Rangeland Ecology & Management 71 (2018) 753–756

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: http://www.elsevier.com/locate/rama

Research Note

Plant Community Responses to Mastication and Mulching of One-Seed Juniper (*Juniperus monosperma*)☆

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ARTICLE INFO

Article history:
Received 7 July 2017
Received in revised form 17 April 2018
Accepted 18 April 2018

Key Words:
grassland restoration
invasive species
northern Arizona
piñon-juniper
pinyon-juniper

ABSTRACT

Mechanical cutting and mastication of juniper trees aims to restore grassland habitat by reducing the density of encroaching woody species. However, the associated soil disturbance may also create conduits for invasive species, a risk that must be mitigated by land managers. We characterized herbaceous communities in treated and adjacent untreated areas in a piñon-juniper (*Pinus edulis* and *Juniper monosperma*) woodland in northern Arizona 2.5 years after treatment. Untreated plots had 4× the herbaceous cover (82%) than treated plots (21%). Within treated plots, native species cover (19%) was 10× higher than invasive species cover (2%). Furthermore, treated plots exhibited greater plant community variability and diversity than untreated plots, driven by an increase in the diversity of native grasses and non-native forbs. No new recruits were Arizona listed noxious weeds, indicating that, at least in the short term, mastication is not producing invasive species hot spots in this piñon-juniper woodland.

Introduction

It is estimated that piñon-juniper (*Pinus edulis* and *Juniperus* spp.) range has increased 10-fold in the past 130 years (Miller and Tausch, 2001). Managing juniper encroachment can increase infiltration (Pierson et al., 2007) and groundwater availability (Cline et al., 2010; Roundy et al., 2014a). However, juniper cutting and mastication may also promote the spread of invasive species. The negative effects of herbaceous species invasion span altered fire regimes (Levine et al., 2003), nutrient cycling, water availability (Lacey et al., 1989), decreased forage quality (DiTomaso, 2000; Wolk and Rocca, 2009), and impacts to native biodiversity (Newbold, 2005).

Cutting trees followed by mastication of branches disturbs soil through skid trails, tire and track marks, and soil compaction (Cline et al., 2010; Kerns and Day, 2014). The associated soil disturbance also increases nitrogen (N) mineralization (Bates et al., 2002; Aanderud et al., 2017), favoring ruderal annual grasses and forbs (Dawson and Schrama, 2016). However, leaving masticated woody debris (hereafter referred to as *mulch*) in place may ameliorate the disturbance over the long term, because lignin and cellulose-rich compounds promote N and phosphorus (P) immobilization by microbial communities (Blumenthal et al., 2003; Aanderud et al., 2017), limiting opportunistic colonizers that are adapted to high nutrient conditions (Sollenberger et al., 2016). Other benefits of mulch include moderating daily and seasonal temperatures and increasing soil moisture (Young et al., 2013a).

As a means to mitigate invasion, carbon (C) amendments have had mixed results in the field. In tallgrass prairie, sawdust amendments decreased exotic species biomass by 40% (Averett et al., 2004). In pile burn scars, 4 − 6 inches of mulch immobilized plant available N, reducing exotic cover (Fornwalt and Rhoades, 2011). Conversely, in a California grassland, sawdust amendments failed to reduce growth of exotic grasses or benefit native grasses (Corbin and D'Antonio, 2004).

In 2014, cutting and mastication treatments were replicated across three sites in the Kaibab National Forest, offering a unique opportunity to study the impacts of a common grassland restoration technique on herbaceous communities. Our study questions were 1) How does juniper mastication and mulching influence the composition, diversity, and variability of plant communities? 2) Does juniper mastication and mulching produce hot spots for invasive species?

Methods

Site Description and Field Methods

Our study used three sites that ranged from 11.3 ha to 17.5 ha and were spaced 3 − 4 km apart in a grassland-woodland ecotone in the Kaibab National Forest (Region II, 7W), approximately 15 miles north

☆ Funding for Rachel Rubin was provided by the ARCS Phoenix Chapter and the Soil Science Society of America. Funding for Carla Roybal was provided by the BLM Colorado Plateau Native Plant Program and Great Basin Native Plant Project.

