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Original Research

Longer-Term Evaluation of Revegetation of Medusahead-Invaded Sagebrush Steppe☆

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ABSTRACT

Medusahead (*Taeniatherum caput-medusae* [L.] Nevski) and other exotic annual grasses have invaded millions of hectares of sagebrush (*Artemisia* L.) steppe. Revegetation of medusahead-invaded sagebrush steppe with perennial vegetation is critically needed to restore productivity and decrease the risk of frequent wildfires. However, it is unclear if revegetation efforts provide long-term benefits (fewer exotic annuals and more perennials). The limited literature available on the topic questions whether revegetation efforts reduce medusahead abundance beyond 2 or 3 yr. We evaluated revegetation of medusahead-invaded rangelands for 5 yr after seeding introduced perennial bunchgrasses at five locations. We compared areas that were fall-prescribed burned immediately followed by an imazapic herbicide treatment and then seeded with bunchgrasses 1 yr later (imazapic-seed) with untreated controls (control). The imazapic-seed treatment decreased exotic annual grass cover and density. At the end of the study, exotic annual grass cover and density were 2-fold greater in the control compared with the imazapic-seed treatment. The imazapic-seed treatment had greater large perennial bunchgrass cover and density and less annual forb (predominately exotic annuals) cover and density than the untreated control for the duration of the study. At the end of the study, large perennial bunchgrass density average 10 plant·m^{-2} in the imazapic-seed treatment, which is comparable with intact sagebrush steppe communities. Plant available soil nitrogen was also greater in the imazapic-seed treatment compared with the untreated control for the duration of the study. The results of this study suggest that revegetation of medusahead-invaded sagebrush steppe can provide lasting benefits, including limiting exotic annual grasses.

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Introduction

Exotic annual grass invasion is a serious threat to the historically perennial-dominated sagebrush (*Artemisia* L.) steppe ecosystem and fauna dependent on it (Davies et al., 2011). Exotic annual grass-invaded communities may burn more frequently than native dominated communities because of decreased fuel moisture, increased fine fuels, and fuel continuity (Brooks et al., 2004; Davies and Nafus, 2013). Exotic annual grasses can develop a grass-fire cycle, which can be particularly devastating to native plants that are not adapted to frequent fire (D'Antonio and Vitousek, 1992). One of the most problematic exotic annual grasses invading sagebrush steppe communities is medusahead (*Taeniatherum caput-medusae* [L.] Nevski) (Young, 1992; Nafus and Davies, 2014). Medusahead is rapidly spreading across the western United States (Duncan and Jachetta, 2005). Medusahead has high silica content and sharp awns that greatly limit its forage value to livestock (Hironaka, 1961; Torell et al., 1961). Invasion by medusahead results in the formation of a thick, persistent thatch layer that decreases native plant establishment and increases dry fine fuel amounts (Torell et al., 1961; Young et al., 1972; Young, 1992). Medusahead is also highly competitive with native vegetation (Hironaka and Sindelar, 1975; Goebel et al., 1988; Young and Mangold, 2008), leading to decreases in biodiversity and native plant abundance as medusahead density increases (Davies, 2011). Medusahead-invaded sagebrush steppe also does not provide quality habitat for a sagebrush obligate wildlife (Davies and Svejcar, 2008; USFWS, 2013).

Revegetation of medusahead-invaded rangeland is needed to restore ecosystem productivity and decrease the frequency of wildfires. Most successful efforts to revegetate medusahead-invaded sagebrush rangelands first control annual species with prescribed burning followed by a preemergent herbicide application, such as imazapic (Nafus and Davies, 2014). Burning is often applied before imazapic application to improve soil-herbicide contact and prepare the seedbed for planting (Davies, 2010; Davies and Sheley, 2011). Seeding perennial vegetation is usually postponed until 1 yr after preemergent herbicide

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application to allow herbicide toxicity to subside (Davies, 2010; Davies et al., 2015). Short-term revegetation success has been variable (Monaco et al., 2005; Davies, 2010; Davies et al., 2014b), but successfully established perennial vegetation generally limits medusahead and other exotic annuals (Davies, 2010; Davies et al., 2015; Davies and Johnson, 2017). Longer-term evaluations of medusahead control are limited, especially evaluating revegetation success (James et al. 2015). Particularly important is determining if seeded perennial vegetation limits medusahead and other exotic annuals expression over extended time frames.

A critical component of a successful revegetation program is to establish enough plants to use soil nutrients to reduce their availability to exotic annual species. Though exotic annual grasses are more competitive for soil nutrients than perennial species (James, 2008; Leffler et al., 2011), exotic annual grasses are even more favored with greater nutrient availability, particularly nitrogen (Vasquez et al., 2009). Seeding competitive perennial vegetation can reduce soil nutrient availability, thereby increasing biotic resistance to exotic annual grass invasion (Davies et al., 2010). However, the effect of revegetating medusahead-invaded rangeland on soil nutrient availability is relatively unknown.

The purpose of this study was to investigate the longer (5-yr) effects of revegetation of medusahead-invaded sagebrush rangeland on perennial vegetation and exotic annuals, as well as soil nutrient availability. We hypothesized that areas prescribed burned followed by a fall imazapic application and then seeded with bunchgrasses 1 yr later (imazapic-seed) would have greater large perennial bunchgrass abundance and cover and reduced exotic annual grasses compared with untreated controls. We also expected that soil nutrient availability would be greater in the imazapic-seed treatment compared with the untreated controls because of reduced exotic annual species but would decrease over time with increases in perennial vegetation.

