Western North American Naturalist 67(1), © 2007, pp. 63–70

VEGETATION CHANGES AFTER LIVESTOCK GRAZING EXCLUSION AND SHRUB CONTROL IN THE SOUTHERN CHIHUAHUAN DESERT

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ABSTRACT.—Vegetation cover and production were evaluated after nearly 7 years of livestock grazing exclusion and shrub control in an area with a long history of heavy livestock grazing in the southern Chihuahuan Desert, Mexico. An exclosure was established to prevent livestock grazing. In half of the excluded area, the main shrub, *Larrea tridentata*, was mechanically controlled. Outside the exclosure, heavy livestock grazing occurred as customary and shrubs were not controlled. Absence of grazing resulted in 50% higher grass cover and 35% higher total biomass. *Larrea tridentata* cover was twice as high on the grazed area as on the ungrazed area. Vegetation cover was dominated by grasses (42%) in the ungrazed area, whereas in the grazed area, cover was equally divided between grasses (28%) and shrubs (27%). Shrub control did not affect vegetation cover or herbage production. Multivariate analysis confirmed that inside the excluded area, shrub control had little impact on the plant community. The effect of grazing, however, clearly distinguished the community outside the exclosure from that inside the exclosure.

Key words: Altiplano Potosino-Zacatecano, central Mexico, Larrea tridentata, *livestock exclosure.*

The southernmost part of the Chihuahuan Desert, the Saladan subdivision, comprises arid portions of San Luis Potosí and Zacatecas in central Mexico (Fig. 1). Part of the Saladan subdivision is known as the Altiplano Potosino-Zacatecano. In this region, as well as in other areas of central and northern Mexico, extensive livestock grazing commenced on native rangelands during the Spanish colonization (1521–1810) to support the mining centers (Ezcurra and Montaña 1990, Romero-Manzanares and García-Moya 1990, Dregne 2002). Over time livestock grazing has maintained importance in the area, because crop production is hindered by limited precipitation and infertile soils. However, excessive livestock grazing in the Altiplano Potosino-Zacatecano and adjacent areas of central and north central Mexico has led to significant losses of vegetation cover and increases in soil erosion (Martinez-Morales and Meyer 1985, Romero-Manzanares and García-Moya 1990, Morales-García 1992, Aguado-Santacruz and García-Moya 1998).

In the northern Chihuahuan Desert, excessive livestock grazing has also been considered, either alone or in conjunction with other factors, a cause for loss of grassland area and advance of shrubs (Buffington and Herbel 1965, Kerley and Whitford 2000). Because excessive grazing may lead to losses in vegetation cover and production, it is often assumed that removal of livestock grazing in arid and semiarid rangelands results in increasing grass cover and herbage production as previously reported (Pieper 1968, Smith and Schmutz 1975, Anderson and Holte 1981, Valone and Sauter 2005). However, in other cases, removal of livestock grazing has not improved range productivity or vegetation cover (West et al. 1984, Beck and Tober 1985, Gibbens and Beck 1988, Omar 1991, Muscha et al. 2004).

In the northern Chihuahuan Desert, shrubs like *Larrea tridentata* have gained dominance in recent history (Buffington and Herbel 1965, Gibbens et al. 2005). In areas with *L. tridentata* at high density, forage production and grass cover tend to decrease (Beck and Tober 1985, Miller and Huenneke 2000) and the potential for soil erosion may increase (Abernathy and Herbel 1973). Control of *L. tridentata* is an option to promote recovery of the

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Fig. 1. Study area location near Salinas de Hidalgo, San Luis Potosí, within the Altiplano Potosino-Zacatecano, southern Chihuahuan Desert, central Mexico.

grassland area, but control efforts have not always been successful (Havstad et al. 1999, Rango et al. 2005).

