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Prescribed burning to affect a state transition in a shrub-encroached desert grassland

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ABSTRACT

Prescribed burning is a commonly advocated and historical practice for control of woody species encroachment into grasslands on all continents. However, desert grasslands of the southwestern United States often lack needed herbaceous fuel loads for effective prescriptions, dominant perennial graminoids may have poor fire tolerance, and some systems contain fire-tolerant invasive species. We examined long-term vegetation responses of a black grama (*Bouteloua eriopoda* Torr.) grassland that had been invaded by honey mesquite (*Prosopis glandulosa*) following a single prescribed burn. Vegetation responses to a 1995 prescribed burn were evaluated in a replicated randomized complete block design with a 2×2 factorial treatment structure. Treatments were prescribed burning and livestock exclusion for both a grassland-dominated and a shrub-encroached grassland state within a complex of sandy and shallow sandy ecological sites. Vegetation responses were measured in 2008, 13 years after the burn treatment application. Neither black grama basal cover nor honey mesquite canopy cover were responsive ($p < 0.05$) to any treatment. A single prescribed burn would be ineffective as a shrub control practice in this environment. Repeated but infrequent prescribed burning within shrub-encroached vegetative states, when used in combination with managed grazing, may be the management required for a transition to desert grassland states within these ecological sites.

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1. Introduction

Prescribed burning is a commonly advocated and historical practice for control of woody species encroachment into grasslands on all continents. However, arid grassland systems often lack needed herbaceous fuel loads for effective prescriptions, especially grasslands utilized for grazing by livestock (Humphrey, 1974). In deserts of the southwestern United States there are further perceived limitations due to either poor tolerance of dominant perennial graminoids to fire, or the presence of invasive species, including introduced graminoids, that exploit disturbed environments (Drewa and Havstad, 2001). As a result, prescribed burning is seldom employed as a restoration management tool in these arid grasslands.

Yet, fire has been a frequent disturbance over the millennia throughout the southwestern US, including within grassland-dominated systems (Humphrey, 1974). Typically, the fire history of this region has displayed 3 characteristic patterns: (1) the classic pattern of a dry year with fire preceded by 1 or more wet years where these fires were of small spatial extent with short return intervals (<10 years), (2) large landscape scale to regional scale fires in dry years but preceded by long intervals (decades) of fire suppression and/or absence, and (3) fires that were unconnected to climatic patterns (i.e., precipitation) indicating human ignition and set for various purposes over the centuries of human habitation (Baisan and Swetnam, 1997). Though there have been claims that this arid region does not have an important fire history (Hastings and Turner, 1965), the ecological dynamics of desert systems have commonly been interpreted as fire dependent (Wooton, 1916; Humphrey, 1958; McPherson, 1995). It is argued that without fire these desert grasslands cannot be sustained (Van Auken, 2009).

For arid grasslands dominated by the old world grass, black grama (*Bouteloua eriopioda* Torr.), interpretations of the historic role of fire in this system have been variable (Drewa et al., 2001). Recovery times for black grama following fire are notoriously lengthy, often in excess of a decade post-fire event (Parmenter, 2008). There have been few long-term studies of fire as these grasslands lack fine fuels due to low annual net productivity (Sims and Singh, 1978) and a history of heavy grazing by domestic animals since the end of the 16th Century (Havstad et al., 2006).

