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Enduring a decade of drought: Patterns and drivers of vegetation change in a semi-arid grassland

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ABSTRACT

This study evaluated patterns and drivers of vegetation change in a semi-arid grassland in southern Arizona across eleven years of extended drought and high temperatures, 2004–2014. Changes included declines in C4 perennial grass basal cover with patchy grass mortality, leaf litter increases, shrub declines, and increases in non-native grass *Eragrostis lehmanniana*. Linear mixed-effects models identified precipitation during January–June "extended spring" as the best predictor of grass basal cover, especially when plots were grouped by soil and topographic features. Models showed that a decrease in extended spring precipitation from 150 to 50 mm was associated with loss of one-quarter to one-half of plots' total grass cover. Association of grass declines with this novel season of drought is especially relevant because global circulation models predict steep declines in spring rainfall. Increasing *E. lehmanniana* dominance was also associated with native grass declines. There was little support over this time for predicted effects of livestock grazing or shrub encroachment. This study demonstrated how monitoring data from working landscapes can improve ecological understanding of drought. Findings also suggest managers could improve chances for sustaining resilience by responding to rainfall in multiple seasons, monitoring for mortality events, and establishing contingency plans for various types of drought.

1. Introduction

Grasslands cover some 40% of global lands that are not under ice, with a third of these occurring in semi-arid climates (White et al., 2000). These lands are changing quickly, with the pace and extent of vegetation shifts and land conversion exceeding many other major biomes (MEA, 2005; White et al., 2000). Across the world, grassland vegetation changes are ascribed to a handful of major driving forces: drought, shrub encroachment, grazing by livestock and/or wildlife, fire, invasion of non-native species, and human interventions such as land conversion or brush removal (White et al., 2000); many of these forces have a climate change component.

Of these drivers, drought and associated climate changes have gained urgency as people in many drought-stricken parts of the world try to understand how recent extreme dry and hot conditions will affect their ability to sustainably manage grasslands now and into the future. Drought, and research into drought impacts, has long been a major focus of range science as land managers, livestock producers, and others strive to sustain various ecosystem services through inherently variable climate conditions. Recognized effects of rangeland drought include lost productivity and cover (McClaran et al., 2003; MEA, 2005; Moran et al., 2014; Robinett, 1992; Ruppert et al., 2015), mortality of perennial grasses (Godfree et al., 2011; Hamerlynck et al., 2013; Svejcar et al., 2014), shifts in species and/or functional groups (McClaran et al., 2003; Moran et al., 2014), altered gas and nutrient exchange (Hamerlynck et al., 2013; Scott et al., 2015), soil erosion (Polyakov et al., 2010), and a wide range of economic and social impacts (MEA, 2005). Studies on drought impacts in grasslands have found grass mortality and/or declines in cover associated with rainfall deficits at seasonal, annual, and multi-year scales, with no consensus on the time frame of associated with primary effects (e.g. Cable, 1975; Crimmins and Crimmins, 2003; Fuhlendorf et al., 2001; Gremer et al., 2015). Additionally, the duration, magnitude and spacing of precipitation events, soil moisture, and temperatures has been shown to influence drought responses (e.g. Godfree et al., 2011; Gremer et al., 2015; Hamerlynck et al., 2013). Effects of drought can also be strongly mediated by site conditions like soil characteristics, topographic setting, grazing use, mulch, vegetation cover and composition (e.g. Chamrad and Box, 1965; Duniway et al., 2010; Godfree et al., 2011; Robinett, 1992; Ruppert et al., 2015).

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Climate change research indicates that drought effects and associated plant mortality may intensify in the future due to warmer temperatures and potential declines in seasonal rainfall. Higher temperatures have been associated with enhanced drought mortality in woodlands in the American Southwest (Breshears et al., 2005), but such effects have not yet been widely demonstrated in rangelands or even evaluated in these systems (Svejcar et al., 2014). Additionally, most global circulation models (GCMs) predict an approximately 20% decline in spring precipitation in the American Southwest by the end of the century, whereas changes in other seasons are more uncertain (Garfin et al., 2013, chapter 6). Most GCMs also describe intensifying rainfall extremes, with both more frequent drought and flooding events (Garfin et al., 2013, chapter 7).

Improving our ability to sustain grassland services through a variable and shifting climate will require refining our understanding of how grasslands respond to and recover from drought, and how other site conditions and management actions mediate drought effects. Research conducted in working landscapes, where grasslands are managed to provide cattle forage or other human benefits, can add both breadth and realism to our understanding of drought. Studies in these landscapes are important additions to traditional research sites because they encompass a broader set of ecological conditions and land use contexts, and because they represent an underutilized set of data on grassland dynamics. Such research can also be directly applied to figuring out how to minimize impacts of drought and enhance recovery after drought – i.e., how to manage for resilience. Considered broadly, resilience can be described as the ability to absorb disturbance without losing ecosystem function and structure, e.g. vegetation cover and species composition (Elmqvist et al., 2003; Folke et al., 2004).

