupt cliffs and sharp ridges to open valleys, parks and basins. Its semiarid climate receives between 27 and 63 centimeters of annual precipitation, half coming in the form of snow during winter months (Tiedeman 1978). The basin is part of the Green River Geologic Formation, consisting of primarily sandstone, siltstone, mudstone, limestone, and shale. Sagebrush and desert shrub dominate lower elevations, and middle elevations are dominated by upland sagebrush, mixed mountain shrub, and PJ woodlands (Tiedeman 1978). Grasslands, aspen (*Populus tremuloides*) and douglas-fir (*Pseudotsuga menziesii*) forests can be found at the highest elevations (Tiedeman 1978).

Historically, the land was sparsely populated and used primarily for agricultural and recreational purposes (Tiedeman 1978). In recent decades, natural resource extraction of rich oil shale and natural gas reserves has dramatically altered the landscape. As of April 2013, the 1.8 by 10^6 ha Piceance Basin area contained about 24,000 gas wells (Colorado Oil and Gas Conservation Commission 2013). Through the construction of well pads, roads and compressor stations, development of this infrastructure has and continues to fragment suitable mule deer habitat (Anderson 2011). Traffic, noise and increased human presence also contribute to adversely affect this important winter range (Anderson 2011).

The Magnolia area of Piceance occupies the northeastern corner of the basin, and is bounded by Piceance Creek on the south and west, the White River on the north, and the Grand Hogback on the east. It is dominated by PJ woodlands.

METHODS

Site Selection

Study area selection was done in conjunction with Dr. Charles Anderson's larger-scale project to examine deer responses to PJ removal (Anderson 2011). First, several hundred PJ stands were delineated within the Magnolia area of Piceance Basin using aerial photography, excluding areas with slopes greater than 30%. Next, stands were visited and scored for suitability of treatment based on a scale of 1 to 3:

Score 1 – most suitable acreage. These parcels contained abundant younger trees growing in dense stands. Simultaneously, the understory of desired shrubs, grasses, and forbs appeared to be robust. Treatment of these areas should yield a strong growth response from that desired understory.

Score 2 – highly suitable acreage. These parcels contained a mix of younger and older trees that grew in less dense patches. The understory of desired shrubs was also less robust than a Score 1 site. Score 2 parcels were highly suitable for treatment, but will likely yield a lesser initial growth response from the desired understory than a Score 1 site.

Score 3 – suitable acreage. These parcels contained more mature PJ,that possessed larger individual tree canopies, growing in less dense stands. Diameter of tree trunks was larger than trees in Score 1 or 2 sites. The understory of desired shrubs, grasses, and forbs was often lacking, and more bare ground was found here than Score 1 or 2 tracts.

Delineations and suitability scores were assigned by Todd Graham of Ranch Advisory Partners. A total of 203 tracts comprising 585 ha (1, 445 ac) were deemed suitable for treatment. Next, two focal areas were selected based on the following criteria: at least 40 acres with the same suitability score were available, access routes for ground-disturbing equipment were available, and the cover of PJ trees within each area was as uniform as possible. These two focal areas, called North Magnolia (elevation 2194 m, score of 1 on suitability scale) and South Magnolia (elevation 1828 m, score of 3 on suitability scale), are shown in Figure 2. At the North Magnolia (NM) site, a contiguous parcel met the needed criteria. At South Magnolia (SM), the study area was fragmented by gullies which were unsuitable for treatment.

Experimental Design and Setup

We implemented a split-plot design with four blocks at the NM location, and three blocks at the SM location (Figure 2). Block divisions were designed to minimize variation within each block in PJ density, based on visual inspection of the aerial photography. Mechanical treatments were randomly assigned to whole plots within blocks. Each treated plot was further subdivided into two subplots, with seeding treatments (seeded or unseeded) randomly assigned to subplots within plots. Control plots were not seeded. Subplots were 0.40 ha (1 acre) in size and about three times as long as wide. The long axis of each subplot was arranged perpendicular to the slope. This is because mechanical treatments are typically applied across slopes, rather than up and down them, because it is safer and saves fuel to drive heavy machinery across the slope.

Mechanical Treatments

Mechanical treatments were applied between Oct. 23, 2011 and Nov. 28, 2011. The chaining treatment (*hereafter* CHAIN) was done using two D8 bulldozers (Caterpiller, Inc., USA), each attached to one end of an 18 m (60-ft.) ship anchor chain with links weighing 40.8 kg (90 lbs.) each. Trees were pulled over by running the chain in one direction, and then killed more completely by running the chain back over the plots in the opposite direction (2-way chaining; Figure 1a-b). The roller chopping treatment (*hereafter* ROLLER) was accomplished by attaching a 3.7 m (12-ft.) long, 0.6 m (1.9-ft.) diameter roller chopper to a D8 dozer (Figure 1c). The drum weighed approximately 1100 kg (2,500 lbs.) when empty and held 8338 li (2,200 gal) of water. The drum was filled during operation for a total weight of approximately 9100 kg (20,000 lbs.). Roller chopper plates acted as blades to chop downed trees into pieces approximately 30 cm long (Figure 1c-d). The mastication treatment (*hereafter* MAST) was accomplished used a 930 Barko© industrial tractor with a FAE© mulching head, which produced fine masticated material ranging in size from 2 – 20 cm and a few larger sections of tree boles (Figure 1e-f). All vegetation was masticated to ground level (or as close as the equipment would allow; less than 30 cm). In the vicinity of former trees, masticated material was up to 40 cm deep. Equipment operators used handheld GPS units to ensure the correct areas were being treated. Every plot was completely treated and no “leave” areas, or refugia, strips were left in the plots. Although the area of the seeded and unseeded subplots was only 0.4 ha, an area larger than this was mechanically treated in some cases. The estimated total area treated across all 21 thinned plots was 16.8 ha.

Seeding

All seeded plots received the same diverse native seed mix comprised of 10 shrub species, 14 forb species and 10 grass species (Table 1). The mix emphasizes shrubs while incorporating light rates of forbs and grasses in order to fill resource niches and thereby reduce the likelihood of weed invasion. Most species were broadcast seeded prior to mechanical treatment using EarthWay$_{®}$ hand crank spreaders. Because the seed mix contained seeds of varying sizes, seeds were broadcast in groups based on size (Table 1) in order for uniform seed dispersal to occur using the spreaders. Five evenly spaced passes, parallel to the long axis of the plot, were made through each seeded subplot using the hand spreaders. Two seeders followed one navigator using a handheld GPS unit to ensure dispersal occurred in the seeded subplot only. Seeds of Group 5 (Table 1) were large-seeded shrubs and forbs which benefit from deep planting. Seeding method for these species differed by treatment. In the treatments using tracked machinery, CHAIN and ROLLER, Group 5 species were seeded using Hansen seed dribblers mounted to the tracks of the bulldozer (Figure 3). The linear seeding rate for dribbled seed was 3.5 g/m. In MAST, these species were broadcast in a similar manner to Groups 1-4.

Site characterization- soil seedbank and control plot tree density

In May 2012, following treatments and seeding, 3.7 L of soil were collected from each of the 49 subplots. Soil samples were sieved (5.6-mm wire mesh) to remove rocks and debris; sieved soil was then layered 1 cm deep atop bio fungicide potting soil in 20-cm diameter growth pots. Field soil samples for each subplot were distributed between ten growth pots and soaked with water in a greenhouse 2-3 times per week (or when soil surfaces appeared dry). As plants germinated they were identified and removed from the pot. The soil seedbank growth period continued until mid-February 2013.

Tree basal area and density in control plots was measured in spring 2013. Five evenly spaced belt transects per control plot were used for density counts and basal diameter measurements of live trees ≥ 2m tall. Width of belt transects varied from 2 to 18 m to allow roughly 20 trees to be sampled per belt. Single juniper trees were often multi-stemmed or elliptical in shape at the base. Multi-stemmed trees at the ground level were measured separately for diameter and added together to determine basal area for that single tree. For elliptical junipers, diameter measurements taken along the wide and the narrow axes were averaged and that average was used as the diameter. Original control plots in blocks E and G could not be used for these measurements due to logistical issues; similar areas adjacent to the original controls were chosen and also used for subsequent summer 2013 biomass and cover sampling.

