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Short-Term Effects of Pack Animal Grazing Exclusion from Andean Alpine Meadows

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Abstract

Grazing by livestock can have positive, neutral, and/or negative effects on vegetation depending on the intensity and type of grazing. This includes grazing by pack animals used for tourism in mountain protected areas. We assessed the response of vegetation to the exclusion of grazing by pack animals over one growing season in the highest park in the Southern Hemisphere, Aconcagua Provincial Park, dry Central Andes. Twenty pairs of exclosures and unfenced quadrats were established in three high-altitude Andean alpine meadows that are intensively grazed by horses and mules used by commercial operators to transport equipment for tourists. Vegetation parameters, including height, cover, and composition were measured in late spring when exclosures were established and ~120 days later at the end of the growing season along with above-ground biomass. Data was analyzed using mixed models and ordinations. Vegetation responded rapidly to the removal of grazing. Vegetation in exclosures was more than twice as tall, had 30% more above-ground biomass, a greater cover of grasses including the dominant *Deyeuxia eminens,* and less litter than grazed quadrats. These changes in the vegetation from short-term exclusion of grazing are likely to increase the habitat quality of the meadows for native wildlife.

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Introduction

Grazing by large herbivores affects vegetation dynamics in grasslands, including positive, neutral, and negative changes in productivity and biodiversity (Milchunas and Lauenroth, 1993; Briske et al., 2003; Cingolani et al., 2005). In systems with a long grazing history, grazing can contribute to resource availability by increasing productivity, with maximal growth at intermediate levels of grazing (McNaughton, 1984). Grazing can also increase plant diversity by selectively removing more competitive common palatable species, resulting in increased diversity and cover of less palatable species that previously were uncommon (Milchunas et al., 1989; Hobbs and Huenneke, 1992; Buttolph and Coppock, 2004).

In situations where the intensity or the type of grazing has changed, grazing may reduce productivity and biodiversity (Cingolani et al., 2005; Villalobos and Zalba, 2010). Differences between the current and past grazing pressure, even where vegetation is adapted to herbivory, can affect the vulnerability of ecosystems to grazing (Cingolani et al., 2008; Renison et al., 2010). For example, reductions in productivity due to a greater herbivore biomass per unit area can occur with intensive management of domestic livestock, compared to unmanaged systems (Oesterheld et al., 1992; Cingolani et al., 2008). Differences in animal allometry, such as larger hooves and/or body size of domestic livestock compared to wild herbivores, can also result in changes in native vegetation structure and cover (Cumming and Cumming, 2003).

The use of horses and mules as pack animals in protected areas can increase grazing pressure on native grasslands. These pack animals are increasingly used for transporting visitors and their equipment to more remote conservation areas where there is limited road access (Geneletti and Dawa, 2009). This can result in high grazing pressure along hiking trails and campgrounds near water sources, with the numbers of animals often determined by visitor demand rather than sustainable grazing practices (Cole et al., 2004; Byers, 2010). Grazing by these pack animals is of concern in mountain protected areas as it is concentrated during the short snow-free period when most biological processes occur (Geneletti and Dawa, 2009). In addition, alpine plants often have low resilience to disturbance (Körner, 2003).

The effects of grazing by pack animals in alpine regions have received little attention despite their increased use in many mountain protected areas (Parsons, 2002; Cole et al., 2004). This is of particular concern as the principal function of these areas is the conservation of biodiversity (Cole et al., 2004; Crisfield et al., 2012), and grazing is often unregulated and rarely monitored (Moore et al., 2000; Cole et al., 2004). For example, although the use of introduced pack animals (e.g., horses and mules) to transport equipment for mountaineers is increasingly common in some protected areas across the Andes, grazing by these animals is often unregulated (Byers, 2010; Barros et al., 2013).