In this study, we document patterns and drivers of vegetation change from 2004 to 2014 across a multi-year drought at Las Ciénegas National Conservation Area (LCNCA), a working landscape in southeastern Arizona administered by the Bureau of Land Management. This site is representative of a region of semi-arid grasslands in the Southwestern United States and Northern Mexico which is known for its globally high conservation value (McClaran and Van Devender, 1995), while having higher grass cover than many with other sites in the region. Although vegetation data from this site is relatively rich compared with most working landscapes (more plots, more cover points per plot, and more consecutive years), it reflects the kind of data that is widely collected to inform site-specific management decisions, yet rarely gets compiled across years and analyzed to distil ecological insights.

This study had several objectives. First, we described the climate context of our study site by comparing conditions and trends during the study period to long term patterns in total precipitation and mean daily temperature across multiple seasons (winter, summer, monsoon, extended spring, and entire year). Second, we evaluated trends through time in vegetation cover (perennial grass basal cover, bare ground, leaf litter, dominance of exotic grass, and shrub cover). Third, we evaluated how various driving factors might explain the variation we found in perennial grass cover. We focused on perennial grass basal cover as a response variable because it is less temporally variable than many other grass measures and has well documented relationships with key grassland ecosystem processes including soil erosion and biotic integrity (Nafus et al., 2009; Pellant et al., 2005). We based our choice of explanatory variables on available data and on previously published research, using general predictions about potential relationships between perennial grass cover and three types of drivers: climate; local soil and topographic conditions; and vegetation and grazing feedbacks. Lastly, we interpreted these changes in terms of resilience concepts and made recommendations for future actions to sustain that resilience.

2. Methods

2.1. Site description

LCNCA encompasses a grassland valley and stream system in southeastern Arizona and is public land under the jurisdiction of the Bureau of Land Management (BLM; Fig. 1). The climate is semi-arid with a bimodal distribution of precipitation. Mean annual precipitation is 405 mm (PRISM data, Fig. 2), with 57% falling in monsoon season (July–September) and most of the rest falling between December and March. Average annual temperature is 15.7 °C, with winter mean daily temperatures (October–March) averaging 10.4 °C and ranging from −5.3 to 29.9° C. Summer temperatures (April–September) average 21.1 °C and range from 1.9 to 35.8° C. Seasonal climate cycles are similar to those described for the nearby Santa Rita Experimental Range (Gremer et al., 2015, Fig. 2a). Soils are alluvial and hillside formations derived from mixed sedimentary and volcanic parent materials; textures range from gravely to sandy loam to clay loam. Grasslands at this site range in elevation from 1300 to 1500 m, and support over 40 species of native perennial grass.

Valley and foothill grasslands in this area are within the semi-desert grassland community type, further differentiated as Major Land Resource Area 41 (Fig. 1) by the Natural Resources Conservation Service (NRCS; Hernandez et al., 2013; MacEwen et al., 2005). They transition into a mix of Sonoran and Chihuahuan Desert communities at lower elevations, and into montane scrub and woodland communities at upper elevations. These grasslands support high species diversity due to their biogeographic setting, heterogeneous soil types and topography, and highly variable rainfall (McClaran and Van Devender, 1995). In addition to a large suite of native annual plants, perennial herbs and shrubs, grasslands in this region are composed of a diverse mix of native C4 perennial grasses that include species from the Great Plains (e.g. blue grama) as well as species typical of Chihuahuan Desert Grasslands (e.g. black grama) and several species endemic to this smaller region (e.g. Santa Rita grama) and locally adapted varieties of wide ranging species (e.g. sideoats grama). An exotic perennial grass *Eragrostis lehmanniana* (Lehmann lovegrass) was brought to the region for erosion control and forage in the 1930's, spread beyond its planting locations, and continues to expand in both extent and dominance across the region (McClaran et al., 2003; Schussman et al., 2006). Most of the region's grasslands have also supported domestic livestock grazing for the last 130–300 years.

LCNCA is managed as a working landscape to sustain biodiversity, livestock grazing, watershed function, and other ecosystem services. Managers and partners have attempted to improve resource outcomes by applying adaptive management principles, setting measurable resource condition objectives for the site's grasslands and comparing annual monitoring results with these objectives when making livestock management and restoration decisions (Gori et al., 2010; Caves et al., 2013). Condition objectives for grassland habitats include numerical targets for maximum bare ground (as an indicator of erosion risk and site integrity) and minimum basal cover of perennial grasses (live rooted area of grass plants as an indicator of biotic integrity, forage potential, wildlife hiding cover, soil erosion, etc.; Hernandez et al., 2013, Pellant et al., 2005). These objectives were initially set at <30% and >10% respectively (Gori et al., 2010), but later tailored to better match the needs and potentials of each Ecological Site (<20-<30% for bare ground and >5–10% grass basal cover). Ecological Sites are descriptive units characterized by distinct combinations of climate,