Plant Cover, Biomass, and Seeded Shrub Density

Percent cover, biomass, and shrub density data was gathered along systematically placed transects in each subplot. In 2012, 20 transects per subplot were sampled; in 2013, 10 transects per subplot were sampled. Transects were oriented perpendicular to the long axis of each subplot and were usually 20 m long, unless an usually shaped plot mandated that the transect be shortened. Percent cover, by species, was estimated using the first-hit point-intercept method at every meter along each transect. For biomass, sampling frames (0.25-m x 0.75-m) were placed at a randomly selected point on each transect, and all current year's aboveground plant growth was clipped (up to 1.4-m tall) and bagged by species. Herbaceous species were clipped only if they were rooted inside the frame. For woody species, any current year's growth hanging inside the frame (whether it was rooted in or out) was clipped. All biomass was composited by species for each subplot. Plant biomass was oven-dried to constant mass at 65°C and subsequently weighed to estimate total aboveground production per subplot. Shrubs of seeded species rooted within biomass frames were counted for density prior to being clipped.

Statistical Analysis

Because the design of the experiment was not fully factorial (there were no plots which were seeded, but not mechanically treated), two types of analyses were used to examine cover, biomass, and shrub density data: the *Mechanical treatment analysis,* and the *Seeding effect analysis.*

The *Mechanical treatment analysis* used only unseeded subplots to examine effects of mechanical treatments relative to one another and also to untreated controls with a nested randomized complete block mixed effects model where mechanical treatment (CHAIN, ROLLER, MAST, CONTROL) and site (NM and SM) were fixed effects, and block within site was a random effect; the Kenward-Rogers denominator degrees of freedom method was used to account for unequal variances. Results from these analyses will be designated *MEA.*

The *Seeding effect analysis* excluded plots without mechanical treatment to allow analysis of the seeding treatment, and interactions involving the seeding treatment. These analyses were conducted using a nested randomized complete block split-plot mixed effects model where site, mechanical treatment type (CHAIN, ROLLER, MAST), seeding treatment (Seeded or Unseeded), and site (NM or SM) were fixed effects and block within site and mechanical treatment within block were random effects; the Kenward-Rogers denominator degrees of freedom method was used to account for unequal variances. Results from these analyses will be designated *SEA.*

For significant interactions involving site (cutoff of $\alpha = 0.1$), further analyses to test for mechanical and/or seeding treatment effects were conducted separately for each site.

Biomass and cover variables were split into the following six groups: native annual forb, exotic annual forb, perennial forb, cheatgrass, perennial grass, and shrub. Species with biennial life cycles were lumped in with annuals. Because both native and exotic annual forbs were present, they were analyzed as two separate groups. Perennial forbs were all native with trace amounts of exotics. Cheatgrass, an invasive non-native, was the only annual grass present. Perennial grasses and shrubs were all native. Data were transformed to improve normality prior to parametric analyses [Perennials: log (biomass + 1) or arcsin(sqrt(cover)); annuals: log (biomass + 0.01) or sqrt(cover); shrub density: sqrt(density)], and residual plots were examined to ensure proper adherence to normality assumptions. Years were analyzed separately. Because biomass and cover, especially for annuals, were very low in 2012 due to drought conditions (Figure 4), analysis of 2012 data was limited to biomass of perennial plants. All analyses were conducted in SAS 9.3 (SAS Institute, Cary, NC, USA).

RESULTS

Site characterization and year effects

Tree composition and structure differed between NM and SM. Mean total tree basal area and mean basal area of *J. ostersperma* was greater at SM than at NM (Figure 5a). Density only differed when looking at *P. edulis* alone; NM had far more trees/ha than SM (Figure 5b). Control plots at NM (Figure 6a) had characteristics of a more mature tree stand than those at SM (Figure 6b).

The soil seedbank study also indicated possible differences between NM and SM. Pots from NM and SM in total germinated 723 and 415 plants, respectively. Twenty-five plants, about 2% of the total, were seeded species.

Shrub and perennial grass biomass also differed between NM and SM, with grasses being more dominant at SM, and shrubs being more dominant at NM. Biomass of perennial grasses in CONTROL in 2013 was 0.4 ± 0.1 g m^{-2} at NM and 2.5 ± 1.2 g m^{-2} at SM (Figure 7b vs 7d, 'ACONTROL' bars). Biomass of shrubs in CONTROL in 2013 was 21.3 ± 4.0 g m^{-2} at NM and only 8.4 ± 7.7 g m^{-2} at SM (Figure 7b vs 7d, 'ACONTROL' bars). Dominant shrub species also differed by site. At NM, 67% of all biomass was Serviceberry (*Amelanchier sp.)*, and 26% was snowberry (*Symphoricarpos rotundifolius*). At SM, bitterbrush (*Purshia tridentata*) was most prevalent, comprising 43% of shrub biomass, while Big sagebrush (*Artemisia tridentata*) and mountain mahogany (*Cercocarpus montanus*) comprised about 17% each.

Total understory plant biomass was much greater in 2013 than 2012, due to drought conditions during 2012; mean plant biomass in 2012 was less than 12 g m^{-2} in mechanically treated plots, but in 2013, plots averaged greater than 49 g m^{-2}. Few effects were statistically significant in 2012.

Perennial plant responses

In 2012, perennial grass biomass differed by mechanical treatment; chain plots had greater grass biomass (3.46 g/m^2) than either MAST (2.08 g/m^2) or ROLLER (1.75 g/m^2) plots ($p < 0.01$, *MEA*). In 2013, perennial grass biomass was not different among mechanical treatments ($p > 0.19$) but mechanically treated subplots had 10 - 15 times greater grass biomass than in CONTROL (*MEA, p*-values vs. CONTROL: chain $p = 0.0015$, ROLLER $p < 0.0001$, MAST $p = 0.0001$; Figure 7). Although grass biomass at SM was higher on average than NM (Table 2, Figure 7), the response of grass biomass to treatments was similar at both sites (site by mechanical treatment interaction $p = 0.72$ *MEA*). Perennial grass cover in 2013 followed similar patterns to biomass data. Grass cover in mechanically treated plots was 2-3 times higher than in CONTROL ($p < 0.02$), cover did not differ by treatment type ($p > 0.17$) and there was no significant interaction between treatment type and site ($p= 0.45$ *MEA*). We did not detect any effects of seeding or interactions involving the seeding treatment for perennial grass biomass or cover in either year ($p > 0.21$; *SEA*).

For perennial forbs (mostly native with trace exotics), we detected no differences in response to site or mechanical and seeding treatments in either year, for either cover or biomass.

Mean shrub biomass in all mechanically treated subplots far exceeded that of CONTROL in 2013, especially at NM (Figure 7). However, because of variation among plots, we detected no statistical differences in response to treatments in either cover or biomass data for shrubs.

The effect of seeding on seeded shrub density depended on site (site*seeding interaction $p= 0.08$ *SEA*). At NM, seeding did not have a detectible effect ($p = 0.60$ *SEA*), but at SM, seeding increased seeded shrub density from 0.24 plants/m^2 to 0.77 plants/m^2 ($p = 0.009$ *SEA* Figure 8). Bitterbrush was the most prevalent species in seeded subplots at SM (Figure 8). Seeded shrub density was not influenced by mechanical treatment nor by an interaction between seeding and mechanical treatment ($p > 0.22$ *SEA*).

Annual plant responses

Annual plant growth was extremely limited in 2012. Biomass of exotic annual forbs was only 0.04 g/m^2, that of native annual forbs was only 0.10 g/m^2, and cheatgrass was only 0.009 g/m^2. In contrast, annual plant biomass values in 2013 were roughly 150 times higher than these values.

In 2013, exotic annual forb biomass responded to mechanical treatments at NM and SM differently (interaction $p = 0.01$ *MEA*). At NM, exotic annual forb biomass was similar between mechanical treatment types ($p > 0.16$ *MEA*), but was higher in mechanically treated plots, which averaged 2.9 g/m^2, than in CONTROL, which averaged 0.0 g/m^2 ($p < 0.009$ *MEA*). At SM, exotic annual forb biomass in ROLLER was 33.4 g/m^2, which was higher than in all other treatments ($p < 0.03$ *MEA*), while CHAIN and MAST were similar to CONTROL, which averaged 0.0 g/m^2 ($p > 0.25$; *MEA* Table 3). Exotic annual forb cover in 2013 responded similarly at NM and SM (site by mechanical treatment interaction: $p = 0.28$ *MEA*). ROLLER averaged 7.2% exotic annual forb cover, which was significantly higher than all other treatments ($p < 0.02$ *MEA* Figure 9). Exotic annual forb cover in CHAIN and MAST was similar (3.1% and 3.2%, respectively), and cover in both of these treatments was significantly higher than in CONTROL ($p < 0.001$ *MEA*), which averaged 0.2% (Figure 9). For biomass, there was a significant interaction between site and seeding ($p = 0.04$ *SEA*). At NM, there were no significant effects of seeding or seeding by mechanical treatment interactions ($p > 0.36$). At SM, the effect of seeding depended on mechanical treatment (interaction $p = 0.05$). For CHAIN, seeding increased exotic annual forb biomass from 0.0 g/m^2 to 2.2 g/m^2. A similar effect was not quite significant in MAST ($p = 0.11$), while in ROLLER, no effect of seeding was evident ($p = 0.91$). For cover, there were no significant effects of seeding or interaction involving the seeding treatment ($p > 0.17$ *SEA*). Common exotic annual forbs were *Salsola tragus* L., *Chenopodium album* L, and *Alyssum alyssoides* L.

