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Vegetation Response to Removal of Plant Groups and Grass Seeding in a Microphyllous Desert Shrubland: A 4-Year Field Experiment

Miguel Mellado [1], Juan A. Encina-Domínguez [2], José E. García [1], Eduardo Estrada-Castillón [3] and José R. Arévalo [4,*]

[1] Department of Animal Nutrition, Autonomous Agrarian University Antonio Narro, Saltillo 25315, Mexico; miguel.mellado@uaaan.edu.mx (M.M.); edugarmartz@gmail.com (J.E.G.)
[2] Department of Natural Resources, Autonomous Agrarian University Antonio Narro, Saltillo 25315, Mexico; juan.encinad@uaaan.edu.mx
[3] Faculty of Forestry Sciences, Autonomous University of Nuevo León, Linares 67700, Mexico; andres.estradacs@uanl.edu.mx
[4] Department of Botany, Ecology and Plant Physiology, University of La Laguna, La Laguna 38200, Tenerife, Spain
* Correspondence: jarevalo@ull.edu.es

Abstract: Grazing is one of the most important land management activities worldwide, and cases of overgrazing increase erosion, land degradation, and plant invasion. The objective of this study was to assess the effect on individual species and species composition in response to groups of plants removals or grass seeding after four years of vegetation transformation in a microphyllous desert shrubland excluded from cattle grazing. Nine treatments involved (1) clearing of vegetation and seeding of *Bouteloua curtipendula* (BOCU), a native grass, (2) clearing and seeding of *Chloris gayana* (CHGA), an introduce grass from Africa, (3) clearing except for grasses (GRA), (4) clearing except for grasses and fodder shrubs (GRA-SHR), (5) free grazing by cattle (GRAZ), (6) clearing except fodder shrubs (SHR), (7) no modification (CON), (8) clearing of all plants (BARE), and (9) clearing except plants not eaten by cattle (UND). Treatments were replicated five times each in 10 m × 10 m experimental plots. Plots were surveyed for density, cover of all plants, and standing forage. Total plant cover was higher in CON and UND than the other treatments. Except for BOCU, where forage production was the highest, forage production ha^{-1} was low among all other treatments. Plant density was highest in SHR and lowest in CON. Results after four years of transformation indicate that seeded *Chloris gayana* failed to become established, but seeding of *Bouteloua curtipendula* was able to persist, and had the greatest influence on the vegetation restoration, which is what we consider the most appropriate restoration treatment.

Keywords: rehabilitation; semi-arid; shrub; grasses; grazing

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1. Introduction

In arid ecosystems, rangeland managers struggle to neutralize the impacts of multiple disturbances such as drought, overgrazing, fire, weeds, or human influences, which affects the rangeland health [1]. Rangeland managers must have an understanding of current strategies, temporal, and spatial processes affecting the rangeland structure, as well as biotic and abiotic elements contributing to disturbance. This is necessary to maintain productive rangelands and, consequently, productivity of livestock on rangelands where frequent drought, low and erratic annual rainfall, and spatiotemporal variation in forage prevail [2].

Management of arid rangeland is a multiscale effort, with the interactions of climate, soil, herbivores using the rangeland, dynamics of present vegetation, and historic management of the ecosystem [3,4]. The vegetation composition of arid rangelands can present a variety of different plant communities due to successful increase of dominance of undesirable plants for livestock. Thus, range managers must prioritize management actions to maintain high availability of forage plants and focus upon the removal of invasive plants for the reestablishment of native forage species.

In desert ecosystems with low resource availability, strong competition for water and interaction between nurse shrubs and herbaceous vegetation is expected [5,6]. Therefore, a marked response to the elimination of some species by the remaining plants is also expected [7]. It is often thought that in desert rangelands most plant species are constrained by abiotic environmental constraints, rather than by biotic interactions [1]. In semi-arid systems, it has been demonstrated that members of one group (e.g., perennial grasses) may be influenced by individuals of another group (e.g., [8,9]). These interactions may lead to important changes in the vegetation and forage availability, and this transition can happen relatively quickly (e.g., from grassland to shrub-dominated rangeland [10,11]) if the right environmental conditions occur, but once the change occurs it is not easy to reverse. This means that some changes are ultimately permanent. This can reduce forage availability for livestock as shrub dominance affects the structure and functioning of grassland ecosystems [12]. Thus, this increase in shrub dominance and ecosystem change are two drivers of biodiversity loss and altered plant communities [13]. Perturbed rangeland ecosystems are dynamic and changing, and therefore there is no one combination of plants that is the optimum state ecologically.

Reseeding open areas of the rangeland is an alternative for reversal of desertification caused by overgrazing or high-risk agriculture. In northern Mexico, reseeding important native grasses such as *Bouteloua curtipendula* has resulted in good establishment and adequate and excellent forage production [14], whereas *Chloris gayana*, an introduced grass from Africa, has failed to become established in arid and semiarid plant communities [15].

It is imperative to understand the way arid rangelands respond to the elimination of some components of the ecosystem. Particularly, it is necessary to find out if the elimination of certain plants from the ecosystem increases the abundance of certain plant species or if this removal generates further species losses from the rangeland. The objective of this study was to examine changes in plant density, cover, and forage production of areas with selective removal of species relative to untreated *Larrea tridentate—Flourensia cernua*-dominated shrubland. Specifically, we asked the following questions: (1) Do the responses of native plant communities of a *L. tridentata-F. cernua*-dominated shrubland depend on the removal of invasive shrubs?; (2) Do the responses of native vegetation differ among removal of specific groups of plants?; (3) Does elimination of particular groups of plants result in greater native plant diversity and forage production?; (4) Does seeding of drought-tolerant grasses result in greater vegetation cover and forage production?

2. Materials and Methods

2.1. Study Site

The experimental site is located in northeast Mexico (25°49′ N, 101°21′ W) at an altitude of 1150 m above sea level with a slope of less than 1%. Mean annual precipitation is 199 mm, most of which falls as high-intensity thunderstorms from June to October. However, annual rainfall during the four years of exclusion was 215, 105, 84, and 117 mm. The mean annual temperature is 21.1 °C. The soil is a deep, alluvial sandy loam with low nitrogen and organic matter content, and the vegetation corresponds to a microphyllous desert shrubland [16].