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Black grama dominated grasslands are most noted for undergoing extensive degradation due to a combination of disturbances, primarily overgrazing by livestock during acute periods of drought from the late 19th through the mid 20th centuries (Buffington and Herbel, 1965; Gibbens et al., 2005). Consequences of degradation have been vast expansions of areas dominated by woody shrubs. The primary genus is mesquite (*Prosopis*), either velvet mesquite (*Prosopis velutina*) in the Sonoran Desert (McClaran, 2003) or honey mesquite (*Prosopis glandulosa*) in the Chihuahuan Desert (Peters and Gibbens, 2006). Vegetation dynamics have been captured in recently developed state-and-transition (S&T) models of characteristic ecological sites of southwestern desert grasslands (Bestelmeyer et al., 2003; Bestelmeyer et al., 2009). A typical S&T model for a classic upland grassland site that reflects these dynamics is presented in Fig. 1. State transitions from grass dominated to shrub dominated communities represented in Fig. 1 by 3a, 4a, and 5a have proven difficult to reverse without substantial inputs. Typical control methods utilize herbicides to control woody species, even though the economic returns (associated with increased forage production) generated from herbicide use are unfavorable (Herbel and Gould, 1995). Once established, shrub dominated states persist (Schlesinger et al., 1990) even with light grazing pressure by livestock and periods of complete non use (Havstad et al., 2006). A few studies have examined vegetation responses of black grama dominated grasslands to prescribed burning (Gosz and Gosz, 1996; Drewa et al., 2006; Parmenter, 2008), but have not been specifically designed to evaluate state transitions in response to burning. These S&T models provide an opportunity to evaluate the use of prescribed burning within specific vegetative states. The purpose of this study was to evaluate the long-term effect of the use of a prescribed burn to transition from a shrub-invaded grassland state to a black grama dominated state (transition 3b in Fig. 1).

2. Methods

2.1. Study area

The study was located on the Jornada Experimental Range (JER) in Dona Ana County, New Mexico (32 37 N, 106 40 W; 1260 m a.s.l.). The study was conducted on sandy (ref # R042XB012NM) and shallow sandy (ref # R042XB015NM) ecological sites within the southern desertic basins, plains, and mountains Major Land Resource Area (MLRA) as delineated by the US Department of Agriculture's Natural Resource Conservation Service (http://soils.usda.gov/survey/geography/mlra/). Parent materials in the area are mixed coarse-loamy alluvium of the ancestral Rio Grande. The