Native annual forb biomass in 2013 responded similarly at both sites, and differed by mechanical treatment. ROLLER had 7.17 g/m^2, which was significantly higher than CONTROL (0.06 g/m^2) or MAST (0.37 g/m^2) plots ($p < 0.01$ *MEA*). It was also higher than CHAIN, which had 0.40 g/m^2, though the difference was not significant ($p = 0.14$). Native annual forb cover followed similar patterns to biomass. ROLLER had 2.8% cover, which was significantly higher than CONTROL (0.7%) or CHAIN (2.0%) plots ($p < 0.02$ *MEA*), but not significantly higher than MAST, which had 1.9% (Figure 9). For biomass, there was a significant interaction between seeding and mechanical treatment ($p = 0.03$ *SEA*), and no interactions involving site ($p > 0.14$ *SEA*). In MAST, seeding increased native annual forb biomass from 0.4 g/m^2 to 20.3 g/m^2 ($p < 0.0001$ *SEA*), while effects in other plots were not significant ($p > 0.10$ *SEA*). For cover, the magnitude of the seeding effect depended on site (site by seeding interaction $p = 0.03$ *SEA*). At NM, seeding increased native annual forb cover from 0.2% to 1.2% ($p = 0.04$ *SEA*), and at SM, seeding increased native annual forb cover from 0.5% to 2.8%. ($p = 0.0004$ *SEA* Figure 9). At both sites, there was no interaction with mechanical treatment for native annual forb cover ($p > 0.14$ *SEA*). Common native annual forbs were Rocky Mountain bee plant (*Cleome serrulata*), Hoary tansyaster (*Machaeranthera canescens*), Western tansymustard (*Descurainia pinnata*), sunflower (*Helianthus annuus*), and Fremont's goosefoot (*Chenopodium fremontii*).

Cheatgrass biomass did not differ by site or mechanical treatment ($p > 0.06$ *MEA*). Cheatgrass cover responded differently by site (site by mechanical treatment interaction $p = 0.005$ *MEA;* Figure 9). At NM, ROLLER had 4.6% cheatgrass cover, which was significantly higher than MAST or CONTROL ($p < 0.007$ *MEA*). CHAIN had 2.7% cheatgrass cover, which was statistically similar to ROLLER, but higher than MAST or CONTROL ($p < 0.05$ *MEA* Figure 9). Masticated plots had 1.1% cheatgrass cover, which was statistically similar to CONTROL, which had 0.2% ($p = 0.16$ *MEA*). At SM, there were no significant differences by mechanical treatment (p = 0.08 *MEA*). For both biomass and cover, there were no effects of seeding or interactions involving seeding (p > 0.14 *SEA*).

Bare Ground

Mechanical treatments differed in the amount of bare ground produced. In 2012, there was a higher percentage of bare ground in ROLLER (20%) versus CHAIN (16%) and MAST (12%, p = 0.002; Figure 10).

Treatment costs

A summary of the costs incurred by the 3 treatment types in setting up this experiment is summarized in Table 4. ROLLER had the highest cost of mobilization due to the need for a crane to remove the roller chopping drum from the trailer, and the need for a water truck to fill the drum. CHAIN had the next highest mobilization cost, because it required two bulldozers plus the chain. MAST had the lowest mobilization cost, but required more than double the cost per acre of the other two treatments. The times per acre reported here were for times actually spent implementing the treatments, excluding time spent traveling from one plot to another. The costs per acre are inclusive of inter-plot travel, and are therefore about two times higher than normal. Costs per acre also depend on terrain, tree density, and local markets.

DISCUSSION

In general, responses of perennial plants were similar among mechanical treatment types, while those of annual plants differed. By the second post-treatment year, grass biomass and cover were similar among mechanical treatment types, but10-15 times higher in treatment plots than in control plots. Forb biomass and cover were unaffected by treatment, similar to a prior study (Owen et al. 2009). Shrub biomass and cover were not statistically affected by treatment, but a trend for 2-4 times higher current-year growth on shrubs was observed in mechanically treated plots versus control plots.

Annual plant growth was highest in ROLLER. Across sites, ROLLER had the highest exotic annual forb cover, the highest native annual forb cover, and the highest native annual forb biomass. In addition, ROLLER had the higher cheatgrass cover at NM than MAST or CONTROL, and the highest exotic annual forb biomass at SM. This may have been related to the fact that ROLLER produced more bare ground (22%) than CHAIN (14%) or MAST (11%). Reduced competition and a higher degree of disturbance may have allowed quick-responding annual plants, both native and non-native, a window of opportunity. ROLLER also had the highest mobilization costs, making it a less attractive treatment option unless the project area is large and is at little risk of invasion by undesirable annuals.

CHAIN and MAST had similar native annual forb cover, native annual forb biomass, exotic annual forb cover, and exotic annual forb biomass. Cheatgrass cover was higher in CHAIN than MAST. The basically similar responses of annual plants to CHAIN and MAST was somewhat surprising, given that chaining has often been thought to cause a great degree of soil disturbance (Miller et al. 2005). We noted that CHAIN had a much more variable impact to the soil surface than the other treatments. Bulldozer attachment points for the chain were elevated from the ground about a meter, which prevented some of the chain from contacting the soil surface. In addition, when the chain was being dragged it occasionally rode above the ground entirely if it was caught in a pile of slash. Therefore, although the depth of soil disturbance was great where trees were uprooted, large portions of plots had no disturbance at all. Interestingly, grass biomass was higher in CHAIN than in ROLLER or MAST in the first post-treatment year, indicating that more of the understory survived CHAIN than the other treatment types. This result may have been influenced by the type and length of chain used in this experiment. We used a 60 ft chain, smooth chain, which is shorter than typical, and causes less disturbance than an Ely chain. We found that the short chain was helpful in creating the small-patch-size disturbances desired for deer habitat improvement. While the short chain is more expensive per acre than a longer chain would be, we still found CHAIN to be less expensive than the other treatments tested in this study. We concur with Provencher (2014) who found chaining to be a cost-effective way to create desired ecological changes (Provencher and Thompson 2014).

Mastication was the most expensive treatment type tested, but had the best results relative to seeding. We found that seeding in MAST promoted native annual forb biomass to a greater degree than did seeding in combination with CHAIN or ROLLER. The fine mulch produced by mastication likely enhanced germination and growing conditions by reducing erosion, retaining moisture, and reducing soil surface temperatures (Vallentine 1989, Battaglia et al. 2010). It is important to emphasize that seeding was done prior to mastication in this study, which facilitated seed-soil contact. Seeding was done by broadcasting with hand-crank spreaders, as the trees were too dense to permit any other method. Seeding post-treatment would be easier and cheaper, but would likely be less successful. It is not surprising that we observed a benefit of mastication for native annual forbs, but not for perennial forbs or grasses, as annual plants respond quickly to physical conditions found in post-disturbance environments. Whether or not mastication is also beneficial for promoting growth of desired perennial plants is a topic which warrants further monitoring. MAST also had lower cheatgrass cover at NM than in CHAIN or ROLLER. This could have been due to a shading effect of the mulch, as cheatgrass is intolerant of shading (Pierson et al. 1990). We conclude that mastication is a useful technique, especially for smaller areas, where lower mobilization costs are a benefit, and where a seeding prior to treatment can be feasibly conducted.