2.2. Study Species

The overstory was predominantly *Larrea tridentata* and *Flourensia cernua*, two unpalatable aromatic medicinal shrubs that are common of the arid grasslands and microphyllus desert shrub of northern Mexico. Another important shrub present was *Agave lechuguilla*, a dominant or codominant rosetophyllus species in the Chihuahuan Desert which is not eaten by cattle and used by industrial purposes. *Opuntia rastrera*, *Fouquieria splendens*, and *Parthenium argentatum* are other common shrubs that grow on sites that do not support a high level of grass production and comprise low percentage of the cattle diet.

Forbs comprised a minor part of the vegetation. The most abundant forbs were *Euphorbia maculata*, *Lepidium virginicum*, *Meximalva filipes*, and *Tiquilia canescens,* which is not eaten by cattle. The three first species are weeds and the last one is an indicator of overgrazing. Grasses also constituted only a small part of the vegetation and they grew mainly beneath shrubs. Principal species were *Munroa pulchella*, *Setaria macrostachya*, *Bouteloua curtipendula*, and *Muhlenbergia porteri*. The first grass species is an indicator of overgrazing. The stocking rate for this zone is 51–60 ha^{-1} animal unit [17]. In the Appendix A, Table A1, we include species characteristics with the family, life cycle, and growth form indicated, as well as cattle palatability.

2.3. Experimental Design

We established 45 quadrat plots of 10 m × 10 m located in plain terrain positioned to avoid the confounding effects of runoff. Plots were randomly assigned to one of nine groups (five replicates per treatment). The nine treatments are as follows: reference plots (CON) consisted of the undisturbed original vegetation. Total elimination of the vegetation (BARE) consisted of the removal of all plants including roots; therefore, plots had only bare soil. Elimination of the vegetation except for grasses (GRA), total elimination of the vegetation except for fodder shrubs (SHR). Elimination of the vegetation except for undesirable species for cattle (e.g., cactus and succulents, UND), removal of the vegetation except for grasses and fodder shrubs (GRA-SHR), removal of the vegetation and seeding of *Bouteloua curtipendula* (BOCU; broadcast application of 15 kg of seed ha^{-1} of this native perennial grass after a shallow plowing). Removal of the vegetation and seeding of *Chloris gayana* (CHGA; broadcast application of 18 kg of seed ha^{-1} of this introduced perennial grass after a shallow plowing). Finally, a treatment of free grazing cattle at 0.04 animal units ha^{-1} year^{-1} was included (GRAZ). This grazing pressure has been the average stocking rate of this plant community for decades. Vegetation clearing and grass seeding were carried out by a team of four persons in June 2011, and this task took 15 days. Plants were individually severed below the ground level with a pickaxe and removed by hand. Fallen wood, branches, and herbaceous material were removed from the field. There was no further intervention to enable the recovery of the disturbed plots. The study area was tightly fenced with six strands of barbed wire to exclude livestock. Plots remained undisturbed for four years.

2.4. Field Evaluation

The experiment started in July 2011 and ran until August 2015. The vegetation measurement was conducted in the middle of the rainy season of 2015 (August) at the time of peak standing crop and when most grasses were in full flowering stage, which facilitated their identification. To determine plant cover, four permanent 10-m Canfield lines were used [18], with two meters between lines in each sampling plot. Forage production was recorded by both the clipping of all grasses to ground level with hand shears and the annual growth of fodder shrubs present in five subplots 1-m^2 with randomly scattered frames per replication (25 frames per treatment) at peak production in August 2015. Harvested forage was dried at 50 °C for 48 h before weighing.

The number of plant species within each 10 × 10 m plot was defined as species richness. For within-plot species, the Smith and Wilson's evenness index (E_{var}) was used as follows (1), considered the most robust of the nonparametric evenness indexes [19]:

$$E_{var} = 1 - (2/\pi) \times \arctan \sum_{r=1}^{S} (\{\ln[p_r] - \sum_{i=1}^{S} ln[p_i]\ S\}^2/S)) \quad (1)$$

where: S is the number of species in the plant community present; p_i is the relative abundance of species i.

2.5. Statistical Analysis

The UNIVARIATE procedure of SAS (SAS Institute Inc. Cary, NC, USA) was used to test residuals for deviation from normality with the use of the Shapiro–Wilk test. Assuming a criteria of $p < 0.05$, the Shapiro–Wilk test provided evidence that some data for canopy cover and density of plants were not normally distributed and were transformed using log10 (x + 1) to confer normality. Then, parametric analyses were used. For each of the individual species, cover and density data were analyzed with the PROC GLM procedure of SAS for a randomized complete block design with five replications at multiple sites, to test the treatment effect (it was assumed a fixed linear process fitted to normal data). Response variables were forage production, density, and species cover. We also analyzed evenness and richness. Adjustments for multiple comparisons among treatment means were made using the Bonferroni procedure in SAS (PDIFF = CONTROL ADJUST = BON). Differences were considered significant at $p \leq 0.05$.

Ordination techniques help in explaining community variation [20] and were used to evaluate trends in plant species composition [21]. We based the analysis on the cover of the species using a detrended correspondence analysis (DCA). In the plane given by DCA axes I and II, we encircled the samples of different treatments with an envelope, using the minimum possible area. We performed all multivariate analysis with the CANOCO package [21].

3. Results

3.1. Plant Density and Cover

Total vegetation cover markedly varied as a function of the type of vegetation removed (Table 1). Cover was lowest ($p < 0.01$) for CHGA and highest for UND. Shrub cover was mainly dominated ($p < 0.01$) by *F. cernua* in CON and GRAZ, compared to other treatments. In addition, CON presented the highest ($p < 0.01$) cover of *L. tridentata*, *A. lechuguilla*, and *Cylindropuntia leptocaulis*. The native grass with the greatest ($p < 0.01$) cover was *S. macrostachya* in the GRAS treatment, compared to all other treatments. Both *L. virginicum* and *T. canescens* were the forbs with the highest ($p < 0.01$) cover in the GRA-SHR treatment, compared to the other treatments. Except for the GRAZ treatment, these herbaceous plants presented an important aerial cover in all other treatments. The single most important plant species contributing to total vegetation cover was *B. curtipendula* in the BOCU treatment. *Chloris gayana*, on the other hand, barely survived after four years of seeding, and its mean cover was < 0.1%.

