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RESEARCH ARTICLE

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Impact of 25 years of grazing exclusion and shrub removal on plant community structure and soil characteristics in a xerophytic rangeland

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Abstract

Aim of study: We tested the hypothesis that long periods of grazing exclusion in areas with a history of high grazing intensity will have a positive impact on soil nutrient conditions and favor soil infiltration, increase biomass and lead to a recovery in vegetation.

Area of study: Noria de Guadalupe, Zacatecas, Mexico.

Material and methods: We analyzed the impact of grazing exclusion on biomass, species richness, evenness, soil nutrient content and soil water infiltration after 25 years of exclusion during each of the four seasons by excluding two 15 × 15 m plots of grazing and compared with two control plots.

Main results: Exclusion management did not lead to biomass increases; however, it did lead to an important recovery in the plant community. Moreover, soil nutrient content was more affected by the seasonality of rainfall in the study site than by 25 years of exclusion. The elimination of dominant shrubs in the excluded area led to a faster recovery in palatable shrubs and shortgrass vegetation, which was improved by better infiltration values during the end of spring and summer explaining some of the differences in nutrient avaibility.

Research highlights: In our study, exclusion management can lead to an important recovery in vegetation without affecting the growth of *Atriplex canescens*, a valuable source of fodder. Although biomass presented a higher dependence on seasonality and was not related to the treatment, the impact on the forage quality is evident by the different plant communities established after 25 years of exclusion.

Additional key words: *Atriplex canescens*; community; diversity; grazing; infiltration.

Abbreviations used: AU (animal unit); DCA (detrended corresponde analysis); PCA (principal components analysis).

Authors' contributions: JRA, JEG and JAED: design of the experiment; MM, JD and ESH data collection, analysis and discussion of results; JRA and JEG: preparation and edition of manuscript. All authors read and approved the final version of the manuscript.

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Introduction

An ecological force such as grazing with important environmental and social implications must be analyzed thoroughly to propose sustainable practices (Arévalo, 2012). Grazing management is one of the most important traditional and sustainable land uses in many areas of the world (Milchunas *et al*., 1988; Crawley, 1997) and grazing lands require appropriate techniques to maintain species composition, soil conservation and high diversity values of plant communities (Baldock *et al*., 1994; Olff & Ritchie, 1998; Teague & Barnes, 2017). Conversely, mismanagement can cause marked and significant variation in species composition (Casado *et al*., 2004; Arévalo *et al*., 2007). Moreover, overgrazing is a common occurrence in many rangelands, increasing the risks of erosion and desertification and promoting exotic species (Steffens *et al*., 2008; Gusha & Mugabe, 2013; Encina-Domínguez *et al.,* 2014; Arévalo *et al*., 2017).

Different grazing studies have often revealed contradictory results on the impact on soil nutrients and species composition (Olff & Ritchie, 1998) with conclusions varying from herbivores enhancing to having little effect or negative impacts on plant diversity and richness (Osem *et al*., 2004; de Bello *et al*., 2007). Likewise, there are different effects on soil nutrient content (Bakker *et al*., 2004; Fernández-Lugo *et al*., 2009; Wang *et al*., 2016). This lack of consistent responses among studies has been attributed to factors such as the evolutionary history of grazing, productivity gradients, or grazing intensity (Milchunas & Lauenroth, 1993). Thus, to understand the grazing effects on a particular environment, specific studies are required (Perevolotsky & Seligman, 1998). Some authors have related this variability to the stochastic character of grazing ecosystems rather than to deterministic processes (Curtin, 2002). Clearly, measures to avoid degradation of areas due to grazing and adverse environmental conditions are required in many regions such as Africa, where there is strong economic dependence on such grazing activities (Perkins & Thomas, 1993; Thomas *et al*., 2000). Due to this, in South Africa land management has been directly related to the improvement of grasses and forage legume reinforcement (Tavirimirwa *et al*., 2012, 2019), grazing management (Gadzirayi *et al*., 2007), control of grazing pressure (United Nations, 2016) and land tenure reformation systems (Lahiff, 2000).

In many areas of northern Mexico, it is common to have high grazing pressure from goats and cows on grasslands and xerophytic scrub as described by Gutiérrez *et al*. (2007) or Estrada-Castillón *et al*. (2010). These authors recommend establishing recovery periods for the biomass. In some cases, some plants highly appreciated by cattle, goats or horses can be promoted, while other shrub species can be removed (Gutiérrez *et al*., 2007). Other areas with high dependence on grazing management provide similar results to those in Mexico and South Africa. In short, overgrazing results in a steady decline in range condition as evidenced by a reduction in forage plants' palatable quality and in plant species composition (Gusha & Mugabe, 2013). The final situation is a relatively infertile soil and a reduction in the overall productivity of the lands (Toulmin & Scoones, 2001).

In this study, we analyzed the impact of 25 years grazing exclusion in which, as part of the exclusion, all shrubs except *Atriplex canescens* (Pursh) Nutt. were removed, severing them below the ground level and cutting the roots as much as possible. *Atriplex canescens* is utilized by farmers in dry ecosystems as maintenance feed for livestock during the drought feed gap or for landscaping purposes (Ventura *et al*., 2015; Mellado *et al*., 2018).

The main goal of this exclusion management is to improve soil quality as well as improve biomass production. Thus, we tested the hypothesis that long periods of exclusion (25 years) in areas with high grazing intensity in the past have a positive impact on soil nutrient conditions, favor soil infiltration and increase biomass, regardless of the season. We also postulated that exclusion favor the recovery of plant communities, increasing species richness and diversity.

