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Research Article

Crested wheatgrass (*Agropyron cristatum*) seedings in Western Colorado: What can we learn?

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Abstract

Non-native species have been widely transported, becoming components of ecosystems worldwide. In some cases this can change the structure and function of an ecosystem. Crested wheatgrass (*Agropyron cristatum, Agropyron spp.*) was introduced into the Western U.S. in the late 18th and early 19th centuries. Since introduction, it has been planted in western rangelands currently occupying millions of acres. Crested wheatgrass causes significant changes in areas where it dominates the vegetation, and restoring rangelands planted with crested wheatgrass to higher plant diversity and ecosystem function has been met with limited success. Here we revisit historical frequency monitoring data collected in western Colorado on public lands that were planted with crested wheatgrass between 1940 and 1980. We also monitored vegetation before and after mechanical treatment (removal of vegetation with the use of a dixie harrow pulled behind a tractor) and re-seeding of desirable species in three areas dominated by crested wheatgrass. We looked for increasing or decreasing trends in plant species, and for plant species that persist with crested wheatgrass. We found that crested wheatgrass increased significantly ($p=0.09$) over time, we also found five species of grasses, two shrub species, and one forb species that were persistent in areas planted with crested wheatgrass. We found that in mechanically treated areas, the only significant trend was a reduction of native grasses ($p<0.05$). Our findings suggest that in areas planted with crested wheatgrass, frequency of crested wheatgrass can increase over time. Further, mechanical treatments coupled with seeding were not effective at reducing crested wheatgrass cover, or at increasing native and desirable species. These sites may have experienced a shift to a stable state.

Key words: rangeland; vegetative diversity; native species; mechanical treatment; management

Introduction

Restoration of semi-arid and arid western lands can be difficult at best and the use of native seeds, while desirable, can be problematic (Banerjee et al. 2006). Native seeds may be difficult to germinate, expensive, and unable to compete with non-native and invasive seeds which are often present in the seed bank and can establish before natives (Banerjee et al. 2006). Historically, non-native plants have been used in re-seeding projects on public lands for reasons such as increasing forage production, erosion control, and reduced cover of less-desirable invasive plant species (Pellant and Lynse 2005). Crested wheatgrass (*Agropyron cristatum* and other *Agropyron* species) was introduced into the Western U.S. beginning in the late 18th and early 19th century, and since its introduction has been widely planted in western rangelands currently occupying an estimated 5 million acres of rangeland (Lesica and DeLuca 1996; Pellant and Lynse 2005).

Despite evidence against the use of crested wheatgrass, it is often used in seed mixes. Crested wheatgrass is competitive with native plants (Bakker and Wilson 2004; Gunnell et al. 2010), partially through prolific seed production (Hedinga and Wilson 2002). Crested wheatgrass often excludes native plants, thereby reducing species richness of an area and producing almost monotypic stands (e.g. Fansler and Mangold 2010; Henderson and Naeth 2005; Hedinga and Wilson 2002; Christian and Wilson 1999; Lesica and Deluca 1996; Reynolds and Trost 1980; Hull and Klomp 1966). In addition, in areas planted with crested wheatgrass there is increased bare ground (Sutter and Brigham 1998), decreased available soil nitrogen and carbon (Christian and Wilson 1999), and decreased soil organic matter and phosphorus (Dormaar et al. 1995) compared to areas not planted with crested wheatgrass and with more intact native communities. Areas planted with crested wheatgrass can be less favorable for not only native plants, but also birds and wildlife (Reynolds and Trost 1980). While crested wheatgrass does not spread as readily as some other invasive species, it may invade in areas where it has not been planted (Hedinga and Wilson 2002).

One reason for the continued use of crested wheatgrass in the western U.S. is the ability of crested wheatgrass to compete with other more detrimental invasive plants, most notably *Bromus tectorum* (Francis and Pyke 1996). In addition, there have been reports of early success with planting native species into areas with crested wheatgrass present, a process known as 'assisted succession' (Cox and Anderson 2004). While Cox and Anderson (2004) showed good emergence, longer term establishment and persistence of native species in an area planted with crested wheatgrass is unknown (Cox and Anderson 2004) and may be unlikely (Fansler and Mangold 2010).