Flourensia cernua density did not differ among treatments, except for BOCU where this shrub was drastically reduced ($p < 0.01$; Table 2). Likewise, density of *L. tridentata* did not differ among treatments, but this shrub completely disappeared in the BOCU treatment. Treatments did not reduce *A. lechuguilla* density, but this shrub substantially increased ($p < 0.01$) in the UND treatment. CHGA suppressed *O. rastrera,* but GRAS-SRB and GRAZ enhanced ($p < 0.01$) its density.

Table 1. Plant canopy cover (%) * by main species in sites of a microphyllous desert shrubland subjected to different transformations including seeding of perennial native or introduced grasses. Estimations of canopy cover were registered four years after treatments were imposed. Values are means ± standard deviation.

Species	Treatments								
	CON	**BOCU**	**CHGA**	**GRAS**	**GRA-SHR**	**GRAZ**	**SHR**	**BARE**	**UND**
Flourensia cernua	15.2 ± 5.9 ^{b}	0.3 ± 0.2 ^{a}	0.2 ± 0.2 ^{a}	0.7 ± 0.3 ^{a}	1.0 ± 0.8 ^{a}	15.2 ± 5.2 ^{b}	0.7 ± 0.5 ^{a}	0.8 ± 0.4 ^{a}	7.6 ± 3.1 ^{c}
Larrea tridentata	8.7 ± 4.2 ^{b}	0.7 ± 0.4 ^{a}	1.4 ± 1.2 ^{a}	0.6 ± 0.2 ^{a}	0.6 ± 0.4 ^{a}	1.9 ± 2.8 ^{a}	0.3 ± 0.2 ^{a}	0.7 ± 0.3 ^{a}	5.2 ± 4.3 ^{c}
Agave lechuguilla	7.3 ± 4.9 ^{b}	0.8 ± 0.3 ^{a}	0.04 ± 0.0 ^{a}	0.2 ± 0.2 ^{a}	0.5 ± 0.4 ^{a}	2.5 ± 2.5 ^{a}	0.2 ± 0.2 ^{a}	0.1 ± 0.1 ^{a}	10.5 ± 5.1 ^{c}
Cylindropuntia leptocaulis	4.4 ± 1.7 ^{d}	0.3 ± 0.2 ^{ab}	0.1 ± 0.0 ^{a}	0.5 ± 0.5 ^{ab}	0.5 ± 0.3 ^{ab}	2.4 ± 2.1 ^{bc}	0.7 ± 0.1 ^{ab}	0.1 ± 0.1 ^{a}	3.7 ± 3.2 ^{cd}
Viguiera stenoloba	0.01± 0.0 ^{a}	0.1 ± 0.0 ^{ab}	0.1 ± 0.0 ^{ab}	0.7 ± 0.3 ^{cd}	0.4 ± 0.4 ^{ab}	0.7 ± 0.5 ^{cd}	0.3 ± 0.3 ^{ab}	0.5 ± 0.4 ^{bcd}	1.2 ± 1.0 ^{d}
Opuntia rastrera	0.1 ± 0.0 ^{a}	0.1 ± 0.0 ^{a}	0.1 ± 0.0 ^{a}	0.1 ± 0.0 ^{a}	0.1 ± 0.1 ^{a}	1.2 ± 1.6 ^{b}	0.1 ± 0.0 ^{a}	0.1 ± 0.0 ^{a}	0.1 ± 0.1 ^{a}
Sida abutifolia	0.2 ± 0.1 ^{b}	3.5 ± 2.0 ^{a}	1.0 ± 0.7 ^{b}	0.5 ± 0.2 ^{b}	0.3 ± 0.3 ^{b}	0.1 ± 0.0 ^{b}	0.5 ± 0.3 ^{b}	0.5 ± 0.3 ^{b}	0.3 ± 0.3 ^{b}
Lepidium virginicum	1.4 ± 1.2 ^{cd}	4.5 ±1.0 ^{bc}	4.4 ± 1.8 ^{bc}	3.8 ± 1.3 ^{bc}	9.8 ± 5.2 ^{a}	0.3 ± 0.2 ^{d}	5.7 ± 4.0 ^{b}	4.7 ± 1.1 ^{bc}	1.4 ± 1.0 ^{cd}
Tiquilia canescens	1.5 ± 1.1 ^{cd}	5.2 ± 1.6 ^{bc}	5.2 ± 2.4 ^{bc}	4.2 ± 1.3 ^{bc}	12.2 ± 6.1 ^{a}	0.6 ± 0.3 ^{d}	6.4 ± 3.5 ^{b}	4.9 ± 1.4 ^{cb}	1.8 ± 0.8 ^{cd}
Muhlenbergia porteri	1.3 ± 0.9 ^{a}	0.8 ± 1.1 ^{ab}	0.5 ± 0.2 ^{ab}	0.2 ± 0.3 ^{b}	1.3 ± 0.7 ^{a}	0.1 ± 0.0 ^{b}	0.1 ± 0.0 ^{b}	0.3 ± 0.2 ^{b}	0.8 ± 0.6 ^{ab}
Digitaria californica	0.6 ± 0.5 ^{cb}	0.1 ± 0.1 ^{c}	0.1 ± 0.0 ^{c}	2.2 ± 0.8 ^{a}	2.3 ± 1.2 ^{a}	1.0 ± 0.5 ^{b}	1.0 ± 0.0 ^{c}	0.2 ± 0.2 ^{c}	0.1 ± 0.0 ^{c}
Setaria macrostachya	1.3 ± 0.9 ^{c}	0.7 ± 0.6 ^{c}	0.3 ± 0.1 ^{c}	8.3 ± 4.0 ^{a}	5.4 ± 3.6 ^{ab}	2.4 ± 0.7 ^{bc}	1.4 ± 0.8 ^{c}	5.1 ± 3.1 ^{b}	4.8 ± 1.7 ^{b}
Tridens muticus	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.2 ± 0.1	0.9 ± 0.7	1.5 ± 3.0	0.7 ± 0.3	0.2 ± 0.1	0.1 ± 0.1
Bouteoloua simplex	0.1 ± 0.0	0.2 ± 0.2	0.1 ± 0.0	0.2 ± 0.1	0.5 ± 0.6	0.1 ± 0.0	0.3 ± 0.2	0.2 ± 0.1	0.4 ± 0.3
Munroa pulchella	0.3 ± 0.3 ^{a}	0.6 ± 0.8 ^{a}	5.2 ± 2.3 ^{b}	1.1 ± 0.3 ^{a}	0.2 ± 0.2 ^{a}	0.6 ± 0.3 ^{a}	0.9 ± 0.8 ^{a}	0.9 ± 0.5 ^{a}	0.3 ± 0.5 ^{a}
Bouteloua curtipendula	0.1 ± 0.0 ^{c}	19.2 ± 6.1 ^{a}	0.1 ± 0.1 ^{c}	0.1 ± 0.1 ^{c}	0.1 ± 0.1 ^{c}	0.1 ± 0.1 ^{c}	0.0 ± 0.0 ^{c}	0.1 ± 0.0 ^{c}	7.4 ± 4.9 ^{b}
Others	0.7±0.5	1.3±0.9	0.9±06	1.1±06	0.8 ± 0.3	0.5±03	0.9±0.7	0.6±0.2	0.6±0.4
Total	43.1 ± 7.3 ^{ab}	38.5 ± 3.8 ^{b}	19.8 ± 4.8 ^{d}	24.7 ± 6.1 ^{de}	36.9 ± 4.1 ^{bc}	31.2 ± 6.4 ^{cd}	20.2 ± 4.2 ^{d}	20.0 ± 4.3 ^{d}	46.6 ± 5.8 ^{a}