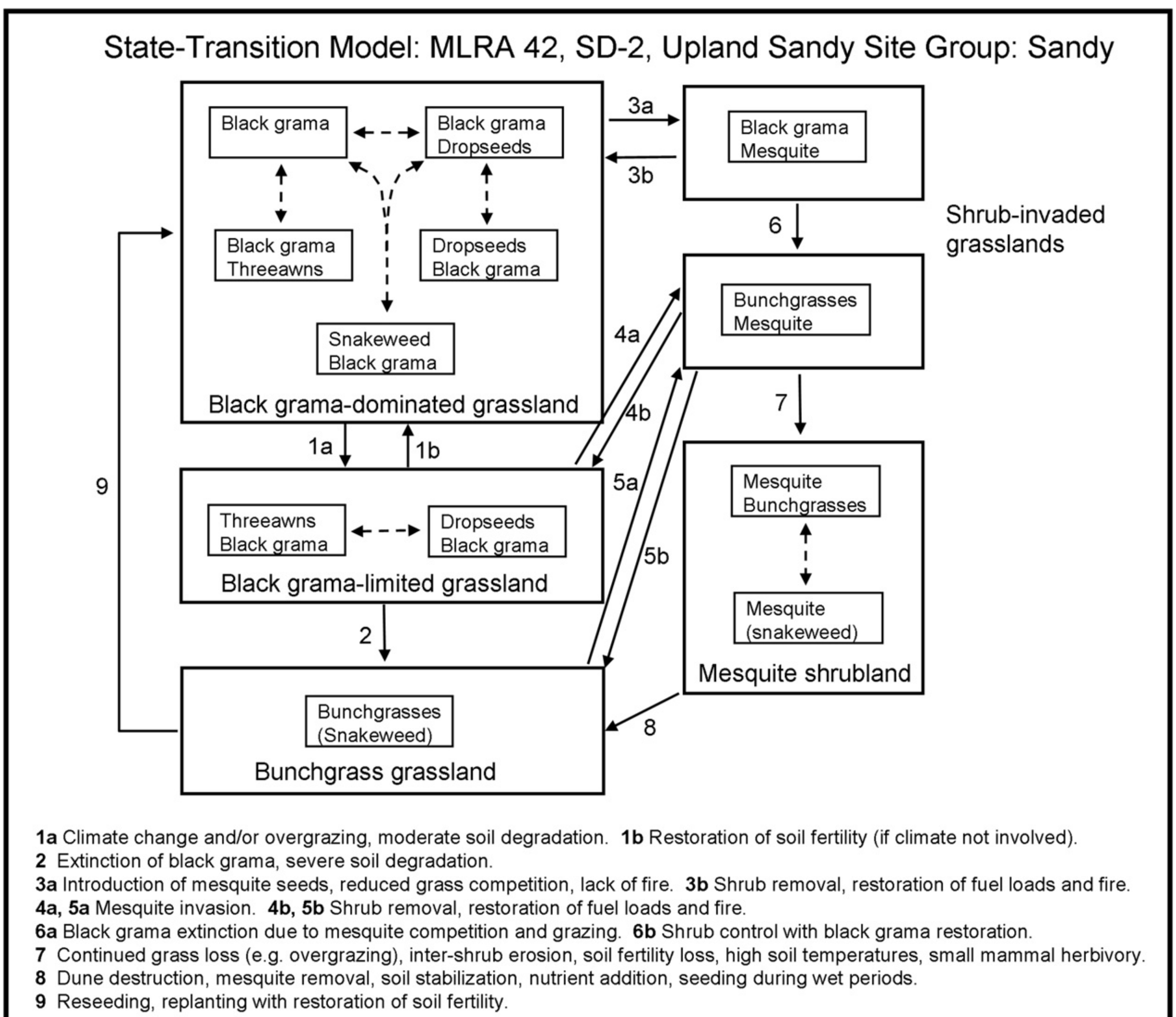

Fig. 1. State-and-transition model for the sandy ecological site (reference # R042XB012NM) of the southern desertic basins, plains, and mountains major land resource area 42 (from: http://esis.sc.egov.usda.gov/esis_report/fsReport.aspx?id=R042XB012NM&rptLevel=all&approved=no).

typical soil profile is sandy loam or fine sandy loam to 1.5 m over an indurated calcium carbonate layer, though the depth to this layer can be highly variable, causing abrupt transitions from sandy to shallow sandy ecological sites. These types of soils are common to the region, and these resulting ecological sites are predominant within these southwestern US desert rangelands. The long-term average (1915–2008) annual precipitation within the study area is 245 mm of which nearly 56% occurs as convective thunderstorms during a 90 day period from early July through September.

2.2. Experimental design and measurements

Disturbance effects were examined using a randomized complete block experimental design with subsampling. Eight 8 m × 12 m plots were established in each of 2 replicated blocks approximately 2 km apart. Four plots in each block were within a desert grassland dominated by black grama (percent canopy cover = 41.0; s.e. = 3.0) and devoid of any mesquite. The other four plots in each block contained black grama (percent canopy cover = 28.1; s.e. = 3.2) and mesquite (percent canopy cover = 4.6; s.e. = 0.9) characteristic of a shrub-invaded grassland state for a sandy or shallow sandy ecological site within this MLRA (see Fig. 1). Individual plots within each block and vegetation state were randomly assigned to one of 4 treatment combinations: burned and excluded from livestock grazing, burned and open to livestock grazing, unburned and excluded from livestock grazing, and unburned and open to livestock grazing. Livestock grazing prior to and during the study period was confined to dormant season use. Low stocking rates (>2.4 ha/animal unit month) typical of the well-established science-based recommendations (<35% use of annual production) appropriate for these upland desert grasslands were employed (Paulsen and Ares, 1962).

Data on vegetation cover, both canopy and basal, by species, were collected prior to treatment applications in June, 1995, on all plots using a vertical line point intercept methodology. Five 8 m transects were randomly located across each plot, with each transect separated from an adjacent transect by a minimum of 1 m. Vertical line point intercept data were collected for vegetation by species, presence of surface litter, and occurrence of bare ground at 10 cm intervals for a total of 400 vertical line point measurements per 96 m^2 plot area, a density of ~4.2 points per m^2. Vegetation measurements were repeated on all plots using the same methodology, including new randomly located transects, in early November, 2008. Both percentages of basal cover and vegetative composition for black grama and honey mesquite differed ($p < 0.05$) between the 2 states prior to treatment applications in 1995.