There has been research on the establishment of native species in the presence of crested wheatgrass (e.g. Wilson and Partel 2003; Gunnell et al. 2010) and after removal of crested wheatgrass (e.g. Hulet et al. 2010), but the long term persistence of native species in the presence of crested wheatgrass is less certain. Here we explore historical data, to look for longer term vegetation trends in areas planted with crested wheatgrass, and current data, to look for initial changes in vegetation after mechanical treatment of historic crested wheatgrass plantings.

Methods

Site description

The sampling area included lands in western Colorado, within the boundaries of the Bureau of Land Management's Grand Junction Field Office (GJFO) and Uncompahgre Field Office (UFO) (http://www.blm.gov/co/st/en.html). Elevation of sampling points ranged from 1813 meters (5950 feet) to 1838 meters (6030 feet), with an average yearly precipitation of 17-28 cm (7-11 inches) (http://www.wrcc.dri.edu/summary/gjt.co.html, http://www.wrcc.dri.edu/summary/mtj.co.html, downloaded August 2012). Precipitation can be quite variable in this area, both temporally and spatially.

Mechanically treated areas sampled were within the McInnis Canyons National Conservation Area within the Grand Junction Field Office (specific locations are available upon request). Over the sample period for the treated areas, precipitation was 30.9cm in 2010 and 30.6cm in 2011. However, during the spring growing season (from April until July when data was collected) precipitation was approximately 7.1cm in 2010 and 14.9cm in 2011 (data from Western Regional climate Center, Colorado National Monument weather station used; http://www.wrcc.dri.edu/summary/Climsmco.html).

GJFO and UFO – Review of rangeland frequency monitoring

We reviewed data from rangeland monitoring points from the Grand Junction Field office (GJFO) and Uncompahgre Field Office (UFO). Historical crested wheatgrass plantings were identified by reviewing range improvement projects listed in the Rangeland Improvement Project System (RIPS) and through conversations with rangeland management specialists and other BLM staff. In order to be included in this study as crested wheatgrass plantings, projects needed to be seeded with a seed mix including crested wheatgrass between 1940 and 1980. Once identified, historical wheatgrass planting GIS layers were reviewed to see where projects intersected vegetation frequency monitoring, and how often monitoring was performed. We included sites that had at least two samplings since planting crested wheatgrass, and had no further treatments since the original treatment/planting. This yielded five sites within the GJFO and six sites within the UFO that were analyzed. These sites have all been grazed by cattle in winter or early spring.

Frequency monitoring of rangelands in these field offices consists of sampling one hundred 0.36m^2 (2ft^2) nested frequency plots approximately every 1.2 meters (4 feet) along ten transects. Transects are approximately 12.2 meters (40 feet) in length and placed on alternating sides of a fixed 50 meter transect. This method is used because it is relatively quick and results are repeatable between different observers (Elzinga et al. 1998). In addition, results are more robust to short term climate variation and levels of

Figure 1. Photo of a dixie harrow. Toothed metal pipes are drug behind a tractor. This can remove some of the shrubby overstory and thin out understory plants (grasses and forbs). Desirable seeds are spread in front of the tractor so that they are incorporated into the soil as the harrow passes over them (Photograph by J. Dollerschell).

herbivory than other common ways of measuring vegetation such as density, cover, or biomass (West 1985). Sites were sampled between May and August from 1984 to 2008.