(*) Plant canopy cover refers to the proportion of the ground surface covered by plant parts both in the uppermost and lower layers of all plant species. CON = control (undisturbed original vegetation); BOCU = removal of the vegetation and seeding of *Bouteloua curtipendula*; CHGA = removal of the vegetation and seeding of *Chloris gayana*; GRAS = elimination of the vegetation except for grasses; GRA-SHR = removal of the vegetation except for grasses and fodder shrubs; GRAZ = free cattle grazing; SHR = total elimination of the vegetation except for fodder shrubs; BARE = elimination of all vegetation; UND = elimination of plants not eaten by cattle. ^{a,b,c,d} Each species means within a row followed by different superscript letters differ ($p < 0.05$).

L. virginicum density was highest in BOCU and BARE and lowest ($p < 0.01$) in GRAZ. *T. canescens* density was high in most treatments, except GRAZ. *Setaria macrostachya* density was highest ($p < 0.01$) in the GRAS, GRAS-SHR, and SHR treatments, with the lowest density in CON. *Bouteloua simplex* was the most abundant native grass in all treatments with the highest density in GRA-SHR and BARE, and the lowest ($p < 0.01$) in CON. Another abundant native grass was *M. pulchella,* which had the highest ($p < 0.01$) density in GRAS and SHR and the lowest in GRAZ. As was expected, the highest ($p < 0.01$) density of *B. curtipendula* was observed in the BOCU treatment; all other treatments show a negligible density of this native grass.

3.2. Species Richness, Diversity, Evenness, and Aboveground Forage

The site studied supported a limited plant community with 23 plants documented during the study period. Mean species richness was higher in SHR, CON, and BARE, with no difference among them, and lowest ($p < 0.01$) in treatments where grasses were seeded (Figure 1a). Values for plant species evenness indicated low equity in the distribution of plant species in the different treatments. Smith and Wilson species evenness was highest for GRA-SHR and GRAZ, and lowest ($p < 0.01$) for CHGA (Figure 1b). The total forage production showed the highest ($p < 0.01$) yield in the BOCU treatment and the lowest in CHGA, GRAZ, and UND (Figure 1c).

Table 2. Density of main species in sites of a microphyllous desert shrubland subjected to different transformations including seeding of perennial native or introduced grasses. Plant density was registered four years after treatments were imposed. Values are means ± standard deviation.