We found that seeding increased shrub density to a similar degree in all three treatment types at the SM site (Figure 8b). This illustrates the usefulness of the Hansen seed dribbler (Stevens and Monsen 2004). In the two treatments requiring tracked machinery, CHAIN and ROLLER, dribblers were mounted onto each track, and large-seeded shrubs and forbs were dribbled onto the tracks and pressed into the soil as the treatment was being completed. The results for shrub seeding were similar via this technique as for MAST, which required a separate seeding effort to broadcast the seed prior to treatment. The dribbler is not appropriate for species such as Big Sagebrush, which should be planted at or near the soil surface. However, if species such as Bitterbrush or Serviceberry are desired, dribbling the seed as the treatment is being completed is a cost-effective and viable technique.

The seeding effect for shrub density was not evident at the NM site, and a seeding effect for native annual forb cover had a larger effect size at SM than at NM. That seeding was more effective at SM is a fairly intuitive result, as SM control plots had less understory biomass and in particular had less shrub biomass than at NM. The seed mix used in this experiment cost $2,000/ha ($810/ac), and about half of that cost was for just 4 species of desirable shrubs: Utah Serviceberry, Saskatoon Serviceberry, Bitterbrush, and Mountain Mahogany. Obviously, it is important to restrict seeding efforts to those sites where it is more likely to be effective. The NM site had 2013 control plot shrub cover of 20%, whereas SM had 5%; shrubs may have been too dominant at NM for seeding to matter. Alternatively, it is possible that grazing had a more detrimental effect on shrubs at NM than at SM. Grazing cages were installed in treatment plots (Stephens 2014), and while there was no overall effect of cages on total shrub density, bitterbrush density at NM was affected by cages, with 19 seedlings within cages compared to 2 in paired control plots. Further monitoring is needed to determine if increased shrub density at SM due to seeding will eventually result in increased shrub biomass and cover.

Our initial assessment was that NM was more suitable for mechanical treatment than SM, and our expectation was that the understory at NM would respond more rapidly. For shrubs, this appears to be true (though results were not statistically significant); 2013 shrub biomass at NM was 65.5 g/m^2 in treated plots versus 21.3 g/m^2 in control plots, while at SM shrub biomass was 7.4 g/m^2 in treated plots versus 8.4 g/m^2 in control plots. For grasses, sites responded similarly with about a 10-fold increased in grass biomass (from 0.4 g/m^2 to 5.8 g/m^2 at NM; from 2.5 g/m^2 to 23.0 g/m^2 at SM). For cheatgrass, responses were not as expected. At NM, 2013 cheatgrass cover in control plots was 0.2% while treated plots averaged 2.8%; at SM cheatgrass cover in control plots was 0% and treated plots averaged 0.5% (not a statistically significant difference). Although data was not taken in 2014, casual observation of the sites revealed a huge increase in cheatgrass cover at NM (Figure 11); this increase was not as evident at SM. Initially, we expected SM to be more vulnerable to invasion by cheatgrass because it had less understory cover and biomass. Clearly, we need additional research to better understand the factors that make sites vulnerable to invasion by undesirable exotics following removal of the PJ overstory.

We found no impact of seeding at controlling weedy annual plants in this study, and found some evidence that seeding increased exotic annual biomass at SM, possibly due to seed contamination. While some prior studies have found that seeding after loss of PJ helps control weedy annuals (Floyd et al. 2006, Thompson et al. 2006), other studies have found seeding to have a negligible or even negative effect (Getz and Baker 2008, Shinneman and Baker 2009). All treatments tended to have higher annual cover and biomass than control plots. It is well understood that mechanical removal of PJ can increase exotics relative to untreated areas (D'Antonio and Meyerson 2002). Many similar studies have observed dramatic increases in cheatgrass following a variety of treatment types including chaining (Skousen et al. 1989), mastication (Owen et al. 2009, Ross et al. 2012a, Ross et al. 2012b), feller-buncher (Baughman et al. 2010), and hand-thinning with chain saws (Huffman et al. 2013). This study confirms these earlier works and provides some additional insight into the relative impact of some different treatment types, with less exotic invasion following the order: Roller chopping > Chaining ≥ Mastication. It's important to note that differences among treatments in exotic responses were less than or equal to the magnitude of differences due to site effects. Therefore, an understanding of site conditions is at least as important as the choice of equipment in creating a desirable outcome. Also, the impacts of tree removal and seeding may require several years to realize (Bates et al. 2000), and further monitoring of this experiment is warranted.

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Table 1. Native seed mix. Functional Group: G - grass, F - forb, S - shrub. Lifespan: P - perennial, A - annual. Seed groups 1 - 4 were hand broadcast while group 5 was seeded using bulldozer mounted seed dribblers in the chain and rollerchop plots. Group 5 was hand broadcast in masticated plots.

Functional Group	Type	Seed Group	Latin Name	Common Name	Pure Live Seeds/m^2	PLS lbs/ ac
G	P	1	*Achnatherum hymenoides* (Roem. & Schult.) Barkworth	Indian Ricegrass	18	0.45
F	A	2	*Amaranthus retroflexus* L.	Redroot Amaranth	12	0.04
S	P	5	*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roem.	Saskatoon Serviceberry	30	2.02
S	P	5	*Amelanchier utahensis* Koehne	Utah Serviceberry	12	1.88
F	P	2	*Artemisia frigida* Willd.	Fringed Sagebrush	36	0.02
F	P	2	*Artemisia ludoviciana* Nutt.	White Sagebrush	24	0.02
S	P	2	*Artemisia tridentata* Nutt.	Wyoming Sagebrush	24	0.09
F	P	1	*Balsamorhiza sagittata* (Pursh) Nutt.	Arrowleaf Balsamroot	12	0.83
S	P	5	*Cercocarpus montanus* Raf.	Mountain Mahogany	24	2.05
S	P	2	*Ericameria nauseosa* (Pall. ex Pursh) G.L. Nesom & Baird	Rubber Rabbitbrush	18	0.18
S	P	2	*Chrysothamnus viscidiflorus* (Hook.) Nutt.	Yellow Rabbitbrush	18	0.10
F	A	1	*Cleome serrulata* Pursh	Rocky Mountain Beeplant	24	1.47
F	P	2	*Crepis acuminata* Nutt.	Tufted Hawksbeard	1	0.01
G	P	1	*Elymus elymoides* (Raf.) Swezey	Bottlebrush Squirreltail	18	0.38
G	P	1	*Elymus trachycaulus* (Link) Gould ex Shinners	Slender Wheatgrass	12	0.36
F	P	3	*Eriogonum umbellatum* Torr.	Sulfur-Flower Buckwheat	10	0.17
F	P	5	*Hedysarum boreale* Nutt.	Utah Sweetvetch	12	1.05
F	A	1	*Helianthus annuus* L.	Common Sunflower	30	2.08
G	P	1	*Hesperostipa comata* (Trin. & Rupr.) Barkworth	Needle And Thread	12	0.35
G	P	2	*Koeleria macrantha* (Ledeb.) Schult.	Prairie Junegrass	24	0.04
S	P	3	*Krascheninnikovia lanata* (Pursh) A. Meeuse & Smit	Winterfat	18	0.66
F	P	1	*Linum lewisii* Pursh	Lewis Flax	24	0.33
F	P	5	*Lupinus argenteus* Pursh	Silvery Lupine	12	0.39
F	P	1	*Oenothera caespitosa* Nutt.	Tufted Evening Primrose	12	0.04
F	P	1	*Oenothera pallida* Lindl.	Pale Evening Primrose	24	0.15
G	P	1	*Pascopyrum smithii* (Rydb.) Á. Löve	Western Wheatgrass	6	0.17
F	P	1	*Penstemon strictus* Benth.	Rocky Mountain Penstemon	36	0.30
G	P	2	*Poa fendleriana* (Steud.) Vasey	Muttongrass		0.02
G	P	2	*Poa secunda* J. Presl	Sandberg Bluegrass	12	0.05
S	P	4	*Prunus virginiana* L.	Chokecherry	6	4.88
S	P	5	*Purshia tridentata* (Pursh) DC.	Bitterbrush	30	7.06
S	P	5	*Rhus trilobata* Nutt.	Skunkbush Sumac	6	0.94
G	A	4	*Triticum aestivum* L. x *Secale cereale* L.	Quick Guard	12	3.74
G	A	2	*Vulpia octoflora* (Walter) Rydb.	Six-Weeks Fescue	18	0.08

Table 2. Mean 2013 biomass (g m^{-2}) from 2 sites in northwest Colorado (North Magnolia, n = 4 and South Magnolia, n = 3) where pinyon-juniper overstory was removed using 3 mechanical treatments: anchor chain, roller chopper, or mastication.