Research on the impact of grazing and shrub control on vegetation of the Chihuahuan Desert has been predominantly conducted in the northern Trans-Pecos subdivision area of New Mexico and Texas. Compared to its northern counterpart, the southern Chihuahuan Desert is higher in elevation and tends to have higher precipitation and less temperature fluctuation (MacMahon 1979, Mata-González et al. 2002), suggesting that responses of vegetation to grazing and shrub control could also be different. However, few studies have been conducted on Mexican subdivisions that comprise the southern Chihuahuan Desert (Valverde et al. 1996). This study was conducted to determine the effects of removing livestock grazing and controlling *L. tridentata* on vegetation cover and herbage production in an area with a long history of heavy livestock grazing in the southern Chihuahuan Desert. We hypothesized that excluding livestock grazing and controlling shrubs would result in increased herbage production and cover.

STUDY AREA

The study was conducted on a communal property (ejido) about 8 km southeast of Salinas de Hidalgo, San Luis Potosí, in central Mexico at 22°37′44″N, 101°42′W (Fig. 1). The altitude is 2185 m; the mean annual temperature is 16°–18°C with little month-to-month variation (Romero-Manzanares and García-Moya 1990); and the long-term average annual precipitation is 391 mm concentrated in the summer months. Annual rainfall measurements during the years of this investigation (1986–1992) were 324, 356, 370, 250, 578, 478, and 562 mm, respectively. The soil texture is sandy loam on the upper horizon, but soils are shallow with a petrocalcic horizon at ≤50 cm. The vegetation was characteristic of a desert grassland, and the main grasses were *Scleropogon brevifolius, Erioneuron grandiflorus,* and *Aristida divaricata.* The dominant shrub was *L.*

tridentata, with a density of ca. 3000 plants · ha^{-1} and an aboveground biomass production of 363 kg · ha^{-1} (Mata-González unpublished data). The fact that shrubs did not occur in compacted groups facilitated the identification of individual plants for density determinations. Although *L. tridentata* has multiple stems deriving from the crown, most of the time it was easy to determine whether those stems belonged to the same plant by simple inspection of the base.

Historically, rangelands in the study area have been heavily grazed (Romero-Manzanares and García-Moya 1990). This area supports communal grazing of cattle, sheep, goats, and horses in that order of importance. Therefore, the main forage removed consists of herbaceous species, although some subshrubs are also consumed. There is little control of the grazing pressure and it was not possible to obtain a specific figure for the stocking rate. However, stocking rates from 0.26 to 0.82 animal units · $ha^{-1}yr^{-1}$ have been reported on similar ranges in the area, and those rates are higher than recommended for the area (0.1 animal units · $ha^{-1}yr^{-1}$; Romero-Manzanares and García-Moya 1990).

METHODS

A square area of about 16 ha was fenced in February 1986 to exclude livestock grazing. The area was divided into 4 strips of equal size (each approximately 100 × 400 m). In 2 alternate strips, the aboveground growth of *L. tridentata* was cut close to ground level with a rotary mower. Although the mowing targeted *L. tridentata,* other shrubs were also mowed. Cut shrubs were removed from the site. In the other 2 strips *L. tridentata* was not removed. Outside the exclosure heavy livestock grazing occurred as customary, and shrubs were not removed. An area equivalent to the size of 2 strips was used for measurements of vegetation outside the exclosure. Therefore, the vegetation was treated in 3 ways: (1) livestock grazing excluded and shrub control (NG-NS), (2) livestock grazing excluded and no shrub control (NG-YS), and (3) livestock grazing permitted and no shrub control (YG-YS). Each treatment was imposed in an area of about 8 ha. We took care to ensure that soil and vegetation characteristics were similar for the 3 treatment areas at the time the study was initiated, but baseline data were not available.

Over time it became evident that *L. tridentata* was starting to regrow in the area where it had been previously controlled (NG-NS treatment), so early in 1991, the species' top growth was removed again. This time, plants were selectively and manually cut with axes (individual plant treatment) to eliminate the basal bud zone (crowns about 5–10 cm below ground) to discourage further regrowth.