Species	**Treatments**								
	CON *	**BOCU**	**CHGA**	**GRAS**	**GRA-SHR**	**GRAZ**	**SHR**	**BARE**	**UND**
Flourensia cernua	1.3 ± 0.6 ^{a}	0.3 ± 0.2 ^{b}	1.0 ± 0.7 ^{ab}	1.8 ± 0.7 ^{a}	1.2 ± 0.5 ^{a}	1.4 ± 0.8 ^{a}	1.7 ± 0.5 ^{a}	1.5 ± 0.7 ^{a}	1.2 ± 0.6 ^{a}
Larrea tridentata	0.2 ± 0.1 ^{bc}	0.0 ± 0.0 ^{c}	1.0 ± 0.2 ^{a}	0.3 ± 0.1 ^{bc}	0.2 ± 0.1 ^{bc}	0.3 ± 0.1 ^{bc}	0.5 ± 0.3 ^{b}	1.0 ± 0.2 ^{a}	0.5 ± 0.3 ^{b}
Agave lechuguilla	0.4 ± 0.3 ^{b}	0.0 ± 0.0 ^{c}	0.0 ± 0.0 ^{c}	0.2 ± 0.2 ^{bc}	0.0 ± 0.0 ^{c}	0.9 ± 0.2 ^{a}	0.0 ± 0.0 ^{c}	0.1 ± 0.1 ^{c}	0.3 ± 0.2 ^{b}
Cylindropuntia leptocaulis	0.4 ± 0.1 ^{cd}	0.7 ± 0.3 ^{bc}	0.1 ± 0.1 ^{d}	1.0 ± 0.4 ^{ab}	0.0 ± 0.0 ^{d}	0.3 ± 0.1 ^{d}	0.4 ± 0.1 ^{cd}	0.8 ± 0.3 ^{ab}	1.1 ± 0.5 ^{a}
Viguiera stenoloba	0.1 ± 0.1 ^{a}	0.0 ± 0.0 ^{a}	0.9 ± 0.3 ^{b}	1.0 ± 0.6 ^{b}	0.2 ± 0.2 ^{a}	1.0 ± 0.6 ^{b}	0.2 ± 0.2 ^{a}	0.4 ± 0.1 ^{a}	0.4 ± 0.1 ^{a}
Opuntia rastrera	0.1 ± 0.1 ^{bc}	0.1 ± 0.1 ^{b}	0.0 ± 0.0 ^{c}	0.1 ± 0.1 ^{bc}	0.3 ± 0.1 ^{a}	0.3 ± 0.2 ^{a}	0.1 ± 0.1 ^{bc}	0.1 ± 0.1 ^{bc}	0.2 ± 0.2 ^{ab}
Sida abutifolia	0.0 ± 0.0 ^{d}	1.0 ± 0.6 ^{a}	0.5 ± 0.1 ^{b}	0.1 ± 0.1 ^{cd}	0.2 ± 0.2 ^{bcd}	0.0 ± 0.0 ^{d}	0.4 ± 0.2 ^{bc}	0.2 ± 0.2 ^{bcd}	0.2 ± 0.2 ^{bcd}
Lepidium virginicum	7.0 ± 3.7 ^{cd}	26.0 ± 7.0 ^{a}	17.4 ± 4.3 ^{b}	19.4 ± 5.1 ^{ab}	18.0 ± 4.1 ^{b}	3.2 ± 1.4 ^{d}	21.6 ± 6.3 ^{ab}	25.4 ± 7.4 ^{a}	10.8 ± 1.8 ^{c}
Tiquilia canescens	7.8 ± 3.3 ^{c}	23.4 ± 5.7 ^{a}	17.8 ± 7.4 ^{ab}	21.0 ± 9.9 ^{a}	19.2 ± 10.0 ^{ab}	3.4 ± 2.3 ^{c}	19.0 ± 10.3 ^{ab}	24.6 ± 6.3 ^{a}	9.8 ± 3.4 ^{bc}
Muhlenbergia porteri	0.1 ± 0.1 ^{a}	0.2 ± 0.2 ^{a}	0.2 ± 0.2 ^{a}	0.0 ± 0.0 ^{a}	0.0 ± 0.0 ^{a}	0.2 ± 0.2 ^{a}	1.1 ± 0.7 ^{b}	0.0 ± 0.0 ^{a}	0.3 ± 0.2 ^{a}
Digitaria californica	0.1 ± 0.1 ^{d}	0.6 ± 0.5 ^{bc}	0.5 ± 0.4 ^{a}	0.7 ± 0.4 ^{b}	1.6 ± 0.5 ^{a}	0.1 ± 0.1 ^{d}	0.2 ± 0.1 ^{cd}	0.3 ± 0.2 ^{bcd}	0.1 ± 0.1 ^{d}
Setaria macrostachya	0.4 ± 0.3 ^{c}	0.8 ± 0.4 ^{c}	0.7 ± 0.4 ^{c}	4.9 ± 2.4 ^{b}	5.9 ± 2.5 ^{ab}	1.4 ± 0.5 ^{c}	7.6 ± 2.4 ^{a}	0.3 ± 0.2^{c}	1.3 ± 0.4 ^{c}
Tridens muticus	0.1 ± 0.1 ^{bc}	0.0 ± 0.0^{c}	0.1 ± 0.1 ^{bc}	0.1 ± 0.1 ^{bc}	0.4 ± 0.3 ^{bc}	1.0 ± 0.5 ^{a}	0.2 ± 0.2 ^{bc}	1.0 ± 0.5 ^{a}	0.5 ± 0.3 ^{b}
Bouteloua simplex	6 ± 2.6 ^{c}	21± 8.4 ^{ab}	26 ± 6.6 ^{a}	25 ± 7.7 ^{a}	27 ± 7.6 ^{a}	24 ± 7.9 ^{a}	25 ± 8.7 ^{a}	27 ± 6.5 ^{a}	14 ± 4.6 ^{bc}
Munroa pulchella	3.0 ± 1.4 ^{bc}	1.3 ± 0.3 ^{bc}	5.8 ± 4.7 ^{b}	14.8 ± 7.1 ^{a}	0.8 ± 0.9 ^{bc}	0.1± 0.1 ^{c}	14.4 ± 7.4 ^{a}	2.5 ± 1.6 ^{bc}	3.6 ± 0.9 ^{bc}
Bouteloua curtipendula	0.0 ± 0.0^{b}	16.8 ± 7.2 ^{a}	0.0 ± 0.0 ^{b}	0.0 ± 0.0 ^{b}	0.1 ± 0.1 ^{b}	0.1 ± 0.1 ^{b}	0.1 ± 0.1 ^{b}	0.0 ± 0.0 ^{b}	0.0 ± 0.0 ^{b}
Others	2 ± 0.6	2 ± 0.7	4 ± 1.3	3 ± 1.1	2 ± 0.9	2 ± 0.8	3 ± 1.0	1 ± 0.4	2 ± 0.8
Total	92 ± 9 ^{a}	94 ± 11 ^{a}	76 ± 12 ^{b}	88 ± 7 ^{a}	80 ± 17^{b}	94 ± 8 ^{a}	76 ± 12 ^{b}	86 ± 19 ^{a}	48 ± 14 ^{b}

(*) CON= control (undisturbed original vegetation); BOCU = removal of the vegetation and seeding of *Bouteloua curtipendula*; CHGA = removal of the vegetation and seeding of *Chloris gayana*; GRA = elimination of the vegetation except for grasses; GRA-SHR = removal of the vegetation except for grasses and fodder shrubs; GRAZ = free cattle grazing; SHR = total elimination of the vegetation except for fodder shrubs; BARE = elimination of all vegetation; UND = elimination of plants not eaten by cattle. ^{a,b,c,d} Each species means within a row followed by different superscript letters differ ($p < 0.05$).

a) b) c)