Treatment areas

Three areas within the McInnis Canyons National Conservation Area were treated with a dixie harrow (Figure 1) in the fall of 2009 and 2010, and then seeded with an appropriate seed mix (Table 1) to reduce understory vegetation and sagebrush (*Artemisia tridentata*) overstory, thereby increasing resources for germinating seeds. In the two areas treated and seeded in 2010 pre-treatment data were collected. In one area we were unable to collect pre-treatment data, so data were collected in an adjacent area that was not treated. The untreated area is comparable to the treated area in vegetation and soils. A random location was chosen within the treatment area where ocular estimates of cover were collected within one hundred marked $0.25 m^2$ quadrats spaced at 1.5 meter intervals along ten transects. Transects were 15 meters in length and placed on alternating sides of a 50

Table 1. Seed mix used for seeding efforts in treatment areas.

Common Name	**Scientific name**
common yarrow	*Achilea millefolium*
indian ricegrass	*Achnatherum hymenoides*
fourwing saltbush	*Atriplex canescens*
thickspike wheatgrass	*Elymus lanceolatus*
slender wheatgrass	*Elymus trachycaulus*
needle and thread	*Hesperostipa comata*
prairie flax	*Linum lewisii*
western wheatgrass	*Pascopyrum smithii*
small burnet	*Sanguisorba minor*

meter transect. This layout was chosen to mimic rangeland frequency monitoring protocols (see above). We collected data at peak production times, between June 20 and August 8 in 2010 and 2011. These sites have all been grazed by cattle in winter or early spring, but were not grazed during the treatment and sampling period (2009 to 2011).

Statistical analyses

All data were tested for normality and we limited our analyses to meaningful groups and species. All analyses were done in r (http://www.r-project.org). For historical data, differences were considered significant at p<0.10. For the more robust data collected from treated areas, differences were considered significant at p<0.05.

GJFO frequency data

Frequency (the number of times a plant was found/the total number of $0.36m^2$ ($2ft^2$) plots sampled) was calculated for each of the five identified GJFO sites. Frequencies for the most abundant species were compared to look for differences in those species over the sampling period (10 to 20 years). Initial analyses considered species that were relatively abundant and consistently sampled. Species in this analysis included: crested wheatgrass (*Agropyron cristatum*), big sagebrush (*Artemisia tridentata*), bottlebrush squirreltail (*Elymus elymoides*), broom snakeweed (*Gutierrezia sarothrae*), needle and thread (*Hesperostipa comata*), scarlet globemallow (*Sphaeralcea coccinea*), and sand dropseed (*Sporobolus cryptandrus).* Year was considered continuous since sites were sampled in different years and year was a proxy for time. We were most interested in finding an overall sustained change in a particular species. To determine the best fitting ANOVA model we performed AIC (Akaike Information Criterion) analysis of mixed models with random intercept, random intercept and slope, and a model with fixed variance (Zuur et al. 2009). AIC is a method of determining the 'goodness of fit' of a statistical model (e.g. Akaike 1974). We determined that the fixed variance model was the best fit (library nlme, gls in R). Therefore, we used a linear mixed effects model with fixed variance (library nlme, gls in R).

We also tested to see if certain species showed correlations with crested wheatgrass. Species analyzed included: *Artemisia tridentata*, *Elymus elymoides*, *Gutierrezia sarothrae*, *Hesperostipa comata*, *Sphlaeralcea coccicinea*, and *Sporobolus cryptandrus*. MANOVA analyses were performed first to provide evidence for an overall trend (protected ANOVA, Scheiner and Gurevitch 2001, MANOVA in R). In this model we first considered variation attributed to year, then site, then a site by year interaction, and finally frequency of crested wheatgrass. Response was frequency of plant species. All four MANOVA tests were significant for correlations with crested wheatgrass (p=0.08), so we performed ANOVA analyses for individual species using the same model (aov in R), with frequency of a specific plant species as the response variable.