All 8 burned treatment plots across the 2 blocks were ignited using a propane torch the morning of June 23, 1995. All above ground live and dead plant material was burned within each plot, and the burning of each plot required less than 10 min. During the burn, air temperatures were 25–35 °C, relative humidity was 8–12%, and wind speed was <3.3 m/s. Standing biomass in May, 1995, at a similar site within 2 km of this study area was estimated at 161.6 g/m^2 (Huenneke et al., 2001).

Plots selected for livestock grazing exclusion were fenced in August, 1995, and exclusion fencing remained intact throughout the post-burning period. These wire paneled fences also likely limited lagomorph use but not the presence of small mammal herbivores or herbivorous insects (e.g., grasshoppers).

2.3. Statistical analyses

Basal and canopy cover were calculated for both individual species and functional groups and analyzed in a complete block design. Prescribed burning, livestock exclusion, and state were modeled as fixed factors. *F*-tests in the analysis of variance and means for treatment effects and interactions were calculated using PROC MIXED in SAS V9.3 (SAS Institute, Cary NC). For species present in both samplings, differences in cover were computed and analyzed in the same way. Analyses of pretreatment data indicated there were no differences within states among species cover for any treatment plots.

3. Results

3.1. Vegetation cover

Responses 13 years after the prescribed burn treatment in percentages of cover by vegetative classes and by species within the shrub-encroached state are presented in Table 1 and Fig. 2. There were no vegetative cover treatment differences ($p < 0.05$) among vegetative classes (Table 1) in response to either an acute disturbance, prescribed burning, or a low level chronic disturbance, managed livestock grazing, 13 years after treatments were originally established. Black grama basal cover did not respond ($p < 0.05$) to either treatment within a vegetative state, and averaged 2.7% across all treatments and states. Other major vegetative components within these 2 states were essentially unresponsive to either treatment.

Encroachment of mesquite into the grassland state during these 13 years was negligible. Temporal changes in canopy cover of mesquite were unaffected ($p < 0.05$) by treatment (Fig. 2). Vegetative cover within these states for these upland, sandy soil textured ecological sites was relatively stable over this period (Table 1 and Fig. 2). Annual precipitation at the study site from 1994 through 2008 reflected the characteristic, highly variable interannual pattern common to this region, and included years of drought as well as years of rainfall well in excess of the 245 mm long-term average.

4. Discussion

Some prior studies have been interpreted to support the contention that these specific or similar arid, upland, sandy-

Table 1
Percent cover by vegetation class for grazing and prescribed burn treatment combinations for grassland and shrub-invaded grassland states 13 years after initial treatments. For each value, $n = 2$.

Pre-treatment vegetative state	Post-treatment vegetative cover (%)					
	Perennial graminoids	Annual graminoids	Perennial forbs	Annual forbs	Shrubs	Bare ground
	Basal		Canopy			
Black grama dominated grassland						
Burned/livestock excluded	4.63	0.25	2.38	0.75	0.88	41.1
Unburned/ livestock excluded	4.88	0.63	0.75	2.00	0.13	22.4
Burned/livestock unexcluded	2.63	0.13	2.25	3.25	1.25	46.8
Unburned/ livestock unexcluded	2.75	0.63	0.50	3.63	0.00	38.6
Mesquite invaded grassland						
Burned/livestock excluded	2.25	0.50	1.50	4.88	4.38	38.6
Unburned/ livestock excluded	1.88	0.25	1.75	3.50	4.38	33.6
Burned/livestock unexcluded	2.00	0.50	2.38	2.25	2.25	48.4
Unburned/ livestock unexcluded	2.38	0.38	1.88	4.75	6.50	41.5

Means within a state and treatment do not differ ($p < 0.05$).