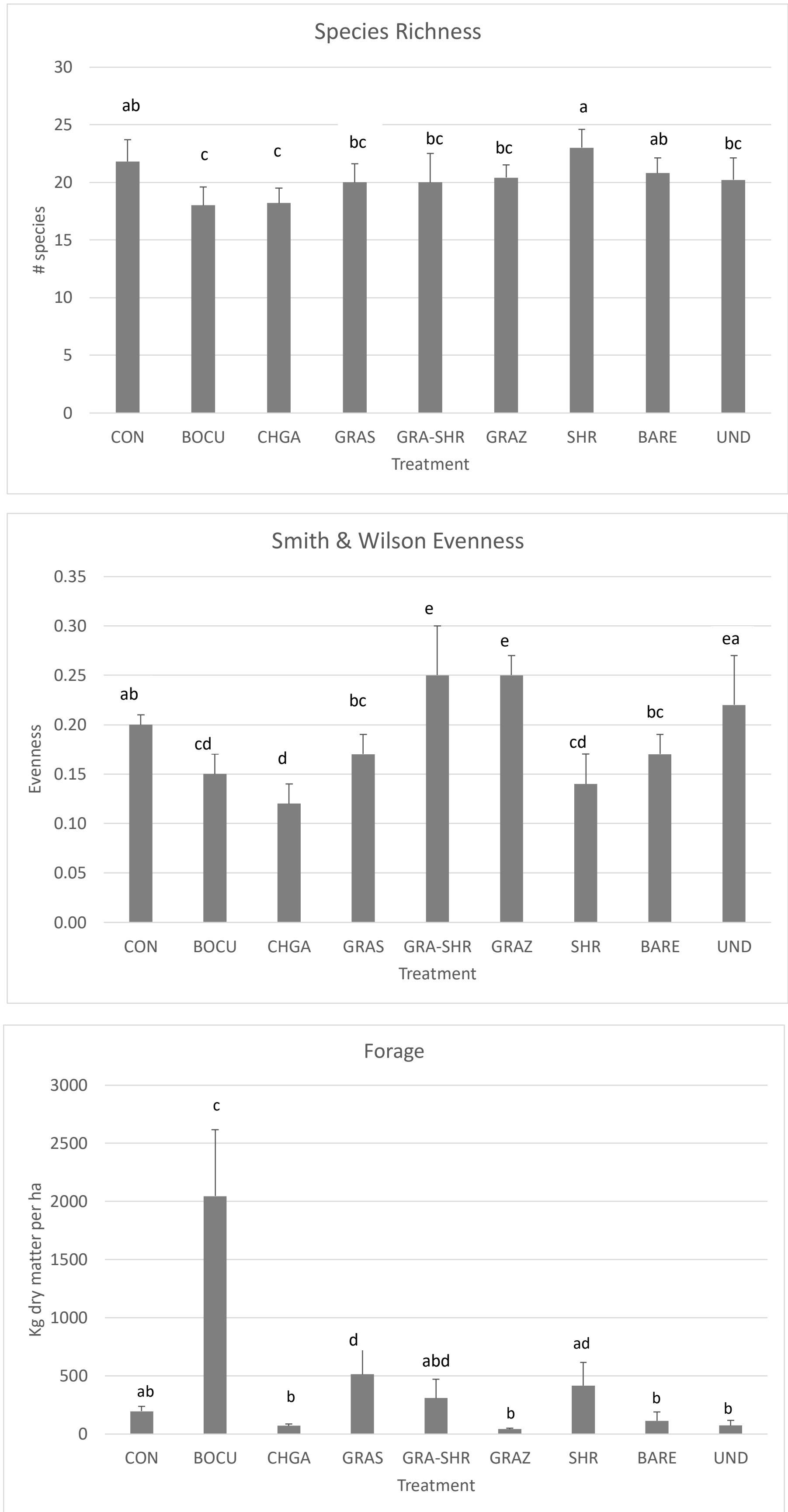

Figure 1. Mean values and standard deviations for (**a**) species richness; (**b**) evenness, and (**c**) forage production/ha of the different groups for the different treatments. Identical letters on top of bars indicate nonsignificant differences ($p < 0.05$ for d.f. = 36 for the error term).

3.3. Species Composition

The species composition analysis revealed three groups of treatments, one discriminated along axis II, the BOCU, with dominance of *B. curtipendula*, *S. abutifolia,* and *Munroa pulchella*. The other group is SHR, BARE, GRA-SHT, and GRA, with a very similar species composition, mainly grasses and forbs, and the last is formed by UND, CON, and GRAZ, where the dominance of the shrubs are the characteristics: *O. rastrera*, *C. leptocaulis*, *A. lechuguilla*, *L. tridentata,* and *F. cernua*.

4. Discussion

Five important findings are presented in this study. First, seeding of *B. curtipendula* presented successful germination and an adequate establishment in this xeric environment. This establishment and persistence suppressed the growth of *L. tridentata*, *A. lechuguilla*, *V. stenoloba*, and *Tridens muticus*. Thus, seeding of *B. curtipendula* was effective for managing the spatial presence of some shrubs not consumed by cattle, and was an effective procedure to boost the spatial development of reconstructed rangelands. Therefore, it would be worth finding ways to seed this native forage over large areas in arid ecosystems [22].

In addition, seeding of this native grass led to the highest forage production after 4 years of grazing exclusion (1147% more forage than CON), which is higher than the 1213 kg ha^{-1} reported by Lair and Redente [23] for this grass seeded in combination with other native graminoids or < 1000 kg ha^{-1} as monoculture [14,24]. Other studies had poor results in establishing *B. curtipendula* by the end of the third [25] or fourth growing season [26] due to low rate of plant establishment in arid ecosystems [27].

Richness in this treatment was the lowest among treatments, but these results do not support other studies conducted under restoration conditions, which have found that higher richness confers greater resistance to invasion of plants [28,29]. However, opposite results have also been found [30]. Therefore, it seems pertinent to increase the plant richness by using grass seed mixes for restoration due to species complementing each other in their resource use [31].

Secondly, a noticeable effect of CHGA was a great decrease in forage production (34% lower than CON), due practically to a total disappearance of this grass. One main challenge of restoring degraded rangelands is detecting forage species that, after seeding, can survive and persist over the long term [32,33]. This was not the case of *Chloris gayana*, which was practically absent following four years of seeding, and could not directly compete with forbs (greatest vegetation cover in this treatment) for limited resources [34,35]. Snyman [36] also observed that, despite a good plant density for this seeded grass during the first season, *C. gayana* showed a poor survival after three years in a semi-arid rangeland. Thus, this grass is not adapted to the prevailing conditions of drought and temperature of the study site. The significantly higher diversity of species of CHGA compared to CON could be attributed to improved soil conditions, as a result of plowing of the terrain and bare soil, which apparently enhances vegetation recovery of plants with proclivity to invade disturbed areas. These results are not in line with findings of Ruthven et al. [37] who noted that root plowing in an arid rangeland decreased diversity and evenness compared to untreated areas.