Material and methods

Study site

The study was conducted at Noria de Guadalupe, Zacatecas, Mexico (24°21'N, 101°22'W; Fig. 1) at an average altitude of 1,800 m. According to García (2003), the climate is subtropical desert, semiarid with hot summers and cool winters (Papadakis, 1980). Average temperature varies between 7.4 °C in winter and 21 °C in summer with an average annual rainfall of 241 mm, primarily during summer and winter. The average annual temperature is 13.9 °C. The soil is yermosol, slightly alkaline (pH=7.6), poor in organic matter (2.2 ± 0.4%; mean and SD) and nitrogen (53 ± 9.1 kg/ha) and with slight salinity (1.2-2.7 dS/m). Soil depths at the study site range from 66 to 125 cm. Over the study area, the mean percentage of sand, silt and clay is 44.1, 34.9 and 21.0, respectively.

The vegetation type is Chihuahuan Desert Scrub (Henrickson & Johnston, 1986), which is dominated by creosote bush (*Larrea tridentata* (DC.) Coville) along with tarbush (*Flourensia cernua* DC.). Other species include mariola (*Parthenium incanum* Kunth), fourwing saltbush (*Atriplex canescens*) and scattered colonies of rosetophyllous species such as rough agave (*Agave asperrima* Jacobi) and lechuguilla (*Agave lechuguilla* Torr.). The main perennial grasses are burro grass (*Scleropogon brevifolius* Phil.), alkali sacaton (*Sporobolus airoides* (Torr.) Torr.) and fluffgrass (*Munroa pulchella* (Kunth) L.D. Amarilla). The most abundant forbs are desert zinnia (*Zinnia acerosa* (DC.) A. Gray), Fendler's bladderpod (*Physaria fendleri* (A. Gray) O'Kane & Al-Shehbaz), fiveneedle pricklyleaf (*Thymophylla pentachaeta* (DC.) Small), spear globe mallow (*Sphaeralcea hastulata* A. Gray) and dwarf

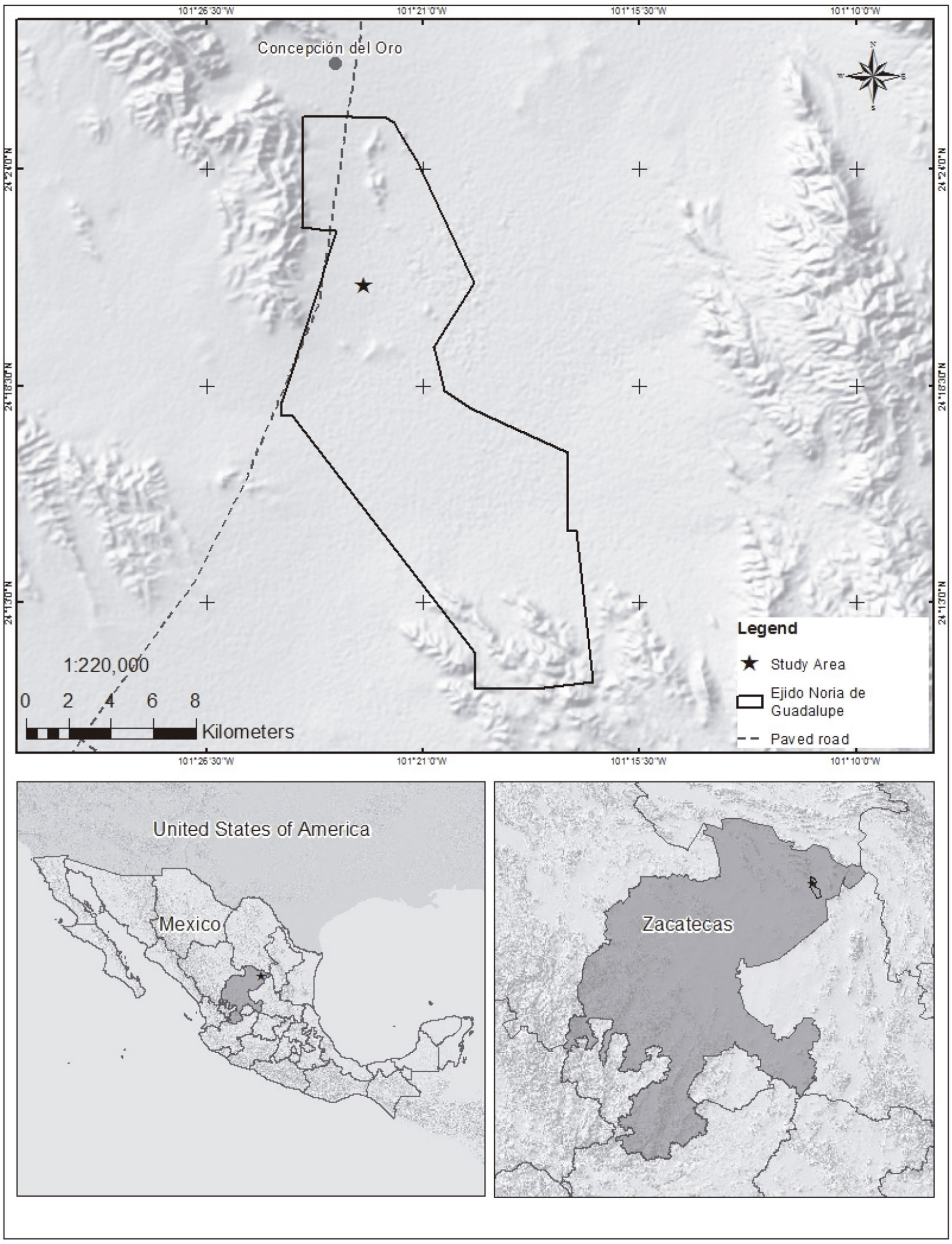

Figure 1. Location of the study site (area enclosed by the black line), Noria de Guadalupe, situated at the northeast of the state of Zacatecas, Mexico.

desert peony (*Acourtia nana* (A. Gray) Reveal & R.M. King). Nomenclature follows Rzedowski (1978).

In the last five decades, the area has been managed to support communal grazing of horses, cattle, sheep and goats with a stocking rate above the grazing capacity recommended for this vegetation type in its present state of plant community degradation (loss of species and biomass). The stocking rate in the area per animal unit (AU) has been estimated in 30-40 ha/AU (assuming that each AU is a representative cow of 450 kg or its standardization to other animals such as horses or goats) (Gutiérrez *et al*., 2007), based on the local information provided by rangers on this area, which has remained relatively constant along the last 25 years. Consequently, the area is dominated by a scrub vegetation community with low diversity and low aboveground biomass (Mellado *et al*., 2012). During the winter of 1987-1988, an experimental degraded site was chosen in which all shrubs except those of *Atriplex canescens* were removed to favor colonization of the native plant community, while maintaining this appreciated shrub for grazing animals. The other shrubs were removed by severing them below ground level. After that, roots were cut as much as possible with a pickaxe and manually removed from the 25-ha (the experimental site). The root balls of shrubs were pulled out using a spade, shovel and a mattock.

Design of the study

In 1987, in the 25-ha study site (where all the shrubs but *Atriplex canescens* were removed), two 20 × 20 m permanent exclosures were established to prevent grazing. Inside each exclosure, a 15 × 15 m plot was established, located in the center. Two control plots (outside of the exclosures) of the same size (15 × 15 m) were randomly established in the experimental site (on the 25-ha) as controls with free grazing of goats, cattle and horses. These plots were situated more than 100 m far from the fence and from any trails or roads, avoiding areas with evident human disturbance. Both plots were representative of the extension of the study area and treatments.

Plant and soil traits were measured four times on the year 2012 at the end of each season (end of June, September, December and March) in order to provide data on periodical changes of vegetation composition, biomass, soil composition and infiltration. Seasons are remarkably different in this area (especially humidity), so the seasonal effect on those parameters should be analyzed to reveal how important they are with respect the exclusion. As we were interested in the change of biomass, species composition, soil nutrient composition and infiltration after 25 years of exclusion, the control provided the baseline of these changes.

For each plot and season, we collected ten soil samples of 1-kg at 0-30 cm depth (avoiding the biomass subplots). Each sample was mixed, dried and sieved through a 2-mm sieve, and debris and stones were removed from the soil. We analyzed pH, Olsen P (mg/L), total N percentage and NO_3 (mg/L), percentage of organic matter (%OM), available cations in meq L^{-1} (Na, Ca, Mg) and Cu, Fe and Zn (mg/L). Percentages of clay, sand and silt were also analyzed to determine the soil structure. We followed standard methods of analysis (MAPA, 1986; AOAC, 2012). In this case we had 10 soil samples in four plots collected in the four seasons (160 samples in total).

In each plot, four random 1 × 1 m subplots were selected for collection of biomass in each season (they were not the same ones for all the seasons). For each plot, altitude, aspect and slope were measured. The true number of replicates for both excluded and control plots was two, subplots were spatial subsamples and a season is a pseudo-replicated factor. For each subplot, we collected the aerial biomass of each plant species, dried, separated and weighed. Then, we calculated biomass per species, species richness, and the Smith & Wilson evenness index (Smith & Wilson, 1996). We had four subplots collected in each of the four plots in the four seasons (64 subplots in total).

We performed infiltration analyses of the soils following the double ring infiltrometer method (Bouwer, 1986), which is accurate but less labor intensive compared to other methods (using two cylinders 30 cm tall and with diameters of 45 and 25 cm for the interior one). The infiltration was measured at 1, 3, 5, 10, 15, 20, 25 and 30 min on five randomly selected points per plot.

Statistical analysis

The design allowed two replicates for both Grazed and Excluded treatments; subplots were spatial subsamples and a season was a pseudo-replicated factor. Although using season as a pseudo-replicated factor is a limitation of the study and for the inference of results (Hulbert, 1984), the long period of exclusion offers a valuable opportunity to test long-term exclusion effects.

Information on the aerial biomass in the four subplots of each plot was recorded in each season, and biomass per species and species richness calculated, along with the Smith & Wilson evenness index (Smith & Wilson, 1996). A one-way distance-based permutational two-factor ANOVA (Anderson *et al*., 2008) was also performed for comparison between season and exclosure (as factors) for biomass, species richness and evenness index using subplots. Pairwise *posteriori* comparisons using t-statistics were applied to significant factors and interactions. The analyses were based on Euclidean distances of the raw data, with *p*-values ($p<0.05$) obtained with 9999 permutations and a Monte Carlo correction where necessary. Primer 6 and Permanova+ (PRIMER-E Ltd, Plymouth, UK) were used to perform all PERMANOVA statistical procedures. Standardized principal components analysis (PCA) was utilized (using CANOCO; ter Braak & Šmilauer, 1998) to examine the soil properties and nutrient composition, using the data from the subplots in different seasons.

We used DCA (detrended correspondence analysis; Hill & Gauch, 1980) to analyze the species composition (based on biomass) in the subplots as species abundance showed a unimodal response to environmental gradients. We performed all multivariate analysis with the CANOCO package (Gauch, 1982; ter Braak & Šmilauer, 1998). The main objective of this analysis was to reveal how grazing exclusion changes the plant community.

We calculated the average infiltration at each different time (n=10) and compared the values of the curve of each season using a Wilcoxon test (for a $p<0.05$). The statistical methods used followed Zar (1984) and were implemented using Primer 6 and Permanova+ (PRIMER-E Ltd, Plymouth, UK).

Results

Total biomass in the different plots varied between seasons (Pseudo F3,56 = 78.03, p<0.01) but not for the exclosure treatment (Pseudo F1,56 = 2.89, p = n.s.) or interaction among factors (Pseudo F3,56 = 0.94, p = n.s.). The highest value of biomass was found in summer (Fig. 2a). As regard richness, a total of 22 plant species were recorded, 20 in the exclosure plots and only 9 in the grazed plots (Table 1 and Table S1 [suppl]).

Two species were only found in the grazed plots: *Koeberlinia spinosa* Zucc. and *Cylindropuntia leptocaulis* (DC.) F.M. Knuth. Other species were present in both treatments. *Atriplex canescens* presented high biomass after 25 years in both areas, grazed and excluded, maintaining high values.

Richness varied significantly among seasons (Pseudo F3,56 = 24.11, p<0.01) and between exclosure and grazed plots (Pseudo F1,56 = 75,85, p<0.01) as did the interaction between seasons and exclosure (Pseudo F3,56 = 24.11, p<0.01; Fig. 2b). For evenness, differences were only found for seasons (F3,56 = 3.14, p<0.05) but not for the exclosure treatment (F1,56 = 1.75, p = n.s.) or interaction (Pseudo F3,56 = 0.41, p = n.s.).

The average soil nutrients analyzed are presented in Table 2. We were interested in revealing differences between treatments and seasons on nutrient composition. PCA of nutrients did not discriminate between grazed and exclosure plots. In spite of this, Fig. 3a, in the axis I, revealed a strong relationship with NO3 content, while axis II is more related to Ca and Mg and Zn and Cu. However, it is possible to discriminate the plots based on season and exclosure in the bidimensional space of axes I and II. Spring sample plots have a higher content of Ca and Mg, and lower values of Zn and Cu. For the rest of the seasons, the discrimination is very poor, revealing no clear patterns (Fig. 3b).

DCA revealed strong differences in species composition between grazed and exclosure plots (Fig. 4a). As well as evidence of higher richness in exclosure plots, it was also found that shrubs such as *L. tridentata*, *C. leptocaulis*, *Prosopis glandulosa* Torr. and *K. spinosa* are the dominant species in the grazed vegetation. In the case of grasses in exclosure plots, some grasses, such as *Bouteloua gracilis*, *Muhlenbergia repens*, *Aristida adscensionis*, *Achnatherum editorum* or *Eragrostis* sp., are dominant in the community. This pattern is maintained for the different seasons, with poor discrimination among the highly dominant species between grazing *vs*. exclosure treatments (Fig. 4b).

The results of infiltration (Fig. 5) indicate significant differences for summer (Z=-2.52, n=8 and p<0.05) with higher values of infiltration in the exclosure plots, whereas for winter and spring there were higher values of infiltration in the grazed plots (Z = -2.38 and Z = -2.30, n=8 and p<0.05 respectively). With respect to autumn, no significant differences were found.

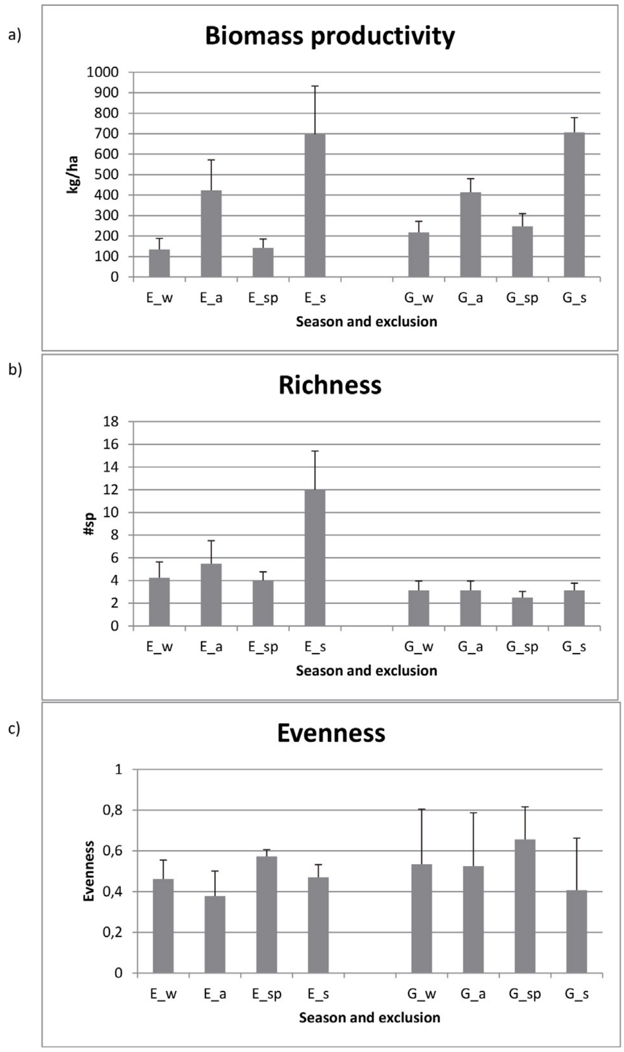

Figure 2. Mean values and standard deviations for (a) above ground biomass (kg/ha dry matter), (b) species richness and (c) Wilson and Smith evenness index. The mean values were calculated for 8 subplots of each treatment separately for grazed plots (E: excluded; G: grazed) and season (w: winter; a: autumn; sp: spring; and s: summer).

Discussion

The vegetation of the studied area can be considered overgrazed (Gutiérrez *et al*., 2007) with an increase in the desertification level (dominant desert and non-palatable species becoming more common), but not a significant reduction in biomass. Instead, significant differences in seasonal biomass production were recorded, especially in summer (Fig. 2a).

Table 1. Average species biomass (N=4) in each season and for each treatment (kg/ha dry biomass).

Species	Exclusion	Grazed
	Spring	
Atriplex canescens	97.5	65.3
Bouteloua gracilis	12.5	-
Eragrostis sp.	20.0	-
Larrea tridentata	15.0	163.5
Prosopis glandulosa	-	37.5
Scleropogon brevifolius	10.0	-
Tecoma stans	20.0	-
Other species	5.0	-
	Summer	
Achnatherum editorum	33.8	-
Ambrosia confertiflora	30.0	-
Atriplex canescens	355.0	273.8
Bouteloua gracilis	31.3	-
Buddleja scordioides	47.1	-
Eragrostis sp.	35.6	-
Gutierrezia sarothrae	50.0	-
Koeberlinia spinosa		50.0
Larrea tridentata	52.5	408.1
Lepidium virginicum	22.5	-
Marrubium vulgare	32.5	-
Muhlenbergia repens	23.5	-
Munroa pulchella	16.3	-
Parthenium incanum	27.5	15.0
Physaria fendleri	17.1	13.3
Scleropogon brevifolius	35.4	-
Sporobolus airoides	106.7	-
Tecoma stans	11.4	-
Other species	5.0	-
	Autumn	
Achnatherum editorum	20.0	-
Ambrosia confertiflora	15.0	-
Aristida adscensionis	10.0	-
Atriplex canescens	262.5	131.9
Bouteloua gracilis	25.0	-
Buddleja scordioides	6.7	-
Eragrostis sp.	17.5	-
Koeberlinia spinosa	-	40.0
Larrea tridentata	28.8	260.0
Physaria fendleri	-	6.7
Prosopis glandulosa	167.5	-
Scleropogon brevifolius	10.0	-
Sporobolus airoides	30.5	-
Tecoma stans	-	17.5
	Winter	
Atriplex canescens	95.0	52.5
Bouteloua gracilis	5.0	-
Cylindropuntia leptocaulis	-	25.0
Eragrostis sp.	12.5	3.3
Koeberlinia spinosa	-	25.0
Larrea tridentata	7.5	143.8
Prosopis glandulosa	37.5	32.5
Scleropogon brevifolius	5.0	-
Sporobolus airoides	10.0	-
Other species	5.0	-

After 25 years of livestock exclusion, we expected an increase on aboveground biomass, as has been confirmed in other studies (Castro & Freitas, 2009; Wang *et al*., 2016). However, this was not the case in this study probably because overgrazing aboveground biomass of grasses and forbs decrease as shrubs increase

(a)

(b)

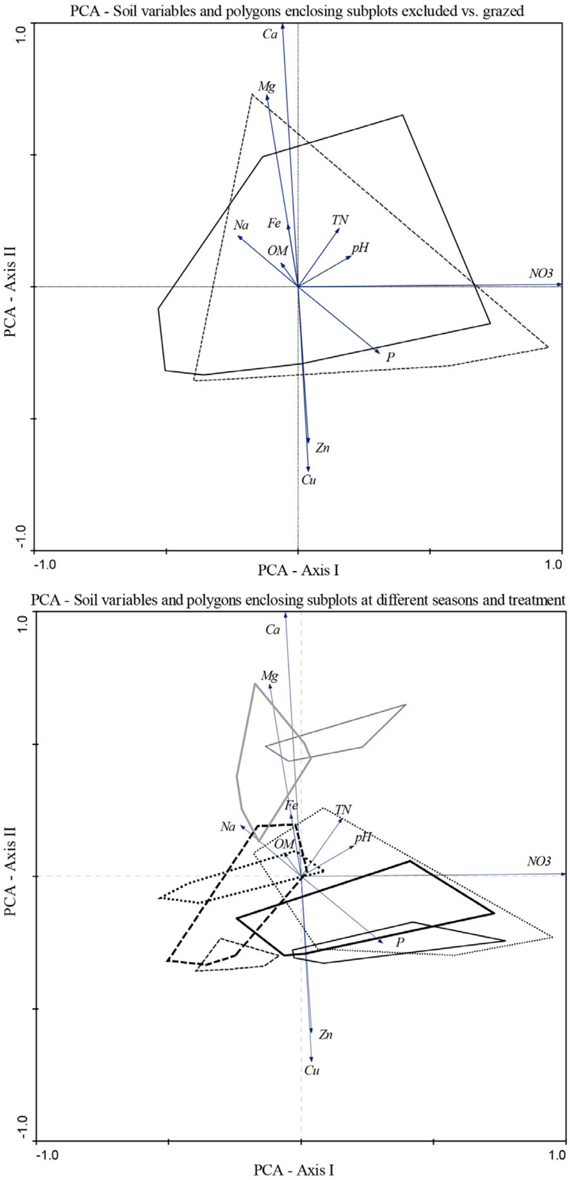

Figure 3. (a) Principal components analysis (PCA) of the soil samples of the plots and soil nutrients. Arrows indicate variables used. We used the information of five samples obtained from each subplot of both plots of the treatment and at each station. Samples of the same treatment are enclosed in a polygon (excluded plots: solid line; grazed plots: dashed line; eigenvalue for axis I: 0.87, eigenvalue for axis II: 0.11; cumulative percentage of variance explained for axes I and II: 97%). (b) In the same PCA analysis, we discriminated the plots based on season (spring, summer, autumn and winter) and treatment (excluded *vs*. grazed plots). Black polygons are used for grazed enclosing subplots at different seasons, while grey color is used for excluded polygons; summer: thin solid line, autumn: dotted line, spring: dashed line and winter: solid line.

Table 2. Mean and standard deviation (SD) of the nutrients in the subplots (n=10) in each season and for each treatment (E: excluded, G: grazed).

		pH	%OM	%TN	Ca	Mg	Na	P	NO_3	Cu	Zn	Fe
					meq L^{-1}			mg/L				
Spring_E	Mean	7.68	2.31	0.14	35.80	4.08	2.54	6.78	115.08	1.61	1.94	9.46
	SD	0.05	0.44	0.02	1.90	1.24	0.99	1.03	18.09	0.05	0.07	0.16
Spring_G	Mean	7.67	2.76	0.12	33.12	6.04	3.21	11.00	88.49	1.65	2.10	9.41
	SD	0.09	0.35	0.04	6.08	0.89	0.80	3.18	10.89	0.05	0.14	0.13
Winter_E	Mean	7.76	2.31	0.13	18.08	2.76	3.19	18.27	81.95	1.89	1.95	9.45
	SD	0.14	0.55	0.02	1.98	0.57	1.55	2.18	24.13	0.21	0.08	0.12
Winter_G	Mean	7.83	2.39	0.12	15.08	3.64	2.44	22.18	131.53	1.83	1.96	9.46
	SD	0.11	0.44	0.02	8.81	1.27	0.54	6.09	39.87	0.14	0.06	0.17
Summer_E	Mean	7.71	1.67	0.16	11.59	2.18	2.04	13.95	130.80	6.55	2.45	9.37
	SD	0.17	0.33	0.01	4.10	0.52	0.62	1.42	41.55	0.10	0.08	0.12
Summer_G	Mean	7.64	2.23	0.11	6.50	1.58	2.00	14.97	132.38	6.40	2.47	9.28
	SD	0.18	0.31	0.04	1.40	0.34	0.59	4.37	32.82	0.07	0.08	0.12
Autumn_E	Mean	7.53	2.61	0.14	12.09	2.00	2.59	7.04	80.94	6.27	2.44	9.37
	SD	0.17	0.38	0.04	8.09	0.43	0.11	2.04	19.67	0.05	0.12	0.12
Autumn_G	Mean	7.58	2.69	0.13	6.39	1.80	2.61	6.01	78.53	6.29	2.39	9.40
	SD	0.39	0.47	0.02	5.12	0.75	0.19	1.06	12.93	0.02	0.09	0.16

compensating for the decrease in grass and forb production (Aguiar *et al*., 1996). Several other studies have also indicated a low impact on aboveground plant biomass after several years of grazing exclusion (Arévalo *et al*., 2011a). However, it is important to note that the biomass of the unpalatable species is dominant in the grazed areas (Table S1 [suppl]).

As other studies have revealed (Karakosta & Papanastasis, 2007; Strand *et al*., 2014), an increase in woody species in grazed areas has been related to an increase in wildfire risk (Arévalo, 2012; Arévalo & Naranjo, 2018). However, regular patterns are still difficult to establish (Hughes *et al*., 2006).

In the study area, species richness was particularly vulnerable to grazing, something that we ascribe to overgrazing activity carried out in the area. Indeed, it is a common result in many overgrazed areas (Al-Rowaily *et al*., 2012; Wang *et al*., 2016; Zhu *et al*., 2016). However, these results are difficult to extrapolate, as they largely depend on the characteristics of the plant community and soil conditions, as well as other human disturbances (Olff & Ritchie, 1998). As mentioned, many studies have shown positive results of grazing on diversity (Tälle *et al*., 2016). In the present study, evenness index did not reveal differences. The highest species richness is found in late spring and summer (humid period), revealing its relationship with precipitation and soil infiltration.

Although *A. canescens* was not removed in the study site, it is not a representative species in the community in the exclosure plots as it maintains high biomass values throughout the seasons in both areas (grazed *vs*. excluded). *Atriplex* species are associated with areas of high salinity, low humidity and high temperature (Ramos *et al*., 2004). They have been used for erosion control and rehabilitation in salt-affected and degraded areas (de Souza *et al*., 2012; Rani *et al*., 2013). In desert regions, they have been used by farmers as maintenance feed for livestock during the drought feed gap (Norman *et al*., 2010; Pearce *et al*., 2010) or for landscaping purposes (Panta *et al*., 2014; Ventura *et al*., 2015).

Soil nutrient content composition changes related to seasonal variability and grazing *vs*. excluded treatment do not show any discrimination among plots (Figs. 3a,b). Although in many areas the impact of grazing shows important differences (Arévalo, 2012), we found that the most relevant factor in soil nutrient composition is related to seasonality. Based on the analysis (Fig. 3b), Ca and Mg showed higher values at the end of spring. In some areas, the increase in Ca and Mg is related to the solubility of these available cations in water (Chapman *et al*., 1997; Walna *et al*., 1998) or is even due to incorporation through rain (Sapek, 2014). From June to September, more than 45% of the total precipitation occurs in the study area, with July being the wettest month (77 mm) and March the driest in this period (12.4 mm; SMN, 2010). We can relate this cation solubilization to the first considerable precipitations of the year, as the soil was sampled at the end of June. This is supported by the infiltration values obtained (Fig. 5),

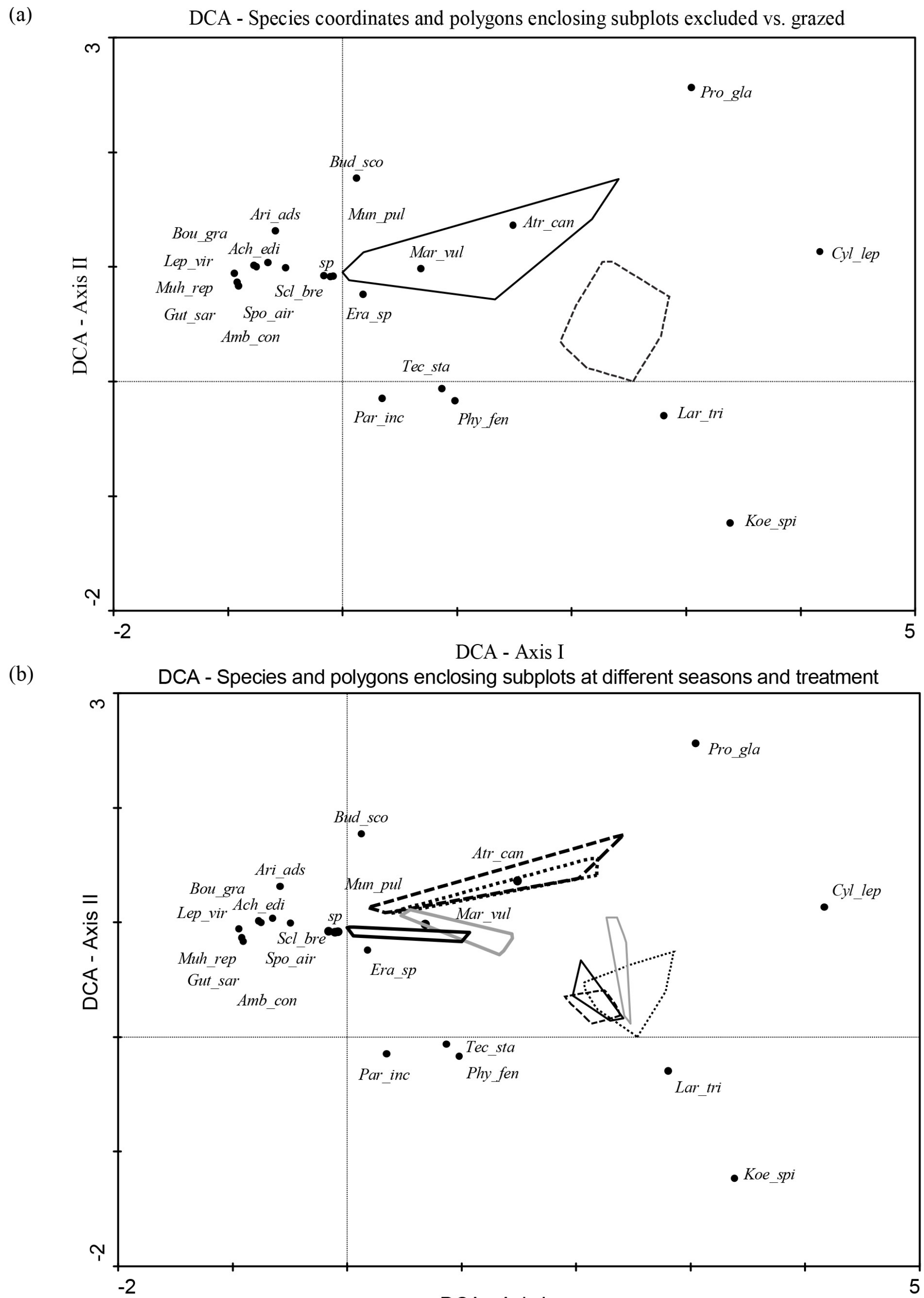

Figure 4. (a) Plot and species scores in the space defined by axis I and axis II of the DCA. Polygons enclose the subplots of the different treatments (excluded plots: solid line; grazed plots: dashed line; eigenvalue for axis I: 0.56; eigenvalue for axis II: 0.27; percentage of total inertia explained by axes I and II: 47%). Species names use the three first letters of the genus followed by the three first letters of the specific epithet from Table 1. (b) Subplot scores in the space defined by axis I and axis II of the DCA. Polygons enclose the subplots based on season (spring, summer, autumn and winter) and treatment (excluded *vs*. grazed plots). Black polygons are used for grazed enclosing subplots at different seasons, while grey color is used for excluded polygons; summer: thin solid line, autumn: dotted line, spring: dashed line and winter: solid line.

revealing significant differences in summer between the two areas once precipitation has become more abundant. Many factors are involved in water infiltration as saturated conductivity and infiltration capacity (Mein & Larson, 1973) as well as rain intensity. These factors determined that all the rain infiltrated into the factors due to the desert characteristics of the area. The excluded area showed

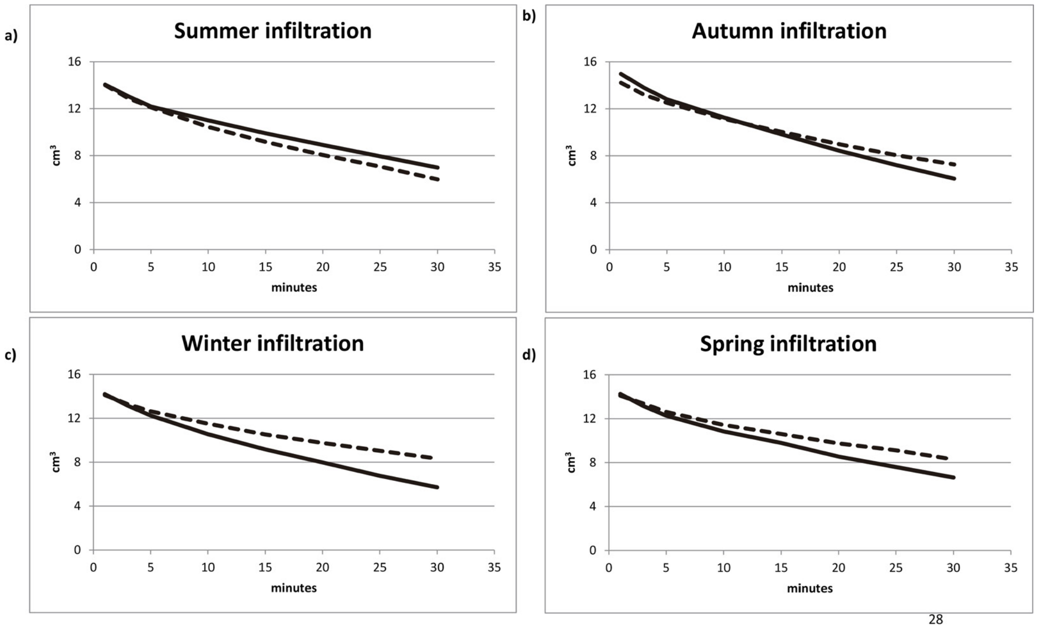

Figure 5. Average infiltration values over 30 minutes in different seasons: a) summer, b) autumn, c) winter and d) spring infiltration. Solid lines: excluded plots; dashed lines: grazed plots.

higher infiltration in summer, but significantly lower in winter and spring. As long as rain appears at the end of spring and summer in this area, we can assume that it will have an impact on the solubilization as availability of cations, as well as on the water available for the vegetation.

Species composition revealed important changes in the plant community determined by exclusion, whereas there was low variability with respect to the species composition determined by season (Figs. 4a,b). Scrub species dominated the grazed vegetation, while the excluded area was dominated by grasses and forbs, which is a common result (Karakosta & Papanastasis, 2007; Mayer *et al*., 2009). Grazing on more palatable species can sometimes promote dispersion, but in overgrazed areas the impact is almost a complete elimination of these species (Gusha & Mugabe, 2013), leaving only a plant community dominated by shrubs of low palatability and with an array of mechanical defenses against herbivores. This was the case in this study with three non-palatable species like *L. tridentata*, *C. leptocaulis* and *K. spinosa* dominating the exclusion area, while the excluded area was dominated by palatable grasses species as *B. gracilis*, *M. repens*, *A. editorum* or *Eragrostis* sp. as well as shrubs such as *Gutierrezia sarothrae* and *Buddleja scordioides*. Thus, it appears that exclusion leads to a partial recovery of the dominant plant community of the short grass. Reducing grazing intensity would likely favor a slight recovery of degraded grazing land, which is an important economic resource for farmers in the area (Teague & Barnes, 2017).

The study of grazing exclusion has potential management implications (*e.g.* setting the maximum number of animals, restricting traditional activities in the protected area, etc.) and environmental implications (*e.g.* plant and animal protection, control of invasive species…). It also has great socioeconomic importance because such research provides useful information to help range managers to continue grazing activity, which is of high cultural value (Arévalo *et al.,* 2011a, b).

In our study, despite the design of the experiment being somewhat limited, it was based on a long-term period of exclusion and a much extended area of plots. Therefore, we consider that the results are consistent and provide information that can be of interest. Exclusion management can lead to an important recovery in vegetation without affecting the growth of *Atriplex canescens*, a valuable source of fodder. Although biomass presented a higher dependence on seasonality and was not related to the treatment, the impact on the forage quality is evident by the different plant communities established after 25 years of exclusion. Therefore, due to the recovery of the plant community in the excluded area, we suggest that a reduction in grazing intensity is necessary to regain the productivity of palatable plants. Reducing grazing intensity also favors soil infiltration in summer, which, in turn, favors productivity and increases species diversity. The removal of shrubs can accelerate recovery, but leaving *A. canescens* untouched seems to have had no effect on its dominance in the area. Thus, in order to protect and favor these traditional activities, we suggest controlling grazing on this vegetation through management of grazing pressure, as a way of preserving landscape uses, cultural values and biodiversity.

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