In fall 1992, nearly 7 years after establishing the experiment, we evaluated all treatments by measuring vegetation cover and aboveground herbage production by species. Evaluations were conducted in the fall to reflect the maximum growth and recovery of vegetation, which reduced the possibility that herbaceous sampling reflected only the annual intake of livestock. Cover was estimated by the line-intercept method (Canfield 1941). Interception of grasses and forbs was measured on the line at ground level (basal cover) and interception of shrubs and subshrubs was measured at canopy-spread level (canopy cover). The length of transect lines was 20 m and interceptions were determined to the nearest 1 cm. Eight lines were randomly placed within the area allocated to each treatment.

We estimated herbage production by clipping aboveground live biomass of herbaceous plants (including subshrubs) at ground level within 1-m^2 quadrats. Three quadrats were randomly located along each of the 20-m lines used for estimating cover. Therefore, 24 quadrats were sampled for the area allocated to each treatment. Clippings were collected by species; and samples were collected in paper bags, ovendried, and weighed. Relative biomass was calculated as a proportion of the total biomass represented by every species. This calculation was made to easily compare the contribution of every species to the total production within each treatment.

Each grazing/shrub removal treatment was applied to only 1 pasture, although every pasture was divided into 2 strips. Therefore, to make statistical comparisons we defined our populations as the individual pastures to which treatments were applied. As such, the samples (line intercepts and quadrats) within each population were considered replications to estimate the inherent variability of the population. Thus, statistical inferences are limited to

TABLE 1. Cover (%) by plant group and by species in grazed and ungrazed pastures, with or without shrub control. Estimations of cover were obtained nearly 7 years after treatments were imposed. Different letters indicate significant differences between treatment means at $P < 0.05$. T = trace (<0.1% but >0).

	NG-NS (ungrazed, shrub controlled)	NG-YS (ungrazed, shrub intact)	YG-YS (grazed, shrub intact)
GRASSES	42.2 a	42.5 a	28.2 b
Aristida divaricata	11.1 a	15.5 a	0.2 b
Scleropogon brevifolius	7.6 a	10.1 a	14.2 b
Erioneuron grandiflorum	6.6 a	6.1 a	2.2 b
Erioneuron pulchellum	3.7	3.5	1.3
Cyclostachia stolonifera	8.4 a	2.8 b	9.3 a
Muhlenbergia villosa	1.8	1.9	0.3
Lycurus phleoides	1.4	0.6	0.2
Bouteloua gracilis	0.1	1.9	0.1
Eneapogon desvauxi	T	T	0.0
Leptochloa dubia	T	0.0	0.0
Sporobolus airoides	0.0	0.0	T
SHRUBS (INCLUDES SUBSHRUBS)	7.2 a	11.3 a	26.6 b
Larrea tridentata	0.0 a	5.2 b	12.1 c
Gutierrezia texana	3.5	3.1	1.2
Jatropa dioica	3.3	1.8	2.4
Artemisia mexicana	0.3 a	0.5 a	5.5 b
Haplopappus venetus	0.0 a	0.1 a	4.2 b
Opuntia spp.	0.0	0.5	1.2
Opuntia imbricata	T	T	T
FORBS	4.8 a	2.8 a	0.7 b
Zinnia acerosa	3.2 a	1.7 a	0.5 b
Sida procumbens	1.2	0.7	0.1
Sphaeralcea angustifolia	T	T	T
Hymenoxys odorata[a]	T	T	0.0

[a] Annual species

differences among pastures within our study area (Wester 1992, Valone and Sauter 2005). Statistical differences between treatments were determined by univariate ANOVA and LSD protected tests at $P < 0.05$. These analyses were made for cover and aboveground production of individual species, groups of species (grasses, shrubs, and forbs), and vegetation totals. However, total cover was not calculated and analyzed because of the impracticality of adding basal cover from grasses and canopy cover from shrubs. Prior to statistical analyses, data were arcsin transformed to meet assumptions of heterogeneity and normality. In addition, discriminant analyses were conducted to determine multivariate differences among treatments including all the species as a mosaic (SPSS, Inc., 2000). We used relative biomass as the variable for multivariate analysis.