Research in the Andes has found positive, negative, and neutral effects on vegetation and soils from grazing by introduced livestock and by native herbivores (Preston et al., 2003; Squeo et al., 2006b; Molinillo and Monasterio, 2006). Most research is in areas used for pastoralism that vary in environmental conditions, seasonality, and grazing regime (Bradford et al., 1987; Adler and Morales, 1999; Alzérreca et al., 2001, 2006; Molinillo, 1993; Hofstede et al., 1995; Preston et al., 2003; Molinillo and Monasterio, 2006; Nosetto et al., 2006; Squeo et al., 2006b; Patty et al., 2010). There is very limited work assessing the impacts of grazing by livestock in protected areas in the Andes, including grazing by pack animals on alpine vegetation.

The dry Andes (31–35°S) can be particularly susceptible to grazing by pack animals, as vegetation is often restricted to the valley floors, where tourism and hence pack animal grazing is also concentrated (Barros et al., 2013). This includes grazing on alpine meadows, which are of high conservation value as they provide habitat for wildlife, including ground nesting birds, and play a key role in ecosystem services, including carbon sequestration and wa-

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ter regulation (Earle et al., 2003; Squeo et al., 2006a; Buono et al., 2010; Otto et al., 2011).

While some impacts of grazing are only evident over the long-term, we were interested in assessing the short-term response of alpine meadows to the removal of grazing by pack animals over a growing season. This included assessing if there were changes in vegetation height, biomass, and composition, as these parameters are likely to reflect the habitat quality of the meadows for native animals. We assessed the initial effects of excluding grazing by horses and mules in the highest park in the Southern Hemisphere, Aconcagua Provincial Park in Argentina. Specifically, we compared vegetation height, biomass, and composition between grazed quadrats and grazing exclosures.

Methods

STUDY AREA

Aconcagua Provincial Park is a Category II IUCN park in the Central Andes (69º50′W, 32º39′S) that protects 70,000 hectares of glaciers, watersheds, and alpine ecosystems around Mount Aconcagua. Temperatures are low all year with winter averages of 0 °C and summer averages of 11 °C at 2900 m a.s.l. (Departamento General de Irrigación, 2011). Above 2700 m a.s.l., there is snow cover for over four months per year, with an annual average snow water equivalent of 100 mm for the past 10 years (Departamento General de Irrigación, 2011).

The park is increasingly popular for tourism, with around 6000 hikers and mountaineers using the park each summer. All of the campsites used by mountaineers are remote, with only 3 km of road compared to 112 km of trails throughout the park. Therefore, mules and some horses are used by commercial tour operators to transport equipment for those staying in the remote campsites. There are around 5000 pack animals using the park each summer, resulting in high grazing pressure along the two main trails. Before commercial mountaineering, there was limited human use of the park, with transient use by indigenous communities for ceremonial rituals (Bárcena, 1998; Schobinger, 1999), military training in the mid-1900s, and a few climbing expeditions (Dirección de Recursos Naturales, 2009).

Grazing by pack animals is concentrated in the high canopy cover (>90%) and highly productive (>1000 g m^{-2}) Andean meadows (Squeo et al., 2006a). These occur close to streams or high groundwater valley bottoms, shallow basins, and other low relief areas between 2400 and 3800 m a.s.l. (Barros, 2004; Mendez et al., 2006) on moist soils rich in organic matter (16% ± 3%) (Barros et al., unpublished). They are preferentially used by commercial operators to graze pack animals, as the surrounding vegetation is sparse growing on shallow soils and often steep slopes.

There are around 124 species of plants in the region (Mendez et al., 2006), predominantly perennials (Mendez et al., 2006). Common species in the Andean meadows include tussock grasses (*Deyeuxia* spp.), geophyte sedges (*Carex gayana, Eleocharis pseudoalbibracteata*), herbs (*Werneria pygmaea, Mimulus luteus),* and rushes (*Oxychloe bisexualis, Patosia clandestina*) (Mendez et al., 2006). As in many arid mountain regions of the world, there is no real timberline at this latitude (33°S) (Hoffmann, 1982).

The only large native grazing mammal in the park is the guanaco (*Lama guanicoe*, a camelid), which is mostly found in the wilderness areas of the park far from tourist trails (Dirección de Recursos Naturales, 2009). The only exotic wild grazer is the European hare (*Lepus europaeus*) (Dirección de Recursos Naturales, 2009), which tends to avoid main trails and campsites (Agustina Barros, personal observation, 2012). Bird diversity is relatively high (92 species), with a high number of bird species nesting in the park (44) (Olivera and Lardelli, 2009).