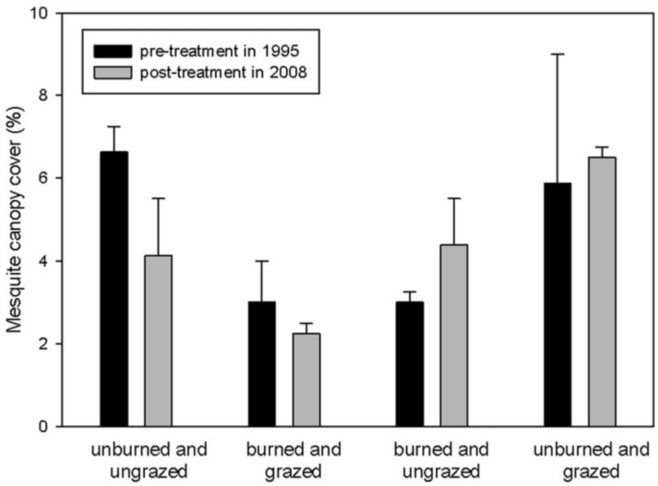

Fig. 2. Changes in mesquite canopy cover (%) of treatment plots within the shrub-encroached grassland state from immediately prior to treatment in 1995 to post-treatment measurements in 2008. Standard errors of means pre- and post-treatment are illustrated.

textured ecological sites across the southwestern US, in either a perennial grass dominated state or a shrub-encroached grassland state, are not fire dependant. There are two different lines of reasoning employed in this argument. The first rationale is that perennial grasses, especially black grama, common to these arid grassland systems are negatively affected to some degree immediately following fire (Drewa and Havstad, 2001; McGlone and Huenneke, 2004; Killgore et al., 2009). One long-term study demonstrated that black grama required 11 years to fully recover to preburn conditions following a single fire (Parmenter, 2008). The second rationale is that a single fire event does not result in significant mesquite mortality (Ansley et al., 2008). Though fire does reduce vegetative canopy cover and retard seed development, complete mortality of mesquite is rare following fire (Drewa et al., 2001). Differential responses to season of fire have also been reported with increased resprouting of mesquite in response to dormant season burns compared to growing season prescribed fires (Drewa, 2003). Our results would support an argument that a single fire would not affect a state transition from a shrub-encroached vegetation state to a grassland state for these sandy ecological sites.

A recent study has shown positive ecophysiological responses of perennial grasses, including black grama, to fire including increased rates of net photosynthesis, stomatal conductance, and nitrogen supply to leaves in burned plants compared to unburned controls (Allred and Snyder, 2008). In addition, post-fire precipitation likely shortens perennial grass recovery periods (Drewa and Havstad, 2001), and perennial grasses eventually recover to prefire conditions (Parmenter, 2008). Long-term studies have demonstrated that mesquite removal within arid sites where mesquite canopy cover is $<$20% does not result in increased grass cover or production in the decades following removal (McClaran and Angell, 2006). Yet, shrub cover increases over time are well documented within this region (Gibbens et al., 2005), including in response to fire suppression (Huebner et al., 1999). Thus, in the long term, an absence of intervention techniques would likely result in continued loss of desert grassland states for some ecological sites. Recently, Ravi and D'Odorico (2009) reported that vegetative states in early stages of shrub encroachment are not susceptible to shrub control by fire or low grazing rates alone. Our results support this observation.

A secondary result of this study was the simple observation that both the untreated grassland and shrub-encroached vegetative states were relatively stable from 1995 to 2008, and that for these untreated states neither transitions 3a nor 3b as illustrated in Fig. 1 occurred despite years of drought or excess precipitation from 1995 to 2008.

Continued encroachment of shrubs into upland desert grasslands within this region is well documented, but transitions are often relatively sudden and triggered by acute and severe disturbances, such as the widespread, extremely severe drought from 1951 to 1956 (Yao et al., 2006). In the absence of a severe disturbance, these states appear to be relatively resilient.

An additional value of this study was the evaluation of treatments within the context of a state-and-transition model applicable to these 2 ecological sites. Further research to identify novel treatments and their combinations to trigger other state transitions depicted in Fig. 1 (such as 4b, 5b, and 8) would likely benefit from experimental designs incorporating treatments specifically evaluated with vegetative state as a source of variation. In addition, ex post facto interpretation of past research results may be possible within the context of state-and-transition models if states can be identified within these prior experiments.