GJFO and UFO data

UFO data were not available with a standardized plot size. Therefore data were converted to presence/absence data. We also converted GJFO data to allow for the most robust data set. We looked at persistence, or those plant species that remained in at least 70% of sites where they were initially found, of plant species that were found in at least 3 sites across both field offices. Specifically, we looked at what species were present at the first sampling date and also at the last sampling date. Species were considered 'persistent' if they were found in at least 70% of sites at both the first and last sampling date. The shortest time between first and last sampling dates was 3 years, the longest was 20 years, and the average time between first and last sampling date was 14 years. This provides a coarse look at how well plants are persisting in areas planted with crested wheatgrass.

Treatment areas

We analyzed cover estimates for the three treated sites for functional groups and species of interest including: ground space (which includes biological soil crusts and bare ground), litter, *Agropyron cristatum*, *Artemisia tridentata*, seeded species (including all species in the seed mix, Table 1, we did not try to distinguish between seeded plants and plants of the same species that did not come from our seeding effort), native grasses (excluding seeded species), native forbs (excluding seeded species), native shrubs (excluding *Artemisia tridentata*), and non-native species (excluding *Agropyron cristatum*), using linear models ('lm' in r).

The functional groups native shrubs, native grasses, and seeded species were log transformed to improve normality of data. Response variables were functional groups and species of interest, explanatory variables were site, treatment, and a site by treatment interaction. To help account for differences in vegetation cover from year to year, we used the untreated (control) site as our intercept.

Results

GJFO frequency monitoring

Crested wheatgrass (*Agropyron cristatum*) increased over time (p=0.09, average increase from 63 to 71 frequency) at the GJFO sites. No other species showed significant trends over time. However, we found 3 species that were correlated with the increasing crested wheatgrass. Scarlet globemallow (*Sphlaeralcea coccinea*) increased with increasing crested wheatgrass (p=0.001, Figure 2), while bottlebrush squirreltail (*Elymus elymoides*) and sand dropseed decreased with increasing crested wheatgrass (p<0.05, Figure 2).

GJFO and UFO frequency monitoring

We found three cool season (C3) grasses that persisted with crested wheatgrass; Indian rice grass (*Achnatherum hymenoides*), bottlebrush squirreltail (*Elymus elymoides*), and needle and thread (*Hesperostipa comata*). We found two warm season (C4) grasses that persisted with crested wheatgrass; blue grama (*Boutelua gracilis*) and sand dropseed (*Sporobolus cryptandrus*). Two shrubs, big sagebrush (*Artimesia tridentata*) and broom snakeweed (*Gutierrez sarothrae*) persisted well, while rabbitbrushes (*Chrysothmanus spp.* and *Ericameria spp.*) did not persist well. One forb, scarlet globemallow (*Sphlaeralcea coccinea*), was persistent (Table 2).

Treatment areas

We did not have significant differences in cover of ground space, litter, *Artemisia tridentata*, *Agropyron cristatum*, seeded species, native forbs, native shrubs, and nonnative species. However, cover of native grass significantly decreased at the treatment sites (decrease of 0.6 percent cover, p<0.05), compared to the control site where cover of native grass increased significantly (increase of 2.6 percent cover, p<0.05).

Discussion

Limitations of the study

The frequency data reviewed from the Grand Junction and Uncompahgre Field Offices were collected to determine grazing impacts on dominant vegetation and available forage. Given that, many forbs were likely not sampled or sampled inconsistently. Therefore, this data set cannot inform the long-term effects of crested wheatgrass plantings on most forbs. In addition, range monitoring began five to forty years from original plantings. Therefore, particularly poor competitors against crested wheatgrass may have been extirpated from the system before sampling began.

Our study addresses the longer term vegetation dynamics in areas planted with crested wheatgrass through the use of historical monitoring data, and the reaction of the vegetative components in crested wheatgrass dominated sites to mechanical harrow treatments and seeding with native and desirable species. While there has been research on the establishment of native species with crested wheatgrass (e.g. Gunnell et al. 2010; Cox and Anderson 2004; Wilson and Partel 2003), studies on the long term persistence of these species are lacking.