STUDY SITE

The effects of excluding grazing by large mammals for one growing season were assessed in three meadows used for grazing by pack animals. The meadows are in the alpine zone intersecting the access trail for one of the two main base camps of Aconcagua, Plaza Argentina (4250 m a.s.l.; Fig. 1). Before reaching base camp, tourists and pack animals stay overnight at intermediate campsites. Although these sites have been grazed by pack animals for over 50 years, there has been an exponential increase in the use of pack animals since 2000 (Dirección de Recursos Naturales, 2011), with around 500 pack animals grazing overnight in this valley in 2000–2001 and 2700 pack animals in 2010–2011 (Dirección de Recursos Naturales, 2011).

Study Meadows 1 and 2 were located close to Casa de Piedra campsite at 3200 m a.s.l., 27 km and 2 days walking from the trailhead. Meadow 1 is a sloping meadow situated on the side of a landslide and is kept wet by springs, rain, and snowfall water. Meadow 2 is on a flat area in an alluvial plain and is fed by surface and underground water from the Vacas River. Meadow 3 is near the informal campsite Plaza Argentina Inferior in Los Relinchos Valley at 3700 m a.s.l., 32 km and 3 days walking from the trailhead. It is

TABLE 1

Details of the three meadows on Vacas route in Aconcagua Provincial Park, where the grazing exclusion experiment was conducted between November 2010 and March 2011. Includes the number of paired quadrats sampled, location, altitude, and slope, and the estimate of the intensity of grazing by pack animals (dry weight of dung per m^2).

Meadow	# paired quadrats	Latitude, Longitude	Altitude (m a.s.l.)	Total area (ha)	Slope (º)	Dung (g m^{-2})
Casa de Piedra						
Meadow 1	5	32°37′50″S, 69°50′18″W	3251	1	10 ± 0.9	27.6
Meadow 2	5	32°38′40″S, 69°50′20″W	3200	1.12	2 ± 0.2	14.9
Plaza Argentina						
Meadow 3	10	32°38′19″S, 69°53′53″W	3795	3	3 ± 0.3	1.1