The third major finding was that clearing of shrubs and forbs enhanced grass production to a much greater degree than CON, although the principal grass increasing in density was *M. pulchella*, a grass unpalatable to livestock [38]. These results are in line with Morton et al. [39], who reported that forage production increased after shrub control on areas with high *L. tridentata* density. However, these results disagree with findings of Mata-González et al. [40] and Brock et al. [41], where mechanical or chemical elimination of shrubs had no impact on the recolonization of the site with native grasses in vegetation similar to the one in the present study. Valone and Sauter [42] indicate that more than 20 years are required for perennial grass to recover in sites excluded from livestock grazing in the Chihuahuan Desert, but the present study suggests an incipient recovery with only four years of grazing exclusion despite the extremely low rainfall during the study period.

A major advantage of expansion of grasses is that enhanced grass production following elimination of competing shrubs can last at least 20 years [43]. However, the dominant shrubs in this landscape, *L. tridentata* and *F. cernua,* reestablished in this site where they had been removed, which indicates that grasses did not competitively limit the growth of shrubs after their elimination. This supports the view of Whitford et al. [44], in that unvegetated patches promote the establishment of *L. tridentata*.

The fourth finding of this study was that the site with free cattle grazing presented the lowest forage production without altering plant diversity (compared to CON). In addition, total aerial cover was lower in GRAZ than CON. Heavy grazing provokes excessive defoliation of vegetation, reducing standing phytomass [45], because grazing is selective, which leads to the replacement of palatable species by less palatable ones. However, an important finding of this study was the marked reduction of forbs with overgrazing, compared to CON. This agrees with observations of Tessema et al. [46], where basal cover and aboveground biomass, diversity, and total abundance of herbaceous vegetation, were lower in heavily grazed semi-arid savanna than in lightly grazed sites. Total forbs had greater relative biomass in protected areas than in grazed areas. Trampling and grazing may explain forb reduction because trampling by cattle is common in xeric ecosystems, and intensely influences plant performance [47,48]. The unchanged diversity in the grazed area stems from the suppression of dominant species by cattle [48] which allow the dissemination of other plants in this ecosystem. In our case, a community defined by undesirable plants are defined by the treatments CON, GRAZ, and UND (Figure 2).

A fifth major finding was that practically all plant species of this landscape reestablished in the site where all vegetation was removed, so that richness did not significantly differ compared with CON, and the structure of the new vegetation did not change much over the years. Except for BOCU, both *L. tridentata* and *F. cernua*, the codominant shrubs in this landscape, presented the same density as all other treatments. These shrubs have an extensive root system, produce seeds that are dispersed by wind or water, and their seedlings present low tolerance to high soil moisture [49,50], all of which allowed them to become rapidly established in the bare soil. The combination of *L. virginicum* and *T. canescens* made up 50% of all plants in this treatment. This agrees with other studies in North America and Australia that show a rapid increase in herbage production following mechanical thinning of the arboreal overstory [51,52]. After clearing all vegetation, there was likely a significant time lag before the codominant shrubs could have reemerged to become canopy dominants in formerly heavily invaded sites, because aerial cover of these shrubs was much lower than CON.

Finally, forage production, richness, and species diversity in the control site (undisturbed and fenced to exclude grazers for four years) did not differ from that of the GRAZ treatment. These results disagree with Mata-González et al. [40], in similar vegetation as the one in the present study, where total herbage production was about 35% higher in ungrazed areas than in grazed areas after seven years of livestock grazing exclusion. On the other hand, Milchunas and Lauenroth [53] analyzed 236 studies worldwide, comparing species composition and aboveground net primary production in grazed versus ungrazed sites, and found that protection from grazing was not always a significant variable in determining vegetation changes and phytomass production. In agreement with the present study, some researchers have reported increased richness in grazed areas [54,55].

Density of most plant species did not differ between these treatments; the exceptions were a drastic reduction of annual graminoid *B. simplex* and an increase of *M. pulchella* in the heavily grazed site. Our results suggest that scarcity of forage in the study site forced cattle to consume *B. simplex* but avoid *M. pulchella*, though additional studies would be required to verify this supposition. The greatest richness was observed in SHR (with no significant differences with respect to the control). It has been suggested that, in arid and semiarid environments, shrubs further the germination and establishment of seedlings due to physical or biotic facilitation provided by the "safe sites" of "nurse plants" [56,57].