Frequency sampling over time showed that crested wheatgrass increased in frequency. Crested wheatgrass can be a prolific seed producer, may produce more seeds than some native plants (Hedinga and Wilson 2002), and can compete with seedlings of some native plants (Gunnell et al. 2010). Seeds of crested wheatgrass may also have higher viability due to fewer natural diseases, parasites, and other stressors (enemy release theory, e.g. Keane and Crawley 2002; Lui and Stiling 2006). However, some native species did persist in these areas. *Artimesia tridentata* was abundant and persistent in the sites we sampled. However, it is unclear if this sagebrush was present before crested wheatgrass was introduced and is persistent, or was able to establish after crested wheatgrass had become established. Other studies have shown that shrubs, such as sagebrush, may be capable of establishing and persisting with recently planted crested wheatgrass (Frischknecht and Bleak 1957). However, crested wheatgrass interferes with the establishment of some shrub seedlings, for example rabbitbrush did not persist

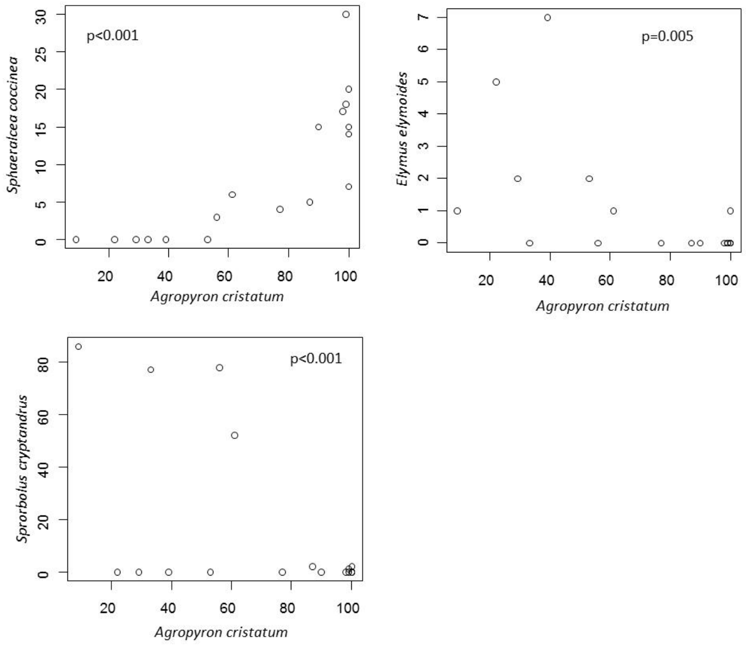

Figure 2. Corrleations between *Agropyron cristatum, Sphlaralcea coccinea, Elymus elymoides*, and *Sporobolus crytandcus*. Frequencies from all sampling dates in 5 sampling areas within the Grand Junction Field office are shown.

Table 2. List of species and persistence values. Persistence refers to those plant species that remained in at least 70% of sites where they were initially found. Data are from presence/ absence data collected from a total of 11 sites (5 within the Grand Junction Field Office and 6 within the Uncompahgre Field Office). Average time between sampling is 14years. Abbreviations are as follows: AGCR – *Agropyron cristatum*, ACHY – *Achnetherum hymendoides*, ELELE – *Elymus elymoides*, HECO26 – *Hesperostipa comata*, SPCR – *Sporobolus cryptandrus*, BOGR – *Bouteloua gracilis*, PASM – *Pascopyrum smithii*, ARTR2 – *Artemisa tridentata*, GUSA2 – *Gutierezia sarothrae*, CHRYS/ERNA – *Chrysothamus spp., Ericameria spp*., JUNIP – *Juniperus spp*., SPCO – *Sphlaralcea coccinea.*

# of sites where present	AGCR	ACHY	ELELE	HECO 26	SPCR	BOGR	PASM	ARTR2	GUSA2	CHRYS / ERNA	JUNIP	SPCO
At 1ast sampling	11	7	5	4	3	3	3	9	7	4	5	6
At last sampling	10	6	4	3	3	3	1	9	7	0	3	6
% of total sites	100	64	45	36	27	27	27	82	64	36	45	55
Persistence	91	86	80	75	100	100	33	100	100	0	60	100

well in our study, and crested wheatgrass does interfere with seedling growth of rabbitbrush (Gunnell et al. 2010).