RESULTS

Grass cover was 50% higher in the ungrazed areas compared to the grazed area ($P = 0.03$; Table 1). However, there were differences among individual grasses with respect to grazing treatments. Cover of *A. divaricata* and *E. grandiflorum* was higher in the ungrazed areas than in the grazed area, whereas cover of *S. brevifolius* was higher in the grazed area.

Shrub cover was 2.3- to 3.7-fold higher in the grazed area than in the ungrazed area ($P = 0.04$; Table 1). *Larrea tridentata* cover was more than 2-fold higher in the grazed than in the ungrazed area. Other shrubs with higher cover in the grazed area were *Artemisia mexicana* and *Haplopappus venetus. Larrea tridentata* and the grass *S. brevifolius* contributed to most of the vegetation cover in the grazed area. Vegetation cover was dominated by grasses (42.2%–42.5%) in the ungrazed parcels, but in the grazed area, cover was equal for grasses (28.2%) and shrubs (26.6%). Similar to grasses, forbs had higher cover ($P = 0.01$) in the areas where grazing was excluded.

In the 2 ungrazed treatments (NG-NS and NG-YS), shrub control did not affect total grass cover, total shrub cover, or total forb

TABLE 2. Total herbage biomass and relative biomass by plant groups and by species in grazed and ungrazed pastures, with or without shrub control. Biomass determinations were made nearly 7 years after treatments were imposed. Different letters indicate significant differences between treatment means at $P < 0.05$. T = trace (<0.1% but >0).

	NG-NS (ungrazed, shrub controlled)	NG-YS (ungrazed, shrub intact)	YG-YS (grazed, shrub intact)
Total biomass (kg $\cdot$ ha^{-1})	504 a	562 a	396 b
Relative biomass (%)			
GRASSES	87.1	72.0	90.4
Erioneuron grandiflorum	25.6 a	24.2 a	5.9 b
Scleropogon brevifolius	16.0 a	12.0 a	48.6 b
Erioneuron pulchellum	20.1 a	10.6 ab	7.4 b
Cyclostachia stolonifera	11.0 a	13.7 a	26.1 b
Muhlenbergia villosa	4.6	2.9	2.2
Aristida divaricata	8.8 a	5.4 a	0.0 b
Lycurus phleoides	0.8	3.2	0.0
Leptochloa dubia	T	T	0.0
Bouteloua gracilis	T	0.0	0.0
SUBSHRUBS	7.0 a	15.6 b	8.3 a
Gutierrezia texana	6.8 a	12.4 b	4.4 a
Artemisia mexicana	0.2 a	3.2 ab	3.9 b
Haplopapus venetus	0.0	T	0.0
FORBS	3.9 a	7.0 a	1.1 b
Zinnia acerosa	2.1 a	4.1 a	0.0 b
Sida procumbens	1.8	2.9	1.1
Sphaeralcea angustifolia	T	T	T
Solanum elaeagnifolium	T	T	0.0
Heterosperma pinnatum[a]	T	T	0.0
Perezia nana	0.0	T	0.0
Hymenoxys odorata[a]	T	0.0	0.0

[a] Annual species

cover ($P > 0.05$; Table 1). Most plant species were not affected by the shrub control. Only 1 grass, *Cyclostachia stolonifera,* had higher cover in the shrub-controlled area than in the shrub-intact area.

Total herbage production was about 35% higher in ungrazed areas than in grazed areas ($P = 0.01$; Table 2). However, the relative biomass of the grass group was not significantly affected by grazing ($P = 0.15$) because individual grasses had different responses. *Aristida divaricata, E. grandiflorum,* and *Erioneuron pulchellum* had higher relative biomass in ungrazed areas, whereas *S. brevifolius* and *C. stolonifera* had a relative biomass 2 to 4 times higher in grazed areas. Total forbs had greater relative biomass in protected areas than in grazed areas ($P = 0.02$). Subshrubs had higher relative biomass in the ungrazed, shrub-intact area than in the other 2 treatment areas ($P = 0.04$).