	Control	**Chained**		**Roller chopped**		**Masticated**	
	Unseeded Subplots	**Seeded Subplots**	**Unseeded Subplots**	**Seeded Subplots**	**Unseeded Subplots**	**Seeded Subplots**	**Unseeded Subplots**
North Magnolia				**Biomass (SE)**			
Native Annual Forb	0.10 (0.06)	1.00 (0.16)	0.41 (0.32)	1.48 (0.62)	11.38 (9.31)	13.86 (11.49)	0.04 (0.04)
Exotic Annual Forb	0.02 (0.01)	0.57 (0.19)	2.33 (0.68)	14.16 (7.30)	1.96 (1.27)	0.77 (0.54)	4.54 (4.35)
Perennial Forb	2.85 (1.05)	10.19 (2.88)	3.44 (2.04)	11.33 (4.45)	6.92 (2.14)	7.31 (2.48)	4.83 (3.74)
Annual Graminoid	0.11 (0.11)	1.27 (0.65)	1.02 (0.5)	1.35 (0.59)	5.00 (3.8)	2.91 (1.7)	0.89 (0.88)
Perennial Graminoid	0.43 (0.13)	4.92 (0.76)	3.76 (1.56)	5.69 (1.59)	8.46 (2.81)	3.96 (1.44)	8.19 (1.72)
Shrub	21.27 (4)	61.92 (18.51)	91.22 (50.53)	30.14 (9.96)	52.28 (24.15)	66.38 (28.01)	91.34 (38.86)
South Magnolia							
Native Annual Forb	0.01 (0.01)	5.19 (4.83)	0.38 (0.24)	19.58 (4.51)	1.56 (1.11)	28.83 (12.1)	0.81 (0.77)
Exotic Annual Forb	0 (0)	2.15 (1.75)	0 (0)	28.75 (25.28)	33.39 (31.49)	2.23 (1.8)	0.13 (0.1)
Perennial Forb	0.58 (0.27)	3.28 (1.39)	2.42 (1.12)	0.77 (0.67)	2.38 (1.58)	5.45 (2.36)	5.28 (3.48)
Annual Graminoid	0	0	0	0.98 (0.59)	1.32 (1.32)	0	0.01 (0.01)
Perennial Graminoid	2.51 (1.23)	15.27 (10.16)	26.5 (17.29)	18.68 (8.3)	27.37 (8.58)	25.52 (11.84)	24.43 (11.17)
Shrub	8.42 (7.65)	11.37 (9.42)	5.43 (1.99)	11.56 (9.74)	0.89 (0.89)	7.56 (0.55)	7.41 (4.15)

Table 3. Percent cover (in 2013) from 2 sites in northwest Colorado (North Magnolia, n = 4 and South Magnolia, n = 3) where pinyon-juniper overstory was removed using 3 mechanical treatments: anchor chain, roller chopper, or mastication.

	Control	**Chained**		**Roller chopped**		**Masticated**	
	Unseeded Subplots	**Seeded Subplots**	**Unseeded Subplots**	**Seeded Subplots**	**Unseeded Subplots**	**Seeded Subplots**	**Unseeded Subplots**
North Magnolia	**Percent Cover (SE)**						
Native Annual Forb	0	1.38 (0.57)	0.63 (0.47)	2.84 (0.87)	1.03 (0.35)	1.8 (1.08)	0.63 (0.25)
Exotic Annual Forb	0.36 (0.23)	3.91 (0.41)	4.78 (0.36)	5.89 (2.76)	6.76 (3.78)	2.15 (0.79)	3.35 (1.31)
Perennial Forb	0.97 (0.21)	2.93 (0.62)	2.07 (0.75)	2.47 (1.17)	1.55 (0.31)	4.42 (0.73)	2.22 (0.25)
Annual Graminoid	0.24 (0.14)	3.13 (1.85)	2.73 (0.79)	4.77 (3.03)	4.98 (2.76)	2.63 (1.60)	1.07 (0.76)
Perennial Graminoid	1.45 (0.6)	4.94 (1.22)	4.06 (1.01)	5.70 (1.59)	5.58 (1.92)	5.85 (1.47)	4.8 (1.80)
Shrub	20.27 (1.94)	16.29 (3.77)	23.71 (4.35)	20.23 (3.51)	11.48 (2.94)	16.75 (2.41)	16.93 (3.17)
South Magnolia							
Native Annual Forb	0.17 (0.17)	6.33 (0.89)	0.48 (0.27)	6.09 (1.98)	2.08 (0.83)	4.49 (0.66)	1.18 (0.13)
Exotic Annual Forb	0 A	2.19 (1.1)	0.97 (0.26)	3.16 (0.83)	7.46 (1.28B	1.57 (0.95)	2.85 (2.09)
Perennial Forb	0.33 (0.16)	1.57 (0.83)	0.47 (0.28)	1.23 (0.98)	0.86 (0.2)	3.10 (1.38)	2.55 (2.06)
Annual Graminoid	0	0.15 (0.15)	0.16 (0.16)	0.17 (0.17)	0.33 (0.33)	0.17 (0.17)	1.12 (0.25)
Perennial Graminoid	5.57 (2.54)	12.7 (3.23)	11.10 (2.91)	10.62 (2.09)	14.79 (1.85)	14.67 (4.55)	17.57 (2.08)
Shrub	5.15 (1.79)	1.92 (0.28)	4.21 (1.14)	5.38 (0.78)	2.25 (1.04)	3.93 (2.11)	4.57 (1.89)

Table 4. Costs incurred in this experiment to implement 3 pinyon-juniper removal treatments: ship anchor chaining (CHAIN), roller chopping (ROLLER), and mastication (MAST). Mobilization costs were for a site in the Piceance Basin a 1-hr drive from the nearest town of Meeker, CO. Costs per unit area were higher than typical, because the replicated, small plots for this experiment were difficult to create. More normal rates on a per-area basis are about half of the costs incurred here.

	CHAIN	**ROLLER**	**MAST**
Mobilization/ demobilization	$5,600	$8,000	$2,050
Time per area	49 min/ha (20 min/ac)	1.9 hr/ha (45 min/ac)	6.2 hr/ha (2.5 hr/ac)
Cost per area	$329/ha ($133/ac)	$368/ha ($149/ac)	$1230/ha ($498/ac)

Figure 1. Types of machinery used and woody debris produced: Ship anchor chaining (a) and tree skeletons left behind by chaining (b); roller chopper (c) and coarse debris left by roller chopping (d); industrial tractor with masticating head (e) with fine debris left behind by mastication (f).