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https://doi.org/10.1016/j.rama.2018.04.008
1550-7424/

of Parks, Arizona (Site 88, 35°26′53.57″N, 111°59′11.87″W, 2 124 m; Site 144, 35°27′07.05″N, 111°57′08.96″W, 2 138 m; Site 736, 35°28′ 59.80″N, 111°58′12.00″W, 2 092 m). Sites were named according to the closest Forest Service road. Dominant tree species included one-seed juniper *(Juniperus monosperma)* and two-needle piñon *(Pinus edulis)*, and dominant herbaceous species included blue grama *(Bouteloua gracilis)*, snakeweed *(Gutierrezia sarothrae)*, and ring muhly *(Muhlenbergia torreyi)*. Opportunistic or invasive species included mullein *(Verbascum thapsus)*, western tansymustard *(Descurainia pinnata)*, stork's bill *(Erodium cicutarium)*, and musk thistle *(Carduus nutans)*. Soils are volcanically derived.

During summer 2014, juniper trees under 8 ft in height were masticated as part of an experimental grant funded by the Arizona Habitat Partnership Committee (Arizona Game and Fish Department, 2016). Treatments were applied using a rubber-tired Hydro-Ax with a Fecon mastication attachment. Mulch was left in place at an average thickness of 2.4 cm, and the average mulch diameter surrounding each juniper stump was 7.7 m. The management goals were to restore historic grassland corridors for pronghorn antelope, elk, and mule deer (Arizona Game and Fish Department, 2016). There was no post-treatment seeding at any of the sites.

We quantified pretreatment (2013) juniper cover within treated and untreated areas from aerial images using the time lapse feature in Google Earth (version 7.3.0.3832), which we then imported into Image J (version 1.41, National Institutes of Health, Bethesda, MD). We adjusted the contrast threshold to create black-and-white images, whereby juniper trees appeared as black and the surrounding plants and soil appeared white. Next, we calculated the percent of black pixels within each treatment area (polygon), as in Coop et al. (2014). Mean juniper cover for the three treated sites, 26%, was within one standard error of the mean juniper cover for the three untreated sites, 29%, indicating that pretreatment conditions were similar across treated and adjacent untreated sites.

We surveyed plant community composition at all three sites during September 2016. Pretreatment data were unavailable; therefore, we compared plant communities between treated and adjacent untreated areas, as in Bybee et al. (2016) and Young et al. (2013b). For each site, we randomly selected 10 mulch footprints from the treated area, where each mulch footprint included the remaining stump from a single juniper tree and the associated mulch. To estimate canopy cover of each plant species, we used a 1-m^2 PVC 100-point frame on the north edge of each mulch footprint, which was formerly a juniper interspace. There was one plot per mulch footprint, and plots were spaced 30 − 40 m apart. For the adjacent untreated areas, we randomly selected 10 plots among juniper interspaces, also located 30 − 40 m apart, using a handheld GPS (model eTrex, Garmin USA, Olathe, KS).

Data Analysis

To evaluate the effects of mastication and mulching treatments on species diversity, we first calculated Shannon's H for each plot using the "diversity" function in the R package vegan (Oksanen et al., 2016). Several response variables had skewed distributions; therefore, to determine the effects of mastication and mulching treatments on the cover, richness, and diversity of native and invasive plants, we conducted individual robust linear mixed-effects models using the R package "robustlmm" (Koller, 2016), with each "site" as a random effect (O'Connor et al., 2017).

To address the effects of mastication and mulching on plant community composition and variability, we conducted a nonmetric multidimensional scaling (NMDS) analysis (5000 iterations) using a square root transformation and a Bray-Curtis dissimilarity matrix in PRIMER ver. 7 + PERMANOVA (Anderson et al., 2008). Permutational tests of multivariate dispersion (PERMDISP) test whether treatments introduce variability in ecological assemblages and can also indicate communities under stress (Anderson et al., 2008). Using PERMDISP, we evaluated whether mastication resulted in a determinable plant community or caused plant communities to become more variable (dispersed).

Results

Total plant cover (including native and non-native species) was fourfold higher (82%) in untreated plots than treated plots (21%) (Table 1). Mastication and mulching reduced the cover of native grasses over eightfold while increasing the cover of native and non-native forbs (see Tables 1 and 2). Furthermore, mastication and mulching increased the diversity (Shannon's H) of native grasses and the diversity and richness of non-native forbs.

