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Short Communication

Restoration of palatable grasses: A study case in degraded rangelands of central Argentina

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ABSTRACT

Restoration of palatable grasses on degraded rangelands dominated by unpalatable grasses in central Argentina is limited by low availability of seeds and safe sites for seedling establishment. The objective of our study was to determine how mechanical disturbance of unpalatable grasses (*Stipa* spp.) in combination with seeding of a palatable grass (*Poa ligularis*) influenced species composition in a degraded rangeland excluded from livestock grazing. In April 2001 10 blocks were uniformly distributed on a previously burned site dominated by unpalatable grasses, and treatments applied in 8 m × 8 m experimental plots. Treatments were 'disked and seeded' and control (no disking, no seeding). Perennial plant cover and end-of-season standing crop, at species or species group level, were assessed in December 2002/2003 and in December 2004/2006, respectively. *P. ligularis* out-competed both tillers of unpalatable grasses that survived mechanical disturbance and seedlings of unpalatable grasses established after mechanical disturbance. The cover and end-of-season standing crop of unpalatable grasses was higher in the control than in the 'disked and seeded' treatment, whereas the cover and end-of-season standing crop of *P. ligularis* was higher in the latter than in the former treatment. Our results suggest that a rapid transition from a state dominated by unpalatable grasses to a state dominated by palatable grasses can be achieved by mechanical disturbance of unpalatable grasses in combination with seeding of palatable grasses in semiarid rangelands of central Argentina.

1. Introduction

Grazing by domestic livestock is commonly associated with changes in species composition in rangelands throughout the world (Milchunas and Lauenroth, 1993; Westoby et al., 1989). Shifts in species composition frequently involve replacement of palatable by unpalatable species (Archer and Smeins, 1991; Briske, 1991; Milton et al., 1994). Once unpalatable species attain dominance it can be difficult to reverse the change by relaxing or even removing grazing (Noy-Meir and Walker, 1986; Westoby et al., 1989). In semiarid rangelands of central Argentina, changes in species composition induced by livestock grazing include the total or partial replacement of palatable by unpalatable grasses

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(Distel and Bóo, 1996; Llorens, 1995). The former are dominant, whereas the latter are subordinate species in the pristine condition (Gallego et al., 2004). Unpalatable grasses are higher in fiber and lignin, and lower in mineral and protein content than palatable grasses (Cerqueira et al., 2004; Distel et al., 2005). These differences are reflected in the botanical composition of livestock diets (Bóo et al., 1993; Pisani et al., 2000).

Dominance by unpalatable grasses has been proposed as a stable state for rangeland vegetation in central Argentina (Distel and Bóo, 1996; Llorens, 1995). Transitions to more desirable states are limited by low availability of both safe sites for seedling establishment and propagules of palatable grass species. Individual tussocks of unpalatable grasses grow tall (60 cm or more) and present a wide canopy cover (0.5 m^2 or more), minimizing the possibilities for seedling establishment while undisturbed or only slightly disturbed (Distel et al., 1992). On the other hand, the soil seed bank of palatable species is strongly depleted in overgrazed areas (Mayor et al., 2003).

We conducted a study to assess the potential of mechanical disturbance in combination with seeding to overcome those limiting factors in a degraded grassland excluded from livestock grazing. We hypothesized that (1) disking stands dominated by unpalatable grasses would open safe sites for seedling establishment, (2) *Poa ligularis* Nees ex Steud, a late seral dominant palatable grass species (Gallego et al., 2004), would readily establish after seeding, and (3) *P. ligularis* would persist at the site by competitively excluding both remnants tillers of unpalatable grasses surviving disking, and seedlings of unpalatable grasses established after the mechanical treatment.

2. Materials and methods

2.1. Study area

The study was conducted in the southern part of the Caldén District (Cabrera, 1976), near Gaviotas (38°45′S; 63°45′W). Dominant soils are coarse-textured Calciustolls. A petrocalcic horizon is commonly found at depths of 60–80 cm. Climate is temperate, semiarid. Mean monthly temperatures range from 7 °C in July to 24 °C in January, with an annual mean of 15 °C. Mean annual rainfall is 400 mm, highly variable between years and with peaks in fall and spring. Precipitation at the study site was recorded with an automatic rain gauge throughout the experimental period.

The potential physiognomy for the vegetation is a grassland with scattered woody plants (Distel and Bóo, 1996). Most abundant herbaceous species are perennial cool-season bunchgrasses. Late seral dominants are mainly represented by palatable midgrasses (*P. ligularis*, *Stipa clarazii* Ball.); subordinate species are mostly palatable shortgrasses (*Stipa tenuis* Phil., *Piptochaetium napostaense* (Speg.) Hack.) and unpalatable grasses (*Stipa ichu* (Ruiz and Pav.) Kunth., *Stipa tenuissima* Trin., *Stipa trichotoma* Nees, *Stipa speciosa* Trin. and Rupr., *Stipa ambigua* Speg., *Stipa brachychaeta* Godr.). Overgrazing of these rangelands promotes replacement of palatable midgrasses by shortgrasses, and then a final replacement of the latter by unpalatable grasses, thus reaching a stable state (Distel and Bóo, 1996).

The study site comprised an area of 2 ha dominated by unpalatable grasses, representative of degraded rangelands in central Argentina. To facilitate the restoration objective, the site was protected from livestock grazing during the entire experimental period. Shortly after site selection, readings of basal cover were performed along ten 20 m transects in order to characterize the site before applying any treatment. Basal cover of palatable shortgrasses and unpalatable grasses was $2.9 \pm 2.5\%$ and $11.4 \pm 4.7\%$ (mean $\pm$ SD), respectively. There were no other perennial species present at the site.

2.2. Experimental design and treatments

In March 2001, the site was burned to eliminate standing dead biomass, and a month later 10 blocks were uniformly distributed on the site. Within each block, two experimental units (8 m × 8 m) were randomly assigned to one of the two treatments: 'disking and seeding' and untreated control. Disking consisted of one pass of a 2.65-m-wide disk ripper. Seeds of *P. ligularis* (60% germination power) were manually spread at an approximate density of 150 seed/m^2. Seeds had been hand harvested from a 30-year-old grazing exclosure located 30 km away from the study site.

To determine the effectiveness of the mechanical disturbance, the density of unpalatable grasses was assessed in December, 2002. Measurements were made on four 0.25 m × 6 m randomly located plots within each experimental unit. Density of unpalatable grasses was assessed by counting the number of plants per plot. Seedlings established after disking were differentiated from intact tussocks and tillers that survived mechanical disturbance.

2.3. Cover

Perennial plant cover at the species (*P. ligularis*) or species group (palatable shortgrasses, unpalatable grasses) level was assessed in December 2002 and 2003. Measurements were made on four 0.25 m × 6 m randomly located plots within each experimental unit. Digital imaging was used for that purpose. Images were obtained with a Canon Powershoot A50 camera (Canon Inc., Tokyo, Japan). Six consecutive images covering 0.25 m × 1 m were obtained from each plot. Photos were taken under full sunlight, between 10:00 and 16:00 h, and images (640 × 480 pixel in size each) saved in JPEG format. Species or species groups were recognized by foliage color and plant architecture, which was ground checked by visual inspection of diagnostic plots, and then differentially colored using Corel PHOTO-PAINT® 12 (Corel Corporation, Eden Prairie, MN, US).

The newly colored images were then saved in TIFF format and processed with Scion Image for Windows® (Scion Corporation, Frederick, MD, US). The color threshold feature in the Scion Image software allowed searching a digital image for areas of a specific color where pixels were counted. The total number of pixels by species or species group was finally divided by the total number of pixels in the plot to calculate plant cover data.

2.4. Biomass

End-of-season standing crop of species (*P. ligularis*) or species group (palatable shortgrasses, unpalatable grasses) was assessed in December 2004 and 2006. Vegetation composition, based on dry weight, represents one of the best indicators of species importance within a plant community. Aerial biomass was harvested by manual clipping 2.5 cm above soil surface in one 6 m long × 0.25 m wide randomly located plot per experimental unit. The harvested material was hand sorted to separate standing dead biomass from previous seasons; current season standing crop was then oven-dried at 65 °C until constant weight and weighed.

2.5. Statistical analyses

Data on cover and end-of-season standing crop were analyzed by ANOVA, according to a randomized block design. Each year of plant cover (2002 and 2003) or biomass (2004 and 2006) measurements was analyzed separately. Cover data were arc sin transformed prior to analysis.

3. Results

Rainfall throughout the experimental period was 566, 379, 365, 789, 187 and 201 mm, from 2001 to 2006, respectively. During the year of seeding (2001), rainfall was below long-term seasonal average in summer (91 vs. 120 mm), whereas it was above long-term seasonal average in fall (126 vs. 100 mm), winter (180 vs. 60 mm), and spring (169 vs. 120 mm).

In December 2002, the density of unpalatable grasses (adult+juvenile) was higher in the control than in the 'disked and seeded' treatment (Table 1). The density of adult plants was higher in the control than in the 'disked and seeded' treatment, whereas the density of juvenile plants was higher in the 'disked and seeded' treatment than in the control.

3.1. Cover

In both 2002 and 2003, the cover of *P. ligularis* was higher in the 'disked and seeded' treatment than in the control, whereas the cover of unpalatable grasses was higher in the control than in the 'disked and seeded' treatment (Table 2). Cover of palatable short grasses was similar between treatments (2002) or higher in the control than in the 'disked and seeded' treatment (2003). In both years total perennial plant cover was higher in the 'disked and seeded' treatment than in the control.

3.2. Biomass

In both 2004 and 2006, end-of-season standing crop of *P. ligularis* was higher in the 'disked and seeded' treatment than in the control, whereas end-of-season standing crop of unpalatable grasses was higher in the control than in the 'disked and seeded' treatment (Table 3). *P. ligularis* contributed the most (88% in 2004 and 100% in 2006) to the total aerial biomass in the 'disked and seeded' treatment, whereas unpalatable grasses contributed the most (66% in 2004 and 82% in 2006) to the total aerial biomass in the control treatment. Total end-of-season standing crop was similar between treatments in 2004, but it was higher in the 'disked and seeded' treatment than in the control in 2006.

Table 1
Density of unpalatable grasses (December 2002) after disking and seeding (fall 2001) with the palatable grass *P. ligularis* ('disked and seeded' treatment) on a site dominated by unpalatable grasses (control: no disking, no seeding).Values are mean ($n = 10$) ± 1 S.E.

Treatment	Density of unpalatable grasses (plants per hectare)		
	Adults[a]	Seedlings[b]	Total
Control	24 391 ± 3020	391 ± 97	24 781 ± 2993
'Disked and seeded'	875 ± 146	1 625 ± 298	2 500 ± 347
P	< 0.0001	0.001	< 0.0001

[a] Tussocks (control) or parts of tussocks that survived mechanical disturbance ('disked and seeded').
[b] Juvenile plants established after treatment application.

Table 2
Perennial plant cover (December 2002 and December 2003) after disking and seeding (fall 2001) with the palatable grass *P. ligularis* ('disked and seeded' treatment) on a site dominated by unpalatable grasses (control: no disking, no seeding). Values are mean ($n = 10$) ± 1 S.E.

Treatment	Cover (%)			
	P. ligularis	Shortgrasses	Unpalatable grasses	Total
2002				
Control	0.00 ± 0.00	3.67 ± 1.10	34.58 ± 3.20	38.25 ± 2.86
'Disked and seeded'	55.00 ± 1.65	4.67 ± 0.93	0.83 ± 0.39	60.50 ± 1.81
P	< 0.0001	0.5668	< 0.0001	< 0.0001
2003				
Control	1.97 ± 0.66	3.39 ± 0.90	34.65 ± 2.23	40.01 ± 1.94
'Disked and seeded'	49.15 ± 1.39	0.20 ± 0.12	0.98 ± 0.36	50.34 ± 1.43
P	<0.0001	0.0476	<0.0001	<0.0001

Table 3
End-of-season standing crop (December 2004 and December 2006) after disking and seeding (fall 2001) with the palatable grass *P. ligularis* ('disked and seeded' treatment) on a site dominated by unpalatable grasses (control: no disking, no seeding). Values are mean ($n = 10$) ± 1 S.E.

Treatment	End-of-season standing crop (Kg dry matter per hectare)			
	P. ligularis	Shortgrasses	Unpalatable grasses	Total
2004				
Control	84 ± 56	1902 ± 515	3922 ± 1114	5909 ± 960
'Disked and seeded'	6396 ± 729	273 ± 117	576 ± 352	7245 ± 736
P	< 0.0001	0.01	0.006	0.1811
2006				
Control	180 ± 120	375 ± 84	2500 ± 363	3055 ± 318
'Disked and seeded'	4381 ± 536	0	0	4381 ± 536
P	<0.0001	0.0016	0.0002	0.0227

4. Discussion

Mechanical disturbance combined with seeding of *P. ligularis* was markedly detrimental to density (Table 1), cover (Table 2) and biomass (Table 3) of unpalatable grasses. The most probable reason for the success of the 'disked and seeded' treatment was reduced competition from large tussock of unpalatable grasses, combined with adequate soil moisture for seedling establishment after seeding. Both surviving tillers and seedlings of unpalatable grasses were out-competed by *P. ligularis*. This species posses traits such as the growth of large tussocks (Distel and Bóo, 1996), high leaf nitrogen content (Cerqueira et al., 2004), high specific leaf area, high relative growth rate, and low tissue density (A. Flemmer 2001, Universidad Nacional del Sur, Bahía Blanca, Argentina, personal communication), which suggest a high potential to compete for resources and become a dominant species (Grime 2001). Although the competitive ability of *P. ligularis* in particular has not been studied, results from a previous study showed a higher ability to compete for resources in palatable than unpalatable grasses in the system under study (Moretto and Distel, 1997). Annual rainfall in the first 4 years of the study was close to or above the long-term average (400 mm), which may have contributed to the expression of the competitive ability of *P. ligularis*. Regardless of wet (2004) or dry (2006) condition, however, *P. ligularis* contributed the most (88–100%) to the end-of-season standing crop in the 'disked and seeded' treatment.

The replacement of palatable by unpalatable grasses, induced by livestock overgrazing, results in the ecological degradation of rangelands. Unpalatable grasses possess traits such as leaf silicification, leaf sclerophylly, large size, and longevity that lead to reduced primary productivity, decelerated nutrient cycling, and decreased plant species diversity (Cingolani et al., 2005; Grime, 2001; Hobbie, 1992). Such floristic changes also lead to economic and social problems because of their negative impact on livestock carrying capacity. Our results show that a rapid transition from a state dominated by unpalatable grasses to a state dominated by palatable grasses can be achieved by mechanical disturbance of mature stands of unpalatable grasses in combination with seeding of palatable grasses.

The lack of replication in space and time, and omitted main treatments like seeding alone, represent design limitations of the present study. However, the stability of mature stands of unpalatable grasses mainly originates in their functional ecological traits (e.g., large tussocks that accumulate huge quantities of senescent biomass that decompose slowly), rather than on edaphic conditions (Distel and Bóo, 1996). This particularity enhances the probability of success of the 'disked and seeded' treatment across sites in the studied grasslands. On the other hand, climate conditions after seeding may be critical

for *P. ligularis* establishment. It is already known that successful establishment of perennial grasses native to central Argentina depend upon adequate soil moisture in fall and winter (Distel et al., 1992), which were the prevailing conditions after seeding in 2001. Finally, mechanical damage to the stand of unpalatable grasses seems to be an indispensable part of any restoration treatment because well-established stands of unpalatable grasses have proved to be impervious to invasion by palatable grasses. This, in turn, occurs because the former species easily out-compete seedlings of the latter species (Distel et al., 1992). Fires of moderate severity, commonly applied by ranchers in late summer–early fall, would not be an alternative to mechanical disturbance since, under the mild conditions of late summer–early fall fires, the mortality of unpalatable grasses is quite limited (Bóo et al., 1996). Pre-fire cover values of unpalatable grasses will be rapidly restored since they show high regrowth capacity after defoliation (Distel et al., 2007). In the present study, unpalatable grasses maintained a high density of adult plants in the control after been burnt to eliminate standing dead biomass in March 2001 (Table 1).

5. Implications

The important practical implication derived from the present study is that a rapid transition from a state dominated by unpalatable grasses to a state dominated by palatable grasses can be achieved by mechanical disturbance combined with seeding. Additional research is needed to determine the implications of restoring palatable grasses on rangeland carrying capacity and to establish how grazing should be managed for long-term persistence of restored palatable grasses in grazed rangelands of central Argentina.

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