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Original Research

Established Perennial Vegetation Provides High Resistance to Reinvasion by Exotic Annual Grasses☆

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ABSTRACT

Exotic annual grasses have invaded millions of hectares of sagebrush (*Artemisia* L.) steppe in the Great Basin region and degraded wildlife habitat, reduced forage production, and promoted increasingly frequent wildfires. Revegetation after control of exotic annual grasses is needed to restore ecosystem services and break the annual grass-fire cycle. The ability of different common revegetation species and combinations of species to limit reinvasion of annual grasses is relatively unknown. We evaluated five species/combinations of perennial native and introduced bunchgrass and shrub species planted as seedlings after exotic annual grass control at two sites in southeast Oregon. To evaluate resistance to reinvasion, exotic annual grasses were seeded into all treatment plots in the fall two growing seasons after planting. Vegetation characteristics were measured in the third and fourth years after annual grass seeding. Exotic annual grass cover and density were greatly reduced in all treatments where perennial seedlings were planted compared with the control (no seedlings planted). Treatments including crested wheatgrass (*Agropyron desertorum* [Fisch. Ex Link] Schult) generally limited annual grasses more than other treatments. Most notably, forage kochia (*Bassia prostata* [L.] A. J. Scott) reduced exotic annual grasses less than crested wheatgrass and crested wheatgrass planted with forage kochia. This suggests that if forage kochia will be planted, it should be used in conjunction with perennial bunchgrasses in efforts to revegetate exotic annual grass—invaded sagebrush steppe. Established native vegetation also greatly reduced exotic annual grass reinvasion. Though some differences existed among established vegetation treatments, our study highlights that established perennial vegetation prevents redomination by invasives after exotic annual grass control.

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Introduction

Exotic annual grass invasion, primarily medusahead (*Taeniatherum caput-medusae* [L.] Nevski) and cheatgrass (*Bromus tectorum* L.), is a critical threat to the sagebrush ecosystem and rural communities and wildlife that depend on it (Davies et al., 2011). Exotic annual grass invasion is correlated to reduce biodiversity and reductions in native vegetation (Mack, 1981; Davies, 2011). Invasion by exotic annual grasses also decreases forage production and degrades wildlife habitat (DiTomaso, 2000; Davies and Svejcar, 2008). Perhaps the most devastating impact of exotic annual grass invasion is an increase in wildfire frequency, which is detrimental to native plants that evolved with infrequent fire (D'Antonio and Vitousek, 1992; Mack et al., 2000; Brooks et al., 2004). Exotic annual grasses promote more frequent wildfires by increasing fine fuel biomass and continuity and drying out earlier than native vegetation (Davies and Nafus, 2013). The increase in fire favors exotic annual grasses and creates a grass-fire cycle that promotes their continued dominance of the plant community and may facilitate invasion of surrounding areas as fires spread from invaded to noninvaded communities (D'Antonio and Vitousek, 1992; Brooks et al., 2004).

Revegetation of exotic annual grass—invaded rangelands is needed to break the annual grass-fire cycle and restore ecosystem services. To successfully revegetate annual grass—invaded rangelands, annual grasses must first be controlled to reduce competition for the establishment of perennial vegetation (Davies, 2010; Davies et al., 2013; Nafus and Davies, 2014). Exotic annual grasses can be effectively controlled with pre-emergent herbicides (Monaco et al., 2005; Musil et al., 2005; Elseroad and Rudd, 2011). The effectiveness of preemergent herbicides can be improved by prescribed burning before application to remove litter to improve herbicide-soil contact (Kyser et al., 2007; Davies, 2010; Davies and Sheley, 2011; Sheley et al., 2012). Effective annual grass control is often temporary as these grasses can rapidly reinvade

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treated areas (Monaco et al., 2005; Kyser et al., 2007). Therefore, after successful control of annual grasses, it is imperative to establish perennial vegetation to limit reinvasion.

Individual and combinations of perennial species likely vary in their effectiveness at limiting annual grass reinvasion. The introduced bunchgrass, crested wheatgrass (*Agropyron desertorum* [Fisch. Ex Link] Schult), successfully competes with exotic annual grasses (Miller, 1956; Arredondo et al., 1998; McAdoo et al., 2017) and can limit their spread (Davies et al., 2010). Crested wheatgrass has been used successfully to prevent reinvasion (Davies, 2010; Davies et al., 2014), but the ability of other introduced species such as the half-shrub, forage kochia (*Bassia prostata* [L.] A.J. Scott), to reduce reinvasion is largely unknown. Forage kochia has been shown to reduce exotic annual grasses in case studies (Monaco et al., 2003). The use of introduced species in revegetation of sagebrush steppe communities is controversial (Davies et al., 2011). Introduced species can form near-monocultures (Pyke, 1990) and can be highly competitive with native plants (Heinrichs and Bolton, 1950; Schuman et al., 1982; Gunnell et al., 2010). Thus, there is a desire to revegetate annual grass — invaded sagebrush communities with native vegetation (Davies et al., 2015). Established native vegetation can also be competitive with exotic annuals (Clausnitzer et al., 1999; Chambers et al., 2007). However, information regarding the ability of native vegetation to prevent reinvasion after exotic annual grass control is generally lacking.