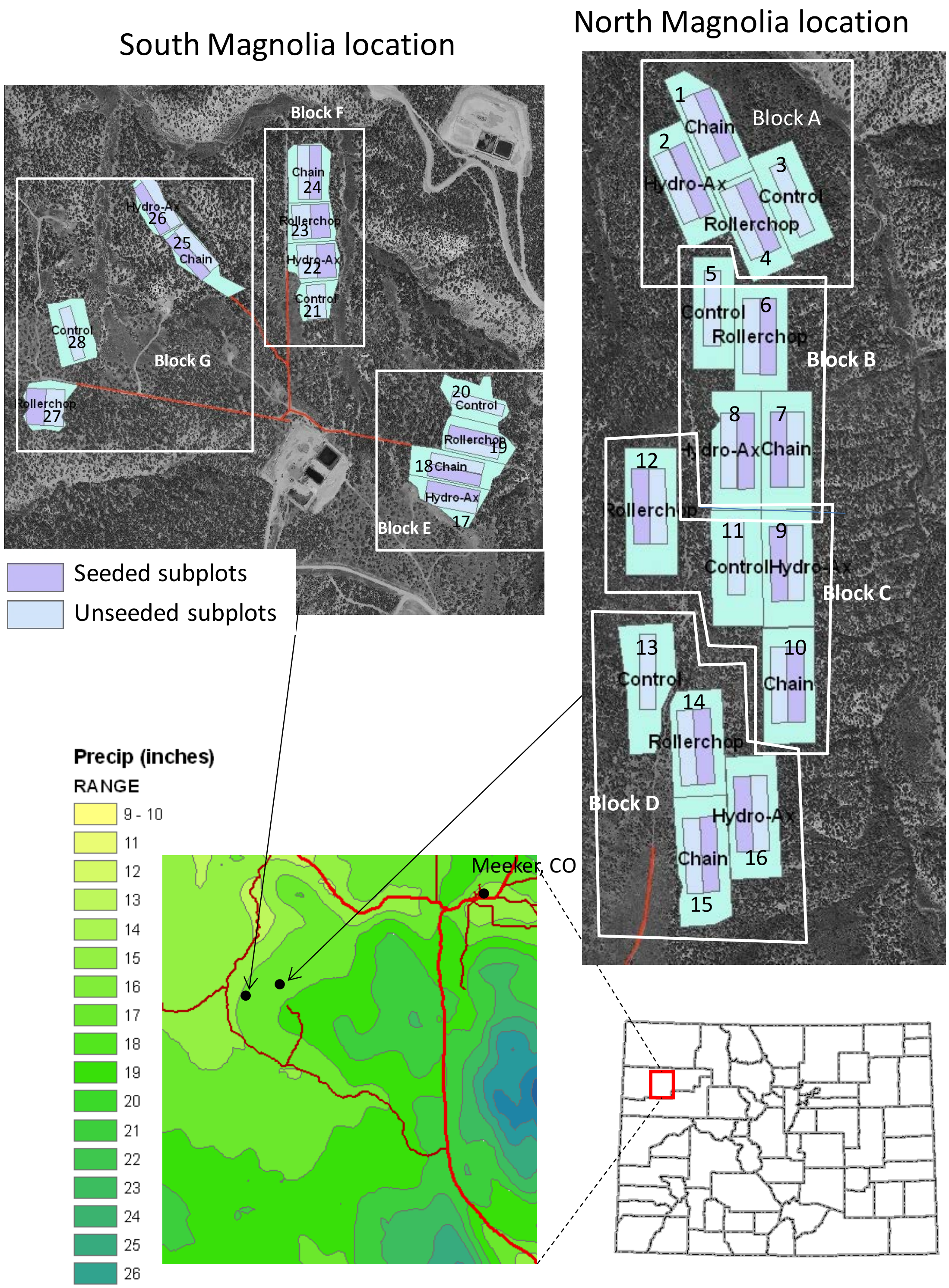

Figure 2. Layout of experiment within North and South Magnolia locations, Rio Blanco County, Colorado.

Figure 3. Hansen-style seed dribbler mounted to the track of bulldozer. Two such dribblers were mounted on each bulldozer used in the chaining and roller chopping treatments.

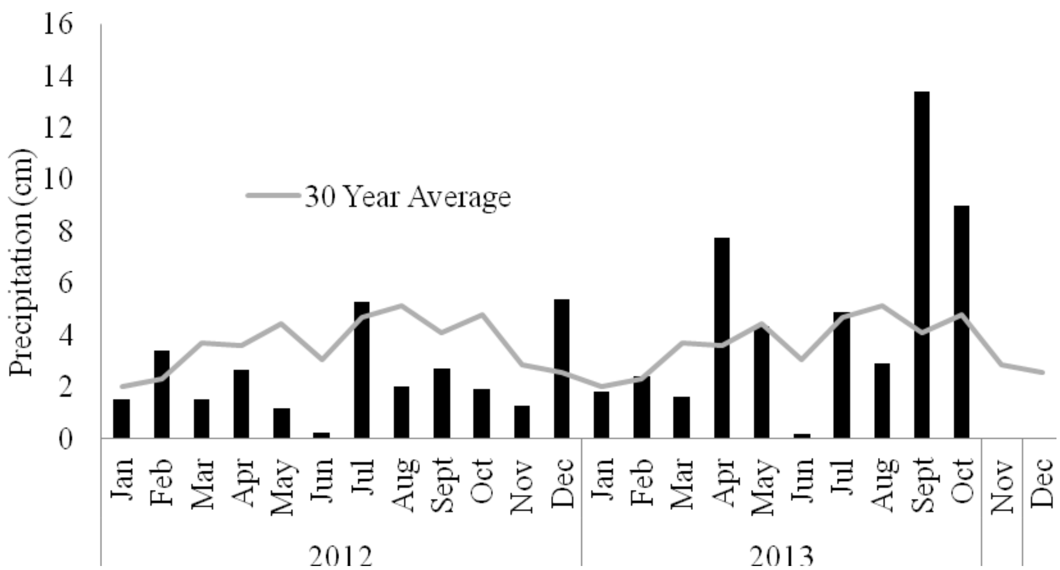

Figure 4. Monthly precipitation data (Station: Rifle 23 NW, 12S 253890E 4405179N, www.ncdc.noaa.gov) and the 30 year average (1981-2010, Station: Little Hills, 12S 254146E 4431731N, http://www.raws.dri.edu/wraws/coF.html). Data were taken from two stations because neither had both monthly precipitation and 30 year average. Rifle 23 NW is approximately 16 km south of the study site and Little Hills is approximately 11 km north of the study sites.

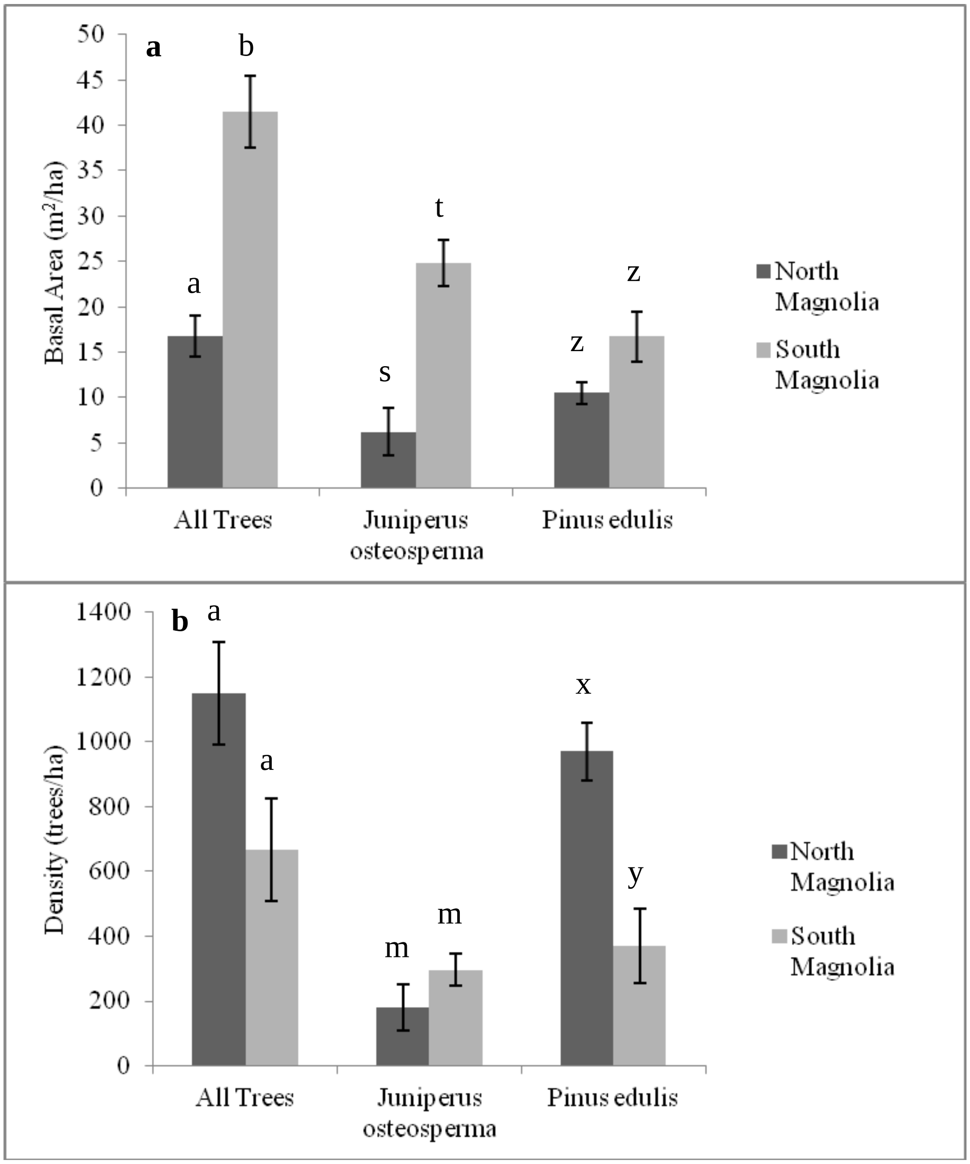

Figure 5. Mean basal area (Fig. 5a) and density (Fig. 5b) for all trees together, just *J. ostersperma*, and just *P. edulis* for North Magnolia and South Magnolia. Raw data was graphed and analyzed. For each comparison, bars with different letters differ significantly at α = 0.05.