Methods

Study Area

The study was located in southeastern Oregon in the northwestern Great Basin. Five study sites were between Crane and Juntura, Oregon in medusahead-invaded sagebrush plant communities and were separated by up to 30 km. Elevation at study sites ranged from 972 to 1 052 m above sea level. Slopes were from 0° to 12° with varying aspects (northeast, southwest, and west aspects) depending on study site. Climate is representative of the northwestern Great Basin with most precipitation occurring in the winter and spring and with hot and dry summers. Long-term (1981 − 2010) average annual precipitation was between 249 and 258 mm (PRISM Climate Group, 2017). Annual crop-year (October − September) precipitation at the study sites varied from <75% to slightly > 100% of the long-term average during the study (PRISM Climate Group, 2017). Seeding crop-year precipitation (2011 − 2012) averaged 75% of the long-term average. The spring of 2015 and 2016 received more precipitation than average. Soil texture varied from loam to clay loam among study sites. Before medusahead invasion, the natural vegetation of study sites was Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* [Beetle & A. Young] S. L. Welsh)—bunchgrass steppe. Before treatments, vegetation at study sites was a near monoculture of medusahead with some cheatgrass (*Bromus tectorum* L.), a few (<0.4 plants·m^{-2}) residual native bunchgrass plants, and no sagebrush or other shrubs. Domestic livestock, but not wildlife, were excluded from study sites for the duration of the study with barbwire fences. Two of the imazapic-seeded plots had heavy and moderate winter − early spring use by elk in 2015 and 2016, respectively, based on density of dung pellet piles.

Experimental Design and Measurements

We used a randomized complete block design with five study sites (blocks) to compare treatments. Treatments were 1) medusahead controlled with a fall-prescribed fire followed with an imazapic application and then seeding 1 yr later with perennial bunchgrasses (imazapic-seed) and 2) untreated and unseeded control (control). Each treatment was applied to one of two 30 × 50 m plots separated by a 2-m buffer within each block. Prescribed burning occurred in late September 2010 using strip-head fires. During prescribed burns wind speed varied from 0 to 6 km·hr^{-1}, air temperature varied from 14°C to 29°C, and relative humidity ranged from 21% to 48%. Burns were nearly complete across plots with 95% of the medusahead litter and other fuels being consumed. Imazapic was applied within 10 d of burning at 87.5 g ai·ha^{-1} using a UTV-mounted 7-nozzle boom spray with a nozzle height of 0.6 m from the ground and a tank pressure of 207 kPa. During imazapic application air temperature ranged from 7°C to 16°C, and wind speed varied from 0 to 5 km·hr^{-1}. In early October 2011, one yr after imazapic application, treatment plots were seeded with crested wheatgrass (variety Hycrest) and Siberian wheatgrass (variety Vavilov) at 21.6 kg·ha^{-1} pure live seed with equal proportions by weight of each bunchgrass species. Crested and Siberian wheatgrass seeds were mixed together before being drill seeded using a Versa-Drill (Kasco, Inc., Shelbyville, IN) with drill rows spaced 23 cm apart.

Herbaceous cover and density were measured in mid-June in 2012 through 2016 along four parallel 45-m transects spaced 5 m apart in each treatment plot. Herbaceous canopy cover was estimated by species in 0.2-m^2 quadrats located at 3-m intervals on each 45-m transect, resulting in 60 quadrats per treatment plot. Quadrats were divided into 1%, 5%, 10%, 25%, and 50% sections to increase the accuracy of cover estimates. Bare ground, litter, and soil biological crust cover were also visually estimated in these quadrats. Herbaceous density was measured by species by counting individuals rooted inside of the 0.2-m^2 quadrats. No shrubs occurred in any of the imazapic-seeded or untreated control plots.

Plant available soil nutrient concentrations of total nitrogen (NO_3^- and NH_4^+), potassium, and phosphorus were estimated using four pairs of cation and anion ion exchange membrane probes (PRS-probes, Western Ag Innovations, Saskatoon, Saskatchewan, Canada) randomly placed in each treatment plot in each block. PRS-probes use an ion exchange membrane buried in the soil to attract and absorb ions to estimate the availability of soil nutrients to plants (Jowkin and Schoenau, 1998). PRS-probes were buried vertically in the upper 20 cm of the soil profile from 1 April through 30 July in 2012 − 2016. PRS-probes were extracted with 0.5 N HCl and analyzed colorimetrically with an autoanalyzer to determine nutrient concentrations.

Statistical Analysis

Treatment effects were estimated using repeated measures analyses of variances (ANOVAs) with years as the repeated factor in PROC MIXED SAS v. 9.4 (SAS Institute Inc., Cary, NC). Treatment was considered a fixed variable, and random variables were site and site-by-treatment interactions. Covariance structure for each repeated measures ANOVA was selected using Akaike's Information Criterion (Littell et al., 1996). Data were square root transformed when assumptions of ANOVA were not met. Figures and text report nontransformed (i.e., original) data. Herbaceous cover and density were grouped into five groups for analyses: large perennial bunchgrasses, Sandberg bluegrass (*Poa secunda* J. Presl), perennial forbs, exotic annual grasses, and annual forbs. Sandberg bluegrass was treated as a separate group because it is much smaller in stature, matures earlier, and responds differently to disturbance than other perennial bunchgrasses in the sagebrush ecosystem. The exotic annual grass group was predominately composed of medusahead with some cheatgrass. The annual forb group was largely composed of exotic annual species (94% cover and 96% density). Treatment means were considered different at $P \leq 0.05$ and reported with standard errors in the text and figures.

Results

The interaction between year and treatment did not influence Sandberg bluegrass cover (P 0.463). Sandberg bluegrass cover did not