Our results showed simply that a single prescribed burn is insufficient to transition a shrub-encroached grassland state to low shrub cover within a grassland state on these ecological sites. If prescribed burning can be a management tool in this system, its use would need to be repeated infrequently and restricted to grasslands in early transition to a shrub-encroached state. Other transitions or states as illustrated in Fig. 1 would be either unsuited to fire due to insufficient fuel and ground cover, or unsuited to appropriate managed livestock grazing due to low availability of forages. There would be no purpose served for burning intact grasslands given the lack of an overall positive response of perennial grassland states, especially those dominated by black grama, to fire.

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References

Allred, B.W., Snyder, K.A., 2008. Ecophysiological responses of Chihuahuan Desert grasses to fire. Journal of Arid Environments 72, 1989–1996.

Ansley, R.J., Pinchak, W.E., Jones, D.L., 2008. Mesquite, tobosagrass, and common broomweed responses to fire season and intensity. Rangeland Ecology and Management 61, 588–597.

Baisan, C.H., Swetnam, T.W., 1997. Interactions of Fire Regimes and Land Use in the Central Rio Grande Valley. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. Research Paper RM-RP-330.

Bestelmeyer, B.T., Brown, J.R., Havstad, K.M., Alexander, R., Chavez, G., Herrick, J.E., 2003. Development and use of state-and-transition models for rangelands. Journal of Range Management 56, 114–126.

Bestelmeyer, B.T., Tugel, A.J., Peacock Jr., G.L., Robinett, D.G., Shaver, P.L., Brown, J.R., Herrick, J.E., Sanchez, H., Havstad, K.M., 2009. State-and-transition models for heterogeneous landscapes: a strategy for development and application. Rangeland Ecology and Management 62, 1–15.

Buffington, L.C., Herbel, C.H., 1965. Vegetation changes on a semidesert grassland range from 1858 to 1963. Ecological Monographs 35, 139–164.

Drewa, P.W., 2003. Effects of fire season and intensity on *Prosopis glandulosa* Torr. var. *glandulosa*. International Journal of Wildland Fire 12, 147–157.

Drewa, P.B., Peters, D.P.C., Havstad, K.M., 2001. Fire, grazing, and shrub invasion in the Chihuahuan Desert. In: Wilson, T.P., Galley, K.E.M. (Eds.), Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species. The National Conference on Fire Ecology, Prevention, and