The most common species within untreated plots included blue grama, squirreltail *(Elymus elymoides)*, snakeweed, pingue rubberweed *(Hymenoxys richardsonii)*, and spike muhly *(Muhlenbergia wrightii)*. The most common species within treated plots included mullein, field sagewort *(Artemisia campestris)*, blue grama, rubber rabbitbrush *(Ericameria nauseosa)*, squirreltail, and snakeweed. We did not record any non-native shrubs or non-native grasses, nor did we observe any Arizona state − listed noxious weeds within sites or treatment areas.

Herbaceous communities in treated plots were distinct from plant communities in untreated plots (Fig. 1), and dispersion was significantly higher in treated plots ($P = 0.001$), indicating an increase in plant community variability following mastication and mulching.

Discussion

As a management tool, cutting, mastication, and mulching can produce confounding effects on herbaceous species cover because the disturbed soil is subsequently covered by a recalcitrant C substrate. Although studies on mastication and mulching footprints are lacking, our finding that overall plant cover was reduced in treated plots agrees with a study in a Colorado *Pinus ponderosa* woodland (Wolk and Rocca, 2009), which found that fine-scale patterning of chips was a significant predictor of understory cover; subplots containing wood chips had half the total understory cover than patches containing no wood chips.

Our finding that plant cover was reduced in treated plots is likely due to the physical effects of mulch, which can forestall propagule establishment and germination (Knapp and Seastedt, 1986; Xiong and Nilsson, 1999). Over time, as mulch decomposes, its influence on soil chemistry likely becomes more important, as bacteria and fungi mine

Table 1
Effects of mastication and mulching on percent canopy cover, species richness, and species diversity of plant functional groups. Table reflects means and standard errors. There were no non-native shrubs or non-native grasses throughout the study area. Mean values were calculated as the average of the 30 plots from each treatment group. Table reflects means and standard errors (zeros indicate the absence of that functional group), and values in bold denote significant differences according to 95% confidence intervals from mixed effects models

	Untreated plots			Treated plots		
	Percent cover	Species richness	Shannon's H	Percent cover	Species richness	Shannon's H
All plants	81.85 (3.14)	3.30 (0.19)	0.28 (0.03)	**20.84 (1.99)**	**4.53 (0.44)**	**0.97 (0.09)**
Native forbs	2.17 (0.46)	1.30 (0.19)	0.26 (0.07)	**5.97 (1.35)**	1.67 (0.25)	0.33 (0.07)
Native grasses	77.4 (3.1)	1.50 (0.10)	0.08 (0.03)	**9.13 (1.68)**	1.57 (0.11)	**0.05 (0.03)**
Native shrubs	2.33 (0.75)	0.50 (0.09)	0.00 (0.00)	3.54 (1.13)	0.50 (0.12)	0.03 (0.02)
All native	81.85 (3.14)	3.30 (0.19)	0.28 (0.03)	**18.64 (2.08)**	3.73 (0.34)	**0.87 (0.08)**
Non-native forbs	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	**2.20 (0.91)**	**0.80 (0.23)**	**0.16 (0.06)**

Table 2
Results from mixed effects models for the effects of mastication and mulching on percent cover, species richness, and species diversity (Shannon's H) of plant functional groups. There were no non-native shrubs or grasses throughout the study area. All models were coded with "Site" as random effects. "lwr" and "upr" are the 95% confidence intervals for the model coefficients, and % var. is the proportion of the variance explained by the random effect of "Site." Significance was inferred when confidence intervals do not overlap zero, shown in bold