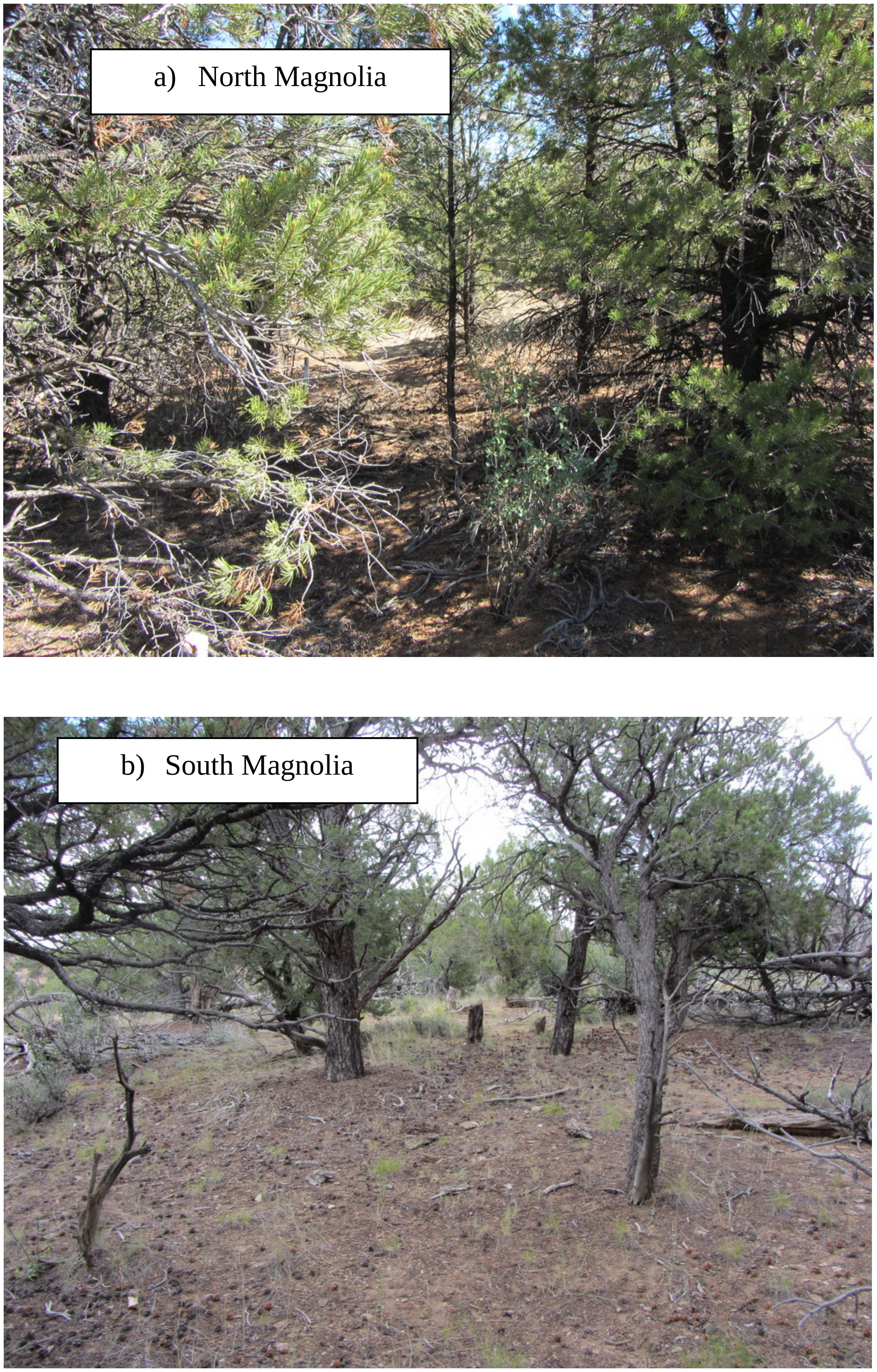

Figure 6. A control plot photo from a) North Magnolia and b) South Magnolia.

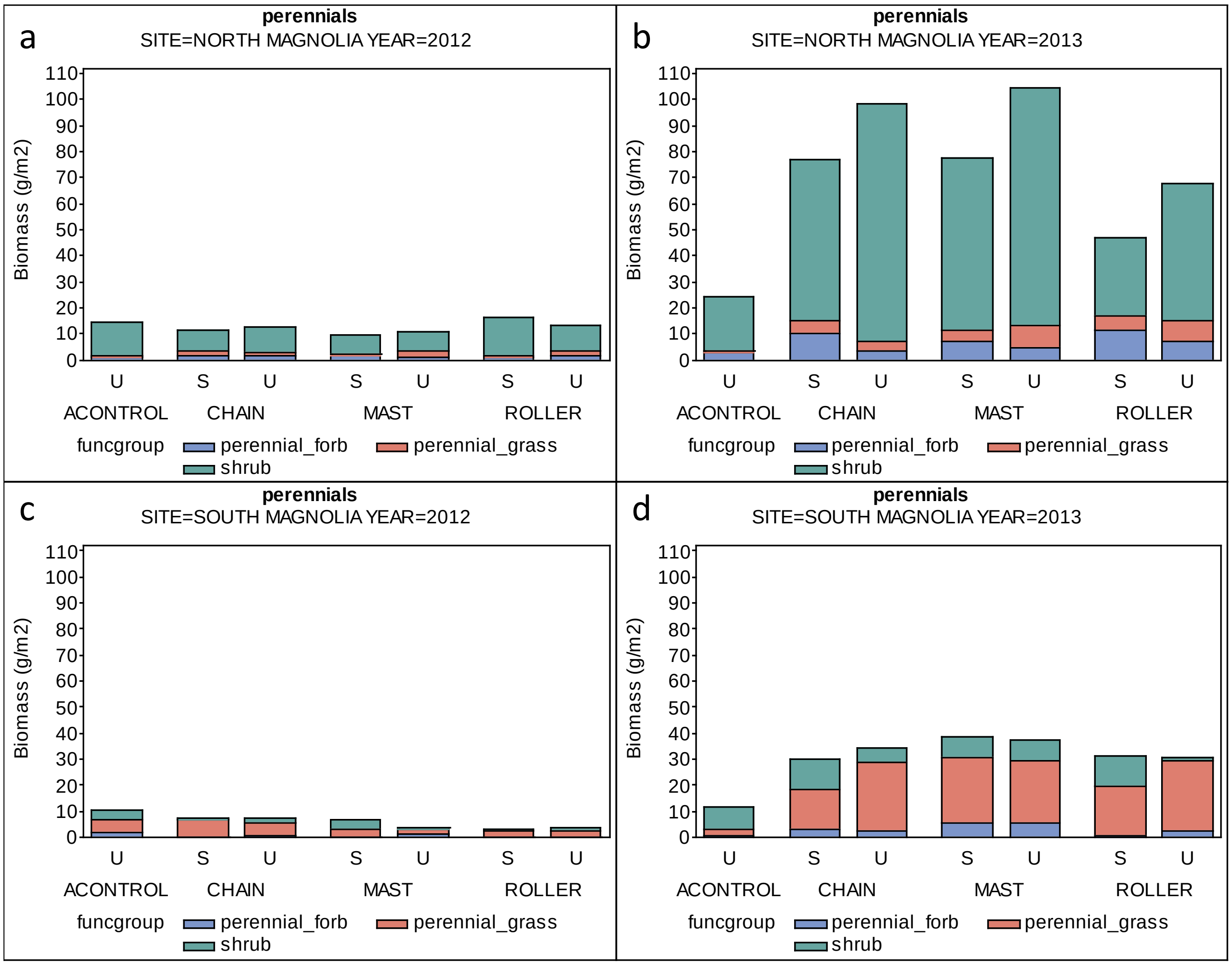

Figure 7. Perennial plant biomass in control (ACONTROL), chained (CHAIN), masticated (MAST) and roller chopped (ROLLER) plots at North Magnolia (a, b) and South Magnolia (c, d) in 2012 (a, c) and 2013 (b, d). Mechanically treated plots were subdivided into seeded (S) and unseeded (U) subplots.