Management, Miscellaneous Publication No. 11. Tall Timbers Research Station, Tallahassee, FL, pp. 31–39.
Drewa, P.W., Havstad, K.M., 2001. Effects of fire, grazing, and the presence of shrubs on Chihuahuan Desert grasslands. Journal of Arid Environments 48, 429–443.
Drewa, P.B., Peters, D.P.C., Havstad, K.M., 2006. Population and clonal level responses of a perennial grass following fire in the northern Chihuahuan Desert. Oecologia 150, 29–39.
Gibbens, R.P., McNeely, R.P., Havstad, K.M., Beck, R.F., Nolen, B., 2005. Vegetation changes in the Jornada Basin from 1858 to 1998. Journal of Arid Environments 61, 651–668.
Gosz, R.J., Gosz, J.R., 1996. Species interactions on the biome transition zone in New Mexico: response of blue grama (*Bouteloua gracilis*) and black grama (*Bouteloua eriopoda*) to fire and herbivory. Journal of Arid Environments 34, 101–114.
Hastings, J.R., Turner, R.M., 1965. The Changing Mile: an Ecological Study of Vegetation Change with Time in the Lower Mile of an Arid and Semiarid Region. University of Arizona Press, Tucson, AZ.
Havstad, K.M., Fredrickson, E.L., Huenneke, L.F., 2006. Grazing livestock management in an arid ecosystem. In: Havstad, K.M., Huenneke, L.F., Schlesinger, W.H. (Eds.), Structure and Function of a Chihuahuan Desert Ecosystem: the Jornada Basin Long-Term Ecological Research Site. Oxford University Press, New York, NY, pp. 266–277.
Herbel, C.H., Gould, W.L., 1995. Management of Mesquite, Creosote Bush and Tarbush with Herbicides in the Northern Chihuahuan Desert. New Mexico Agricultural Experiment Station Bulletin No. 775, Las Cruces, NM.
Huebner, C.D., Vankat, J.L., Renwick, W.H., 1999. Change in the vegetation mosaic of central Arizona USA between 1940 and 1989. Plant Ecology 144, 83–91.
Huenneke, L.F., Clason, D., Muldavin, E., 2001. Spatial heterogeneity in Chihuahuan Desert vegetation: implications for sampling methods in semiarid ecosystems. Journal of Arid Environments 47, 257–270.
Humphrey, R.R., 1958. The desert grassland: a history of vegetational change and an analysis of causes. Botanical Review 24, 1–41.
Humphrey, R.R., 1974. Fire in the deserts and desert grassland of North America. In: Kozlowski, T.T., Ahlgren, C.E. (Eds.), Fire and Ecosystems, Physiological Ecology, pp. 366–387.
Killgore, A., Jackson, E., Whitford, W.G., 2009. Fire in Chihuahuan Desert grassland: short-term effects on vegetation, small mammal populations, and faunal pedoturbation. Journal of Arid Environments 73 TBA.
McClaran, M.P., 2003. A century of vegetation change on the Santa Rita Experimental Range. In: McClaran, M.P., Ffolliott, P.F., Edminster, C.B. (Tech. Cords.). Santa Rita Experimental Range: 100 Years (1903 to 2003) of Accomplishments and Contributions, Proceedings RMRS-P-30. USDA Forest Service, Rocky Mountain Research Station, Tucson, AZ.
McClaran, M.P., Angell, D.L., 2006. Long-term vegetation response to mesquite removal in desert grassland. Journal of Arid Environments 66, 686–697.
McGlone, C.M., Huenneke, L.F., 2004. The impact of a prescribed burn on introduced Lehmann lovegrass versus native vegetation in the northern Chihuahuan Desert. Journal of Arid Environments 57, 297–310.
McPherson, G.R., 1995. The role of fire in desert grasslands. In: McClaran, M.P., VanDevender, T.R. (Eds.), The Desert Grassland. University of Arizona Press, Tucson, AZ, pp. 130–151.
Parmenter, R.R., 2008. Long-term effects of a summer fire on desert grassland plant demographics in New Mexico. Rangeland Ecology and Management 61, 156–168.
Paulsen Jr., H.A., Ares, F.N., 1962. Grazing Values and Management of Black Grama and Tobosa Grasslands and Associated Shrub Ranges of the Southwest. USDA Forest Service Technical Bulletin No. 1270, Washington, D.C.
Peters, D.P.C., Gibbens, R.P., 2006. Plant communities in the Jornada Basin: the dynamic landscape. In: Havstad, K.M., Huenneke, L.F., Schlesinger, W.H. (Eds.), Structure and Function of a Chihuahuan Desert Ecosystem: the Jornada Basin Long-Term Ecological Research Site. Oxford University Press, New York, NY, pp. 211–231.
Ravi, S., D'Odorico, P., 2009. Post-fire resource redistribution and fertility island dynamics in shrub encroached desert grasslands: a modeling approach. Landscape Ecology 24, 325–335.
Schlesinger, W.H., Reynolds, J.F., Cunningham, G.L., Huenneke, L.F., Jarrell, W.M., Virginia, R.A., Whitford, W.G., 1990. Biological feedbacks in global desertification. Science 247, 1043–1048.
Sims, P.L., Singh, J.S., 1978. The structure and function of ten western North American grasslands. II. Intra-seasonal dynamics in primary producer compartments. Journal of Ecology 66, 547–589.
Van Auken, O.W., 2009. Causes and consequences of woody plant encroachment into western North American grasslands. Journal of Environmental Management 90, 2931–2942.
Wooton, E.O., 1916. Carrying Capacity of Grazing Ranges in Southern Arizona. USDA Bulletin No. 367, Professional Paper, Washington, D.C.
Yao, J., Peters, D.P.C., Havstad, K.M., Gibbens, R.P., Herrick, J.E., 2006. Multi-scale factors and long-term responses of Chihuahuan Desert grasses to drought. Landscape Ecology 21, 1217–1231.