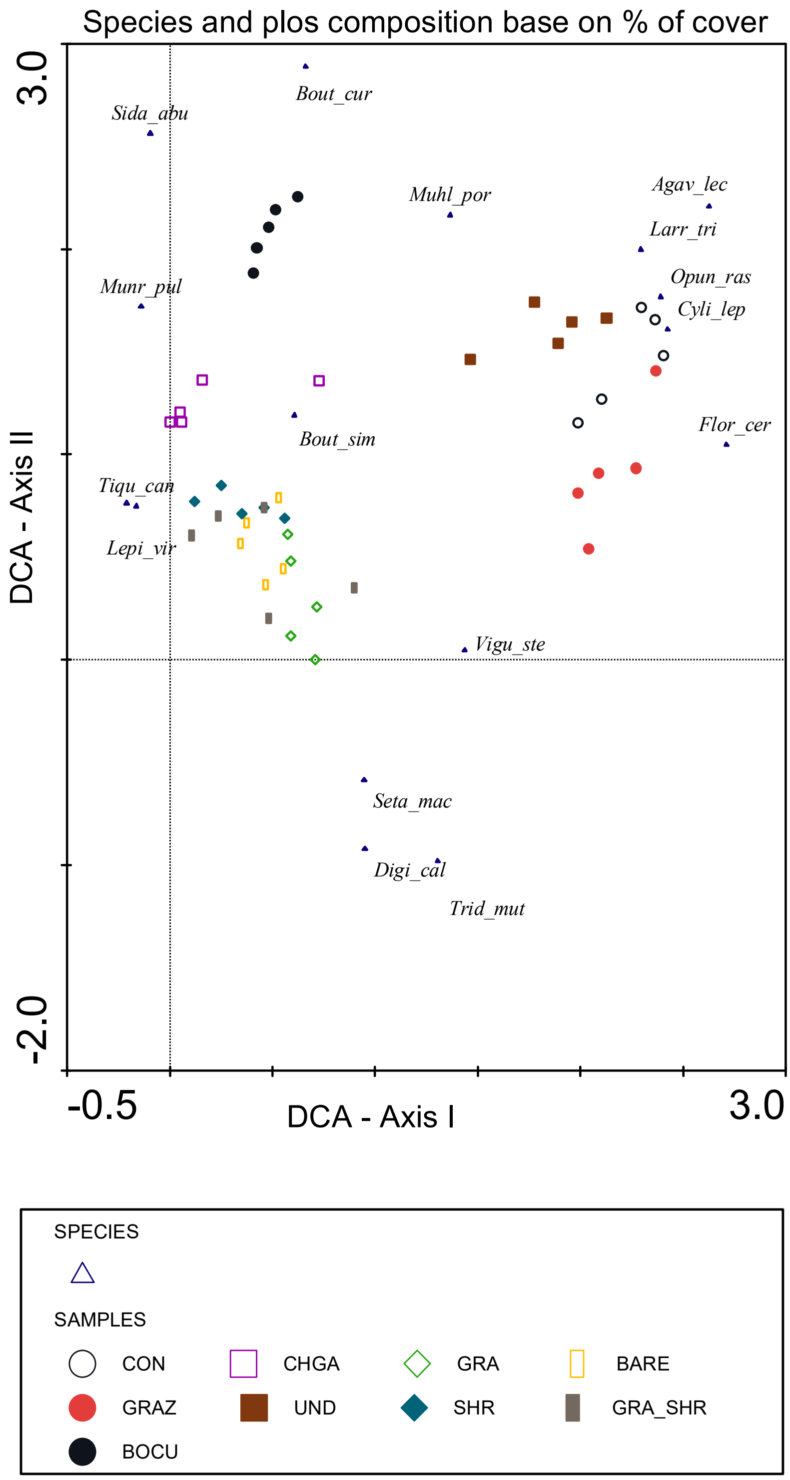

Figure 2. Detrended correspondence analysis axes I and II. Species coordinates and treatments plots coordinates (each treatment with a different symbol). Eigenvalue for axis I: 0.52, eigenvalue for axis II: 0.33, cumulative percentage of total inertia for axes I and II: 53%. Abbreviations for species are: *Agave lechuguilla (Aga_lec), Bouteloua curtipendula (Bou_cur), Bouteloua simplex (Bou_sim), Cylindropuntia leptocaulis (Cyl_lep), Digitaria californica (Dig_cal), Flourensia cernua (Flo_cer), Larrea tridentata (Lar_tri), Lepidium virginicum (Lep_vir), Muhlenbergia porteri (Muh_por), Munroa pulchella (Mun_pul), Opuntia rastrera (Opu_ras), Setaria macrostachya (Set_mac), Sida abutifolia (Sid_abu), Tiquilia canescens (Tiq_can), Tridens muticus (Tri_mut), Viguiera stenoloba (Vig_ste).*

5. Conclusions

Of the transformation approaches evaluated in this ecosystem, the best alternative for controlling shrubs dominance and increasing forage production was the elimination of the vegetation and seeding the native perennial grass *Bouteloua curtipendula*, although this option is labor-intensive and reduces richness. In order to maintain this control of shrubs, the future management should consider a reduction in grazing intensity to favor grass recovery after each season (from 0.04 to 0.02 animal units ha^{-1} $year^{-1}$), monitoring the results to contemplate possible additional grazing intensity reductions. On the other hand, *Chloris gayana* proved to be incapable of withstanding the severe dry conditions of this ecosystem. This Chihuahuan Desert shrubland demonstrated considerable resistance in the face of substantial overgrazing, as the grazed site did not differ much in terms of forage production, richness, and species diversity compared to the natural vegetation excluded from livestock grazing for four years. Native perennial grasses did benefit noticeably from the elimination of shrubs. Overall, these results show that both *Larrea tridentata* and *Flourensia cernua* had a consistent reestablishment following all the clearing treatments.

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Appendix A

Table A1. Species Characteristics with the Family, Life Cycle and Growth Form indicated As Well As Cattle Palatability.

Family	Species	Growth Form	Life Cycle	Palatability
Asteraceae	*Flourensia cernua*	Shrub	Perennial	Unpalatable
Zygophyllaceae	*Larrea tridentata*	Shrub	Perennial	Unpalatable
Asparagaceae	*Agave lechuguilla*	Shrub	Perennial	Unpalatable
Cactaceae	*Cylindropuntia leptocaulis*	Shrub	Perennial	Unpalatable
Asteraceae	*Viguiera stenoloba*	Shrub	Perennial	Unpalatable
Cactaceae	*Opuntia rastrera*	Shrub	Perennial	Palatable
Malvaceae	*Sida abutifolia*	Forb	Perennial	Palatable
Brassicaceae	*Lepidium virginicum*	Forb	Annual	Unpalatable
Boraginaceae	*Tiquilia canescens*	Forb	Perennial	Unpalatable
Poaceae	*Chloris gayana*	Graminoid	Perennial	Palatable
Poaceae	*Muhlenbergia porteri*	Graminoid	Perennial	Palatable
Poaceae	*Digitaria californica*	Graminoid	Perennial	Palatable
Poaceae	*Setaria macrostachya*	Graminoid	Perennial	Palatable
Poaceae	*Tridens muticus*	Graminoid	Perennial	Palatable
Poaceae	*Bouteloua simplex*	Graminoid	Annual	Palatable
Poaceae	*Munroa pulchella*	Graminoid	Perennial	Palatable
Poaceae	*Bouteloua curtipendula*	Graminoid	Perennial	Palatable

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