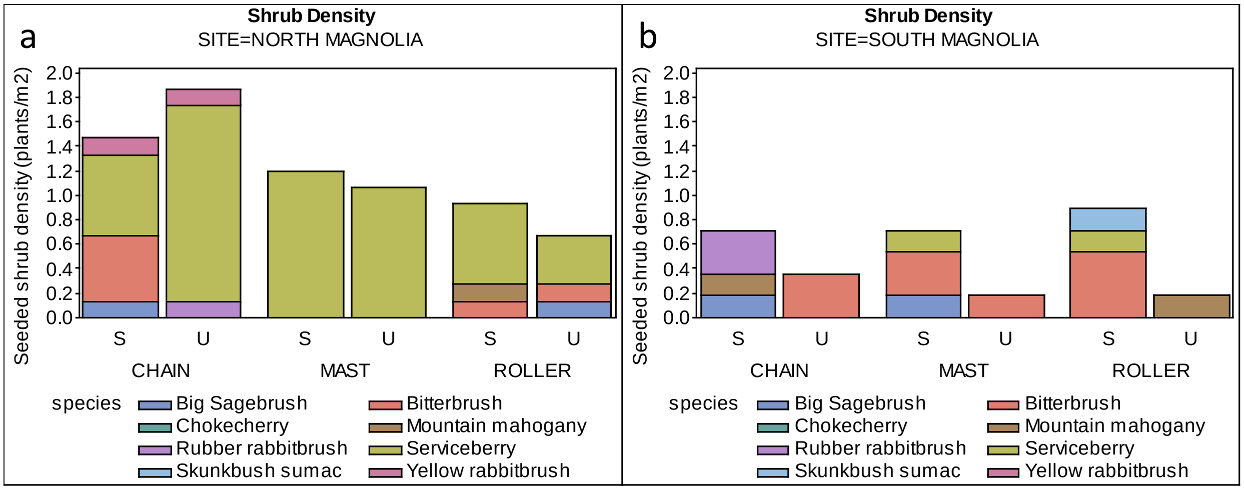

Figure 8. Density of seeded shrubs in seeded (S) and unseeded (U) subplots within 3 mechanical treatment types: chained (CHAIN), masticated (MAST) and roller chopped (ROLLER) at a) North Magnolia and b) South Magnolia.

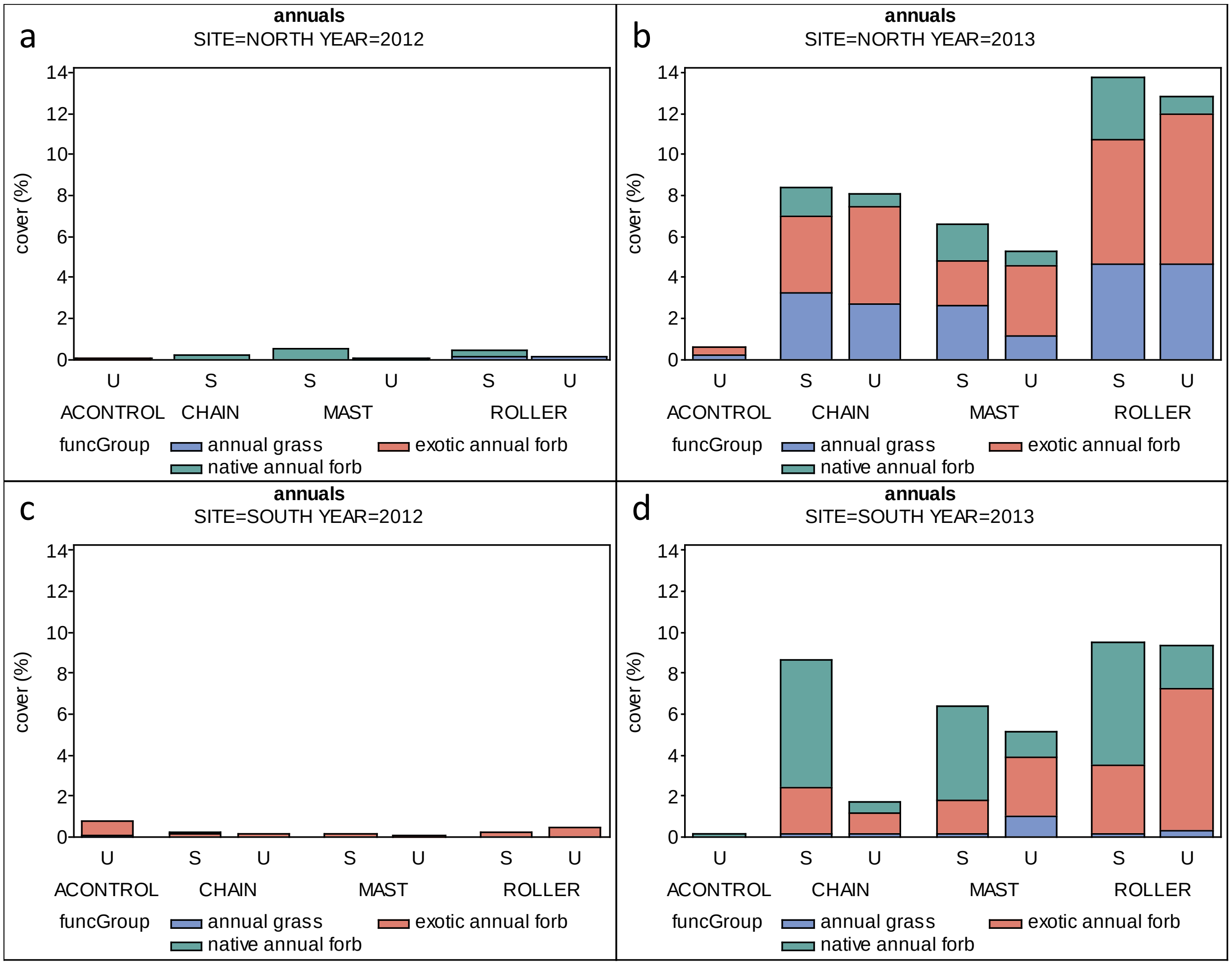

Figure 9. Annual plant cover in control (ACONTROL), chained (CHAIN), masticated (MAST) and roller chopped (ROLLER) plots at North Magnolia (a, b) and South Magnolia (c, d) in 2012 (a, c) and 2013 (b, d). Mechanically treated plots were subdivided into seeded (S) and unseeded (U) subplots.

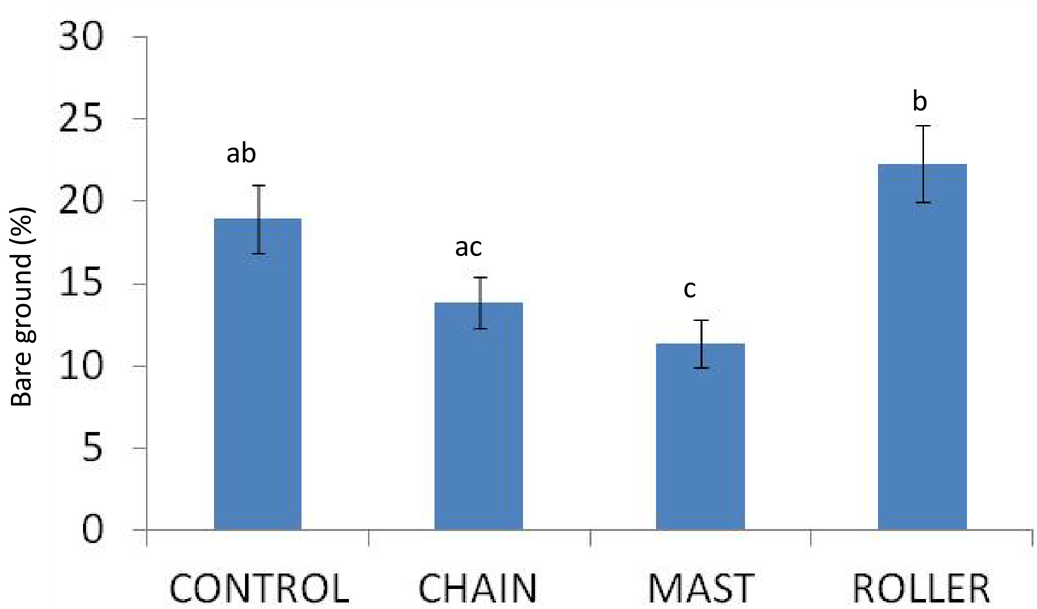

Figure 10. Percent cover of bare soil for each treatment. Rollerchop (ROLLER) plots had a higher percentage of bare ground compared to chain (CHAIN) and mastication (MAST). Raw data was graphed and analyzed. For each comparison, bars with different letters differ significantly at α = 0.05.

Figure 11. A roller chopped plot at North Magnolia in 2014, showing abundant cheatgrass.