The purpose of this study was to evaluate the ability of some common native and introduced revegetation species and species mixes to suppress reinvasion by exotic annual grasses after annual grass control. Our objectives were to determine 1) if establishing commonly used species/species mixes reduced exotic annual grass density and cover; 2) if the ability of grass-shrub combinations to suppress exotic annual grasses depended on whether plants were native, introduced, or a combination of native and introduced species; and 3) which introduced species (crested wheatgrass or forage kochia) suppressed exotic annual grass more and if suppression was greater when planted together. We hypothesized that 1) established perennial vegetation would limit exotic annual grass reinvasion, 2) an introduced grass-shrub combination would limit exotic annual grass reinvasion more than a native or an introduced-native grass-shrub combination, and 3) crested wheatgrass and crested wheatgrass-forage kochia combination would suppress exotic annual grass reinvasion more than forage kochia.

Methods

Study Sites

The study was conducted in southeast Oregon at two sites: the Buck Mountain site and the Warm Springs site located about 65 km southeast and 57 km east of Burns, Oregon, respectively. Climate is typical of the northwest Great Basin with cool, wet winters and hot, dry summers. Long-term (1981 — 2010) average annual precipitation was 287 and 284 mm at Buck Mountain and Warm Springs, respectively (PRISM, 2017). Crop-year (1 October–30 September) precipitation for Buck Mountain was 130%, 72%, 88%, 66%, 94%, and 94% of the long-term average for 2010 — 2011, 2011 — 2012, 2012 — 2013, 2013 — 2014, 2014 — 2015, and 2015 — 2016, respectively (PRISM, 2017). Crop-year precipitation for Warm Springs was 128%, 75%, 96%, 65%, 104%, and 96% of the long-term average for these same time periods (PRISM, 2017). The ecological site at Buck Mountain and Warm Springs was SR Clayey 9-12 PZ (R010XC021OR) and SR Shallow 9-12 PZ (R010XC035OR), respectively (NRCS, 2017). The potential natural vegetation at both sites was dominated by Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* [Beetle & A. Young] S. L. Welsh) and bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] Á. Löve) with some Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth) (NRCS, 2017). Soils at Buck Mountain were well drained and ~70 cm deep before encountering a restrictive layer of bedrock. Soils at Warm Springs were also well drained and ~50 cm deep before encountering weathered bedrock. Both sites were relatively flat (< 2%) and 1235 m (Buck Mountain) and 1147 m (Warm Springs) above sea level. Exotic annual grasses, medusahead and cheatgrass, dominated both sites. Both sites had burned in wildfires in the 15 yr before treatment implementation.

Experimental Design and Measurements

Treatments were applied at two sites and at each site, arranged in a randomized complete block design with four replications. Before planting seedlings, glyphosate (Pronto Big N' Tuf) was applied at 560 g ai·ha^{-1} in May 2010 and then imazapic (Panoramic, Alligare, LLC, Opelika, AL) was applied at 87.5 g ai·ha^{-1} in early October 2010 to all plots to control exotic annual grasses. Herbicide treatments fully controlled (100%) exotic annual grasses for the 2011 growing season. Fences were constructed at each site to exclude livestock and wildlife. Treatments were applied to 5 × 5 m plots and included 1) unplanted control (control), 2) crested wheatgrass (crested), 3) crested wheatgrass and forage kochia (crested-kochia), 4) forage kochia (kochia), 5) bluebunch wheatgrass and Wyoming big sagebrush (bluebunch-sage), and 6) crested wheatgrass and Wyoming big sagebrush (crested-sage). There was a 1-m buffer between treatment plots. All species were planted as seedlings grown in cone containers (3.8-cm upper diameter and 21-cm tall). Seedlings were started in July 2010 in a greenhouse at the Eastern Oregon Agricultural Research Center in Burns, Oregon. Approximately half of the seedlings were planted in November 2010, and the other half was planted in March 2011. Seedlings were planted at a density of 10 plants·m^{-2} when one species was planted. When two species were planted together, each was planted at a density of 5 plants·m^{-2}. Seedlings were planted at a high density to ensure sites would be fully occupied. As plants grow larger, they can self-thin to the appropriate level for the site (Mueggler and Blaisdell, 1955). In the fall of 2012, exotic annual grass (medusahead and cheatgrass) was hand broadcast seeded at 500 PLS·m^{-2} across treatment plots. Exotic annual grass seed was collected from the infestation surrounding each study site; thus, seed composition was representative of the study site. Annual grasses were seeded into treatment plots to ensure that treatments received similar levels of propagule pressure.

Vegetation characteristics were sampled in June of 2015 and 2016. Vegetation foliar cover and density were measured by species in sixteen 40 × 50 cm quadrats (0.2 m^2) per treatment plot. Litter cover and bare ground were also measured in the 40 × 50 cm quadrats. The 40 × 50 cm quadrats were demarcated into 1%, 5%, 10%, 25%, and 50% segments to increase the accuracy of cover estimates. Plants were included for density estimates if they were rooted inside the 40 × 50 cm quadrats. Quadrats were located at 1-m intervals on four 5-m transects (starting at 1 m and ending at 4 m), resulting in four quadrats per transect. The 5-m transects were positioned at 1-m intervals in each treatment plot (starting at 1 m and ending at 4 m).

Statistical Analyses

Repeated-measures analysis of variance (ANOVA) employing the mixed models procedure (Proc Mixed SAS v. 9.4, SAS Institute, Cary, NC) was used to compare treatments. Year was the repeated variable, treatment was considered a fixed variable, and site, replication, and site × treatment interaction were treated as random effect variables in analyses. Akaike information criteria were used to select the appropriate covariance structure (compound symmetry) for repeated-measures ANOVAs (Littell et al., 1996). For analyses, vegetation was separated into the following groups: exotic annual grass, perennial bunchgrass, Sandberg bluegrass (*Poa secunda* J. Presl), perennial forbs, annual forbs, and shrubs. Sandberg bluegrass was treated as a separate