			Fixed effect (mastication & mulching treatment)				Random effect (site)
		ß	std. err	*t* value	lwr	upr	% var.
Percent cover (*N* = 30)	All plants	**−62.55**	**3.84**	**−16.29**	**−70.07**	**−55.02**	13%
	Native forbs	**3.03**	**1.00**	**3.03**	**1.07**	**4.99**	35%
	Native grasses	**−69.47**	**3.12**	**−22.24**	**−75.59**	**−63.34**	35%
	Native shrubs	0.21	0.71	0.29	−1.18	1.60	1%
	All native	**−64.77**	**3.78**	**−17.14**	**−72.17**	**−57.36**	7%
	Non-native forbs	**0.21**	**0.06**	**3.62**	**0.10**	**0.32**	12%
Species richness (*N* = 30)	All plants	**1.00**	**0.42**	**2.40**	**0.18**	**3.86**	0%
	Native forbs	0.27	0.29	0.92	−0.30	0.84	4%
	Native grasses	0.09	0.16	0.57	−0.22	0.39	18%
	Native shrubs	−0.08	0.16	−0.49	−0.39	0.23	7%
	All native	0.28	0.33	0.83	−0.37	0.92	0%
	Non-native forbs	**0.35**	**0.10**	**3.72**	**0.17**	**0.54**	0%
Shannon's H (*N* = 30)	All plants	**0.72**	**0.07**	**9.78**	**0.58**	**0.87**	0%
	Native forbs	0.07	0.11	0.69	−0.14	0.28	14%
	Native grasses	**0.21**	**0.06**	**3.43**	**0.09**	**0.34**	0%
	Native shrubs	0.00	0.00	1.51	0.00	0.00	0%
	All native	**0.61**	**0.06**	**9.57**	**0.49**	**0.74**	0%
	Non-native forbs	**0.08**	**0.02**	**4.14**	**0.04**	**0.12**	0%

the soil for N and P to synthesize cellulose-degrading and lignin-degrading enzymes (Fontaine et al., 2011), reducing plant N availability. This phenomenon has been observed in juniper woodlands (Young et al., 2014), evergreen forests (Wiebe et al., 2014), and agricultural ecosystems (Döring et al., 2005). However, it is still unclear which features of mulch—physical or chemical—are most important for limiting invasive species. We recommend that future studies test non-native and native seedling establishment across mulches of varying decomposability and depths, which could reveal new mulches that are best suited toward preventing invasion.

The maintenance of biodiversity is an important factor in habitat restoration. Our finding that treated plots exhibited increased species diversity is in accordance with studies in Colorado (Potts and Stephens, 2009; Wolk and Rocca, 2009), Arizona (Owen et al., 2009), and the Great Basin (Roundy et al., 2014b). Ephemeral or long term, an increase in native forbs may provide benefits for wildlife. For example, forbs are an important component of pronghorn diets (Schwartz and Ellis, 1981), and native forb cover was twofold higher in mastication and mulching footprints than in untreated areas.

As a tool to increase grassland habitat, cutting and mastication are costly options at $250/acre (Arizona Game and Fish Department, 2016). Therefore, the benefits must exceed the treatment cost and the environmental cost of species invasion. We did not find evidence that mastication and mulching are creating invasion hotspots. However, we report a case study of short-term responses in a northern Arizona grassland-woodland ecotone. Comparative studies of mastication and mulching across environmental gradients or multiple habitat types, as in Bybee et al. (2016)), are needed to predict which environmental factors promote restoration goals. Furthermore, improved understanding of soil biotic factors, such as the effects of mastication and mulching on microbial mutualists (Owen et al., 2009), will reveal additional mediators of plant community structure in response to this commonly used management technique.

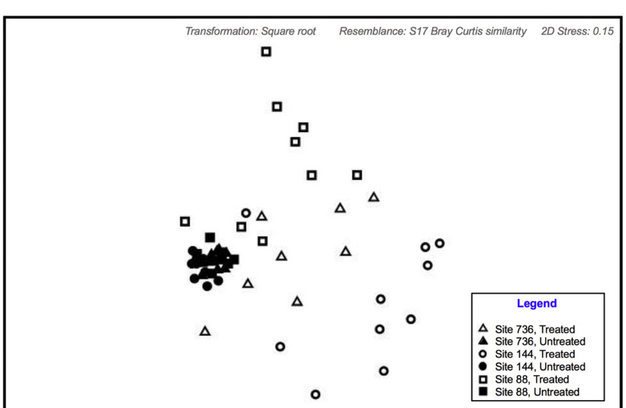

Figure 1. Nonmetric multidimensional scaling (NMDS) ordination of plant communities in treated and untreated areas. Sites were named according to the closest forest service road. The axes in NMDS are arbitrary, as is the plot orientation. Plant communities were compositionally distinct between treated and untreated areas. Furthermore, plant communities were significantly more variable (dispersed) in the treated areas than in the untreated areas (PERMDISP, $P = 0.001$).

Acknowledgments

We thank Dr. Pete Fulé for reviewing an earlier version of this manuscript. Dr. Brad Butterfield, Emily Borodkin, the Arizona Game and Fish Department, and the Kaibab National Forest provided the three masticated study sites.

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