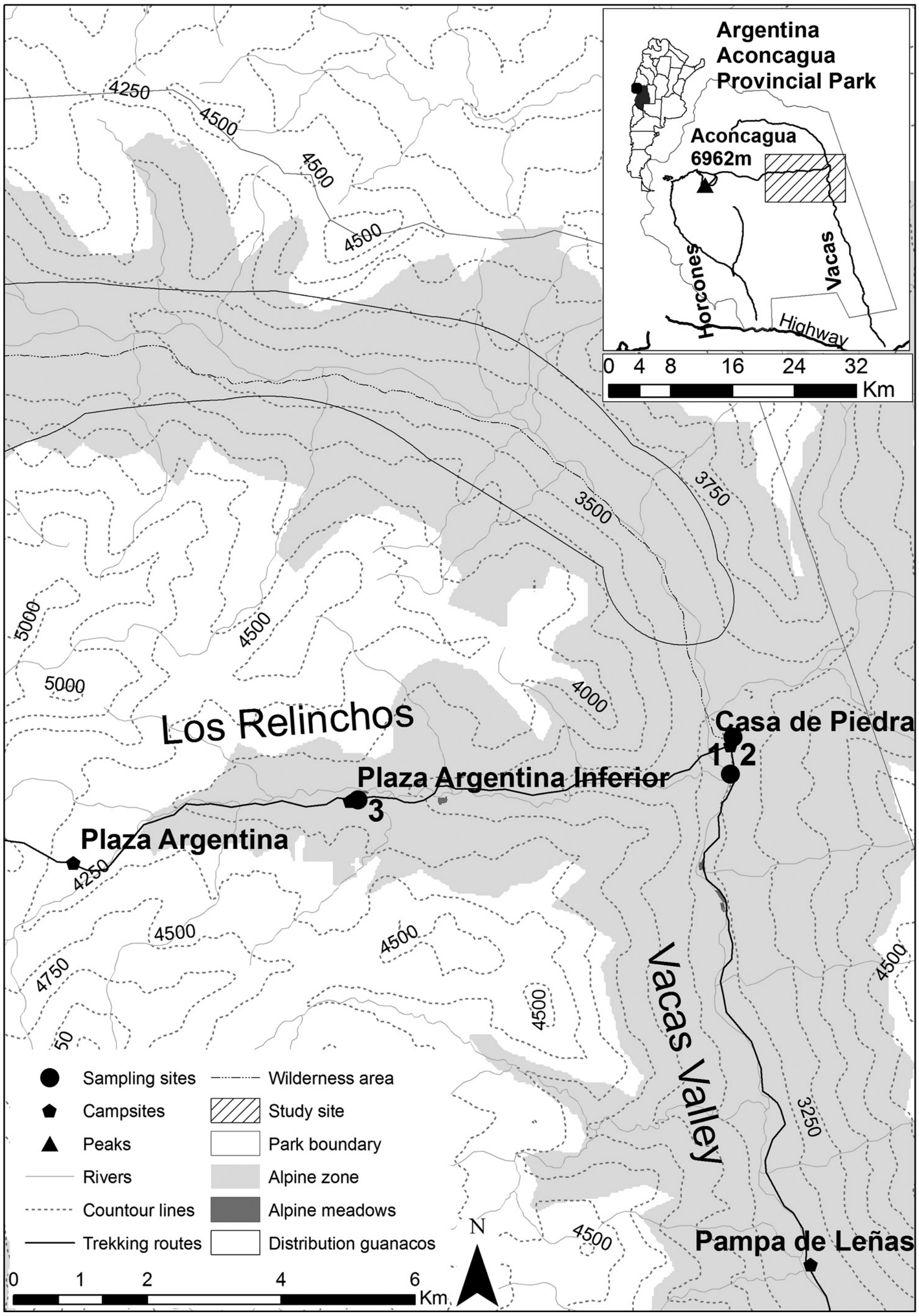

FIGURE 1. Location of the alpine Meadow 1 and Meadow 2 in Casa de Piedra and Meadow 3 in Plaza Argentina Inferior, where the experiment was conducted between November 2010 and March 2011 in Aconcagua Provincial Park (32°39′S, 69°50′W).

situated on an alluvial plain and is fed by ground and surface water from Los Relinchos River (Table 1, Figs. 1 and 2).

FIELD SAMPLING

In the three meadows, paired quadrats (exclosures and unfenced quadrats) were randomly located within each meadow and treatments were randomly assigned. Due to differences in the size of the meadows, the first two meadows contained 5 paired quadrats each, while there were 10 paired quadrats in the third meadow, making a total of 40 quadrats. Paired quadrats were established in late spring in early November 2010 at the beginning of the growing season but before visitors and pack animals entered the park (Fig. 1). Paired quadrats were 3–5 m apart, and a minimum of 30 m apart from other paired quadrats (average 60 ± 34 m). Square exclosures 1 m^2 wide and 0.6 m high with a top were constructed out of sima mesh fence (a 10 × 10 cm mesh).

For each quadrat aspect, slope and altitude were recorded. Vegetation was measured during exclosure establishment at the beginning of the growing season, and 120 days later in March 2011 at the end of the growing season. We recorded vegetation height, litter, bare soil, species richness, composition, and cover in the central 80 × 80 cm area of the quadrat, leaving a 10 cm buffer. Maximum vegetation height was measured at 20 evenly spaced points per quadrat. The cover of each species was assessed by recording the number of 100 evenly spaced points touched by each

FIGURE 2. General view of the three meadows (left) and of an exclosure in each alpine meadow at the end of the experiment in March 2011 (right) in Aconcagua Provincial Park. (a, b) Meadow 1, (c, d) Meadow 2, and (e, f) Meadow 3.