We found both warm season grasses (*Bouteloua gracilis* and *Sporobolus cryptandra*) and cool season grasses (*Achnatherum hymenoides*, *Elymus elymoides*, *Hesperostipa comata*) that persisted in areas planted with crested wheatgrass. However, even the best native competitors may be outcompeted by crested wheatgrass over time. Two grass species (*Elymus elymoides* and *Sporobolus cryptandra*) that showed persistence also showed decreasing trends when more detailed data were taken during the GJFO frequency monitoring data. This leads to the question if these species will continue to persist, perhaps at low levels, in areas planted with crested wheatgrass, or if more detailed sampling over time would show slow decreases to extirpation. We know of no studies that show extirpation of these species, but other studies have found that *Elymus* spp. (squirreltail) and *Bouteloua gracilis* may be good competitors with crested wheatgrass (Bakker and Wilson 2004; Hedinga and Wilson 2002; Gunnell et al. 2010).

The specific characteristics of plant species can provide clues to how species interact (Pyke and Archer 1991) and how some native plants can co-exist better with crested wheatgrass. Competition between crested wheatgrass and native species will not be equal for all species (Gunnell et al. 2010). Two species that fare well with crested wheatgrass (*Gutierrezia sarothrae* and *Sphaeralcea coccinea*) are generally thought to do well in areas of disturbance. *Gutierrezia sarothrae* has wind-dispersed seed and germination is best in full sun, this is likely an early successional species that declines as more competitive species become established (USDA - NRCS 2011). *Sphaeralcea coccinea* does not tolerate shade and also prefers sun (USDA-NRCS 2011). The relative success of these two species in areas planted with crested wheatgrass may be a function of increased bare ground in areas planted with crested wheatgrass, which has been found in other studies (Sutter and Brigham 1998).

While other studies found that mechanical treatments reduced the cover of crested wheatgrass (Hulet et al. 2010), our treatments were likely not aggressive enough to consistently reduce crested wheatgrass over the three sites studied. While establishment of native species can be dependent on both year and site (Bakker et al. 2003), we found that native grasses consistently decreased after mechanical treatment. The shift of native vegetative communities to communities dominated by crested wheatgrass may represent a shift to a new stable state that is resilient to mechanical treatment. Further, mechanical treatments may have more adverse effects on the remaining native components of the systems we are trying to improve than on the dominant crested wheatgrass.

Conclusions and management implications

By considering historic monitoring data, we were able to show longer-term (>20years) increasing and decreasing trends in vegetation in areas planted with crested wheatgrass. However, a better understanding of the external factors (e.g. grazing, fire, abiotic factors) influencing the persistence or reduction of native plant species, as well as the specific traits that make a native plant species a good competitor with crested wheatgrass are needed. We have identified some native species that compete well with crested wheatgrass; however, further research about the long term persistence, versus early establishment, of native species in the presence of crested-wheatgrass is needed. Additionally, research on how both domestic and wildlife grazing contributes toward the persistence of plant species other than crested wheatgrass, particularly species associated with disturbance, is desirable. In general, future research should address appropriate ways to reduce cover of crested wheatgrass in areas currently dominated by this species, while preserving and/or reviving remnant native plant communities.

Given the long term persistence/dominance of crested wheatgrass on these types of sites, managers should weight the long term costs of reduced vegetative diversity, and the likely reduction of desirable native species versus the benefits of reliable establishment and competition against undesirable annuals that crested wheatgrass provides, before including this species in seed mixes. Managers should also be careful about mechanically treating older crested wheatgrass seedings as there may be a risk of increasing the dominance of crested wheatgrass while reducing native grass species, and therefore vegetation diversity.

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