Shrub control did not affect total biomass production in the 2 ungrazed areas ($P = 0.18$; Table 2). Likewise, shrub control did not significantly affect the relative biomass of grasses and forbs ($P > 0.05$). However, shrub control reduced the relative biomass of subshrubs ($P = 0.01$), perhaps because these plants were also affected by the 1st shrub control event.

The multivariate analyses confirmed some trends observed in the univariate analyses. The treatments were significantly different (Wilks-Lambda criterion, $P = 0.01$; SPSS, Inc. 2000). The confidence ellipses around the centroids of the treatments NG-NS and NG-YS overlapped in the canonical scores plot (Fig. 2), indicating that shrub control did not substantially alter the assemblage of species within these 2 ungrazed communities. In contrast, the confidence ellipse of the treatment YG-YS was clearly separated from those of NG-NS and NG-YS, showing that grazing was responsible for the group separation.

DISCUSSION

When the experiment was established, condition of the vegetation was similar for the

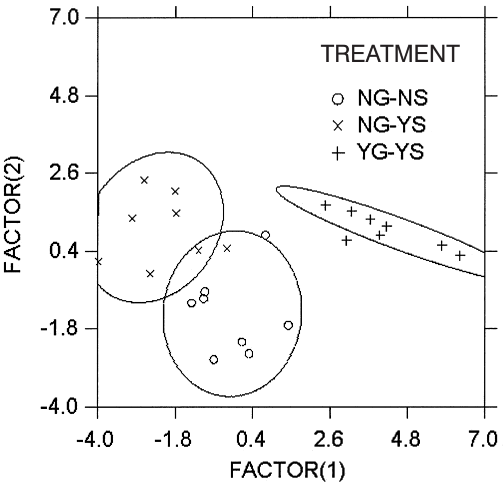

Fig. 2. Canonical scores plot for group separation of treatments based on discriminant analysis. The analysis was performed on relative biomass of all the species. NG-NS = grazing suppression plus shrub control; NG-YS = grazing suppression and no shrub control; YG-YS = no grazing suppression and no shrub control. Factor 1 is the linear combination of variables (species) that best discriminate among the groups. Factor 2 is the next best combination of variables (SPSS, Inc. 2000).

whole area of the 3 treatments. Therefore, the vegetation differences found at the end of the observation period were attributed to the treatments imposed. Most grasses responded favorably to grazing removal. This has been reported for other arid and semiarid environments (Pieper 1968, Smith and Schmutz 1975, Anderson and Holte 1981, Kerley and Whitford 2000, Anderson and Inouye 2001, Valone and Sauter 2005). However, a number of researchers have found little or no recovery of grasses after exclusion of grazing (West et al. 1984, Beck and Tober 1985, Gibbens and Beck 1988, Omar 1991, Muscha et al. 2004), often because drought overrides the exclusion effects.

The positive response of grass cover to exclusion of grazing that we observed was more pronounced than the response observed in the northern Chihuahuan Desert of New Mexico (Kerley and Whitford 2000, Valone and Sauter 2005). The vegetation of our study area, where annual precipitation is 391 mm, may be more likely to recover than that of the northern Chihuahuan Desert, where annual precipitation is 233 mm (Mata-González et al. 2002). Valone and Sauter (2005) suggested that >20 years are necessary to achieve perennial grass recovery following exclusion of livestock grazing in the northern Chihuahuan Desert. Our results indicate that <10 years of grazing exclusion can effect grass recovery in the southern Chihuahuan Desert if precipitation for some years is above average, as occurred in our study. Unfortunately, there are no previous experiences of this nature to compare with our results. It is likely that under conditions of below-average precipitation the grass recovery in our area would be slower, but it still could be faster than in the northern Chihuahuan Desert. We concur with Pieper (1994), who suggested that it is difficult to generalize about the impact of livestock grazing on vegetation without considering other factors such as weather and plant community type.

Aristida divaricata and *E. grandiflorum* were favored by exclusion of grazing. Although these grasses have low palatability for cattle when mature, livestock grazing may limit their growth when they are young, green, and more palatable (Beck and Tober 1985). In contrast, *S. brevifolium* and *C. stolonifera* had higher cover and greater relative biomass on the grazed area, a result which indicates low consumption of these grasses by livestock (Beck and Tober 1985). The multivariate group separation confirmed that livestock grazing outside the exclosure was creating a community qualitatively different from that inside the exclosure. The community outside had less herbaceous vegetation and more shrub species. As indicated by Briske and Richards (1995), excessive livestock grazing indirectly favors the increase of unpalatable species because palatable species are selectively consumed.

Shrub control had no impact on herbage cover and production, and this was also confirmed by the multivariate analysis. Morton et al. (1990) reported that forage production increased after shrub control on areas with high *L. tridentata* density (≥6000 plants · ha^{-1}), but not on areas with lower shrub densities. In our study, *L. tridentata* density was about 3000 plants · ha^{-1}, which may explain the lack of response of herbaceous species to the elimination of shrubs. Therefore, based on our data, we suggest that *L. tridentata* was not competitively limiting the growth of herbaceous vegetation prior to shrub control. Shrub density in the southern Chihuahuan Desert can be highly variable as it is in the northern Chihuahuan Desert (Miller and Huenneke 2000).

Cover of *Larrea tridentata* was higher in grazed than in ungrazed pastures. However, controlling this shrub did not seem to benefit grasses. In agreement with this result, Sala et al. (1989) reported that removal of grasses in the Patagonian steppe favored shrub production, whereas removal of shrubs did not affect grass production. One difference between grasses and shrubs is their degree of adaptation to aridity. Desert shrubs are more drought tolerant than grasses, partly because of their deeper root system (Montaña et al. 1995). The adaptation of shrubs to arid systems makes shrubland communities very resilient and stable in comparison to grasslands (Heitschmidt and Pieper 1983, Rango et al. 2005).

The hypothesis that exclusion of livestock grazing would result in higher herbage production and cover was generally supported by our results. In contrast, the hypothesis that shrub control would increase herbage production and cover was not supported by our results. Our study was limited by its short duration, considering the long-term responses that grazing removal may require. Nevertheless, in an analysis of 236 studies worldwide comparing vegetation in grazed versus ungrazed sites, Milchunas and Lauenroth (1993) found that years of protection from grazing was not always a significant variable in determining vegetation changes. Long-term reports of vegetation change in livestock exclosures also have the limitation of not considering some short-term vegetation dynamics that may occur in response to grazing and precipitation conditions. Our conclusions are also limited by a potential lack of transferability to other sites, but this limitation is shared by similar studies (Valone and Sauter 2005). Nevertheless, these results represent a step forward in understanding vegetation management issues in contrasting areas of the Chihuahuan Desert.

Uncontrolled grazing can be a factor of range degradation as indicated by the replacement of grassland by shrubland area. A shrub-dominated community has less desirable characteristics not only in terms of forage production but also from the perspective of soil and water conservation (Manzano and Návar 2000, Parizek et al. 2002). Nevertheless, livestock grazing has an economic and cultural value in the Altiplano Potosino-Zacatecano and in many other semiarid areas of the world. Therefore, judicious grazing management is necessary to ameliorate the deterioration of vegetation and soil in these areas.

ACKOWLEDGMENTS

We gratefully acknowledge Antonio Gómez-González for initiating the exclosure. Assistance from Joel Juárez Bernal, Humberto Mata González, and Pedro Pablo Mata González is also gratefully acknowledged.

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Received 3 August 2005
Accepted 31 August 2006