species. Multiple hits per point were possible where different species occurred at the same point. The number of points that touched litter underneath living vegetation was also recorded. These data were then used to calculate the cover of each species and growth forms (grasses, sedges, herbs, rushes). All species that were present in the 80 × 80 cm but not "hit" were given an arbitrary low cover value of

0.5% and added to the estimate of species richness for the quadrat. The same 100 points were used to assess absolute cover, but only one record was made per point: where the highest to touch the rod was vegetation, uncovered litter, or bare soil. In March 2011, above-ground biomass was measured by removing at ground level all vegetation and litter from a 25 cm × 25 cm area in the center of each quadrat. These biomass samples were carried out of the park, dried at 70 °C in an oven for a minimum of 48 hours, and then weighed.

To obtain a measure of grazing intensity for each meadow, the dry weight of dung per m^2 produced over the period of the experiment was assessed (Lange, 1969). This was done by removing all horse/mule dung in an area of 36 m^2 in each meadow before commercial operators started using pack animals that season. Then, in March 2011 all dung in the same areas was collected, carried out of the park, dried in an oven for 72 hours at 70 °C, and then weighed.

We could not directly compare the effect of grazing intensity among quadrats because of the design of the experiment, with quadrats nested within meadows that differ in a range of features in addition to grazing intensity (Table 1). Although assessing the effects of grazing intensity would be useful, we were unable to undertake a parallel replicated, randomized experimental design by manipulating grazing intensity due to restrictions on tethering and fencing enclosures for pack animals within the park (Dirección de Recursos Naturales, 2009) and the logistics of conducting such an experiment in a remote site where access involves several days' hiking into the sites.

DATA ANALYSIS

The effect of the removal of grazing over the 120-day growing season was analyzed using a general linear mixed model procedure (SPSS Version 20.0). The dependent variables were change in vegetation height and floristic composition during the growing season, biomass, species richness, and the overlapping cover of litter, grasses, sedges, and the two common species *Deyeuxia eminens* var. *fulva* and *Carex* aff. *gayana* at the end of the growing season. Change in floristic composition was calculated using Sorensen's index of similarity (Magurran, 1988) for presence/absence data between the start and end of the growing season, with a value of 1 for the index indicating there was no difference in composition. Treatment (grazed/ungrazed quadrats), meadow, and the interaction between meadow and treatment were used as fixed factors. Paired quadrats nested within meadows were used as the random factor. When appropriate, post hoc comparisons were conducted using Fisher's Least Significant Difference (LSD) for multiple comparisons ($p > 0.05$). To determine if there were differences between the overlapping cover of growth forms and species between November and March, paired sample *t*-tests were performed for exclosures and for grazed quadrats. The normality of the data was assessed by using quantile-quantile plots of the residuals.

To determine if there were differences in species composition between exclosure and grazed quadrats (treatment) and among meadows, ordinations were performed with treatment nested within meadows for the cover of species and growth forms (grasses, sedges, herbs, rushes, bryophyta), including litter and bare soil at the end of the season using the multivariate statistical package Primer (version 6.0). Dissimilarity matrices were calculated using the Bray-Curtis dissimilarity measures on untransformed data. An Analysis of Similarity (ANOSIM) was used to determine if there were significant differences in species composition between treatments and between meadows. The ANOSIM is a nonparametric permutation procedure applied to the rank dissimilarity matrix that is analogous to Analysis of Variance, except that it is distribution free. The ANOSIM test statistic, rho (ρ), is a measure of variation between samples compared to variation within samples for a suite of species using ranked differences among replicates (Clarke, 1993). It is scaled to lie between –1 and +l, with increasing values representing increasing differences among samples (Chapman and Underwood, 1999).

Results

At the start of the experiment in late spring, the three meadows had high vegetation cover (99%) dominated by grasses (63%) and sedges (34%), with a few herbs (4%), rushes (9%), and bryophytes (0.1%). By the end of the growing season, vegetation height had increased by 12 cm in the exclosures ($p < 0.01$) and 1 cm in the grazed sites ($p < 0.01$) (paired *t*-tests, Table 2). In the exclosures, the cover of herbs and sedges increased by 9% ± 4% ($p = 0.01$) and 14% ± 6% ($p = 0.03$), respectively. The cover of grasses increased by 5% ± 7% ($p = 0.492$). In grazed sites, herbs and sedges increased by 5% ± 2% ($p = 0.032$) and 18% ± 6% ($p = 0.005$), respectively, while grasses cover decreased by 11% ± 3% ($p = 0.04$).

A total of 16 species, all native, were recorded across the 40 quadrats at the end of the growing season, including two grasses (*Hordeum comosum* and *Pucinellia argentinensis*) that were not visible in spring (Appendix 1). There were 9 species recorded in quadrats in Meadow 1, 6 in Meadow 2, and 10 in Meadow 3, with 3 species in all three meadows (*Deyeuxia eminens* var. *fulva*, *Carex* aff. *gayana*, *Eleocharis pseudoalbibracteata*). Bryophytes were found in all meadows (Appendix 1). The sedge, *Carex* aff. *gayana,*

TABLE 2

Mean and standard errors of change in height (cm) between November 2010 and the following March 2011. Above-ground biomass (g/m^2), floristic similarity, and species richness per 0.8 m^2 quadrat in March 2011 in exclosure and grazed quadrats in the three alpine meadows in Aconcagua Provincial Park.

	Overall		Casa de Piedra Meadow 1		Casa de Piedra Meadow 2		Plaza Argentina Meadow 3	
	Exclosure	Grazed	Exclosure	Grazed	Exclosure	Grazed	Exclosure	Grazed
Change in height	12.0 ± 2.6	1.4 ± 0.6	21.8 ± 8.8	1.8 ± 0.5	13.1 ± 2.6	1.0 ± 1.6	6.6 ± 1.2	2.5 ± 0.6
Biomass	1245 ± 157	888 ± 137	1061 ± 358	778 ± 418	1313 ± 362	793 ± 328	1304 ± 211	990 ± 119
Floristic similarity	0.84 ± 0.04	0.84 ± 0.05	0.73 ± 0.11	0.74 ± 0.13	0.96 ± 0.04	0.97 ± 0.04	0.82 ± 0.05	0.82 ± 0.04
Species richness	2.8 ± 0.2	2.8 ± 0.3	3.4 ± 0.4	2.8 ± 0.5	2.0 ± 0.4	2.2 ± 0.6	2.9 ± 0.4	3.1 ± 0.4

was abundant in all meadows, and the grass, *Deyeuxia eminens* var. *fulva,* was abundant in Meadows 1 and 2 (Appendix 1). Species richness was not affected by treatment, meadow, or the interaction between treatment and meadow (Tables 2 and 3). On average, there were 3 species per quadrat in grazed and ungrazed treatments (Table 2).

There were significant differences in vegetation between the ungrazed and grazed meadows at the end of one growing season (Table 3). While above-ground biomass, the overlapping cover of grasses, *Deyeuxia eminens* var. *fulva,* and litter all differed between grazed and ungrazed quadrats, there were no significant differences between meadows and the interaction between treatment and meadow (Table 3). Excluding grazing resulted in 30% more biomass in the exclosures (Tables 2 and 3) and 9% more cover of grasses (Tables 3 and 4). The cover of the most common grass, *Deyeuxia eminens* var. *fulva,* was significantly greater in the exclosures (30%) than in the grazed quadrats (25%) (Tables 3 and 4, Appendix 1). Grazed quadrats also had significantly more litter (22%) than exclosures (8%) (Tables 3 and 4).

The cover of herbs, sedges, *Carex* aff. *gayana,* and the floristic similarity, however, was not affected by treatment, meadow, and the interaction between treatment and meadow (Tables 3 and 4). The overall composition was not affected by grazing exclusion, as measured by the overlapping cover of growth forms ($\rho = 0.064$, $p = 0.904$) and species ($\rho = 0.091$, $p = 0.983$). Plant composition did not differ among meadows based on the overlapping cover of growth forms ($\rho = 0.444$, $p = 0.067$) or species ($\rho = 0.944$, $p = 0.067$).

The three meadows had different grazing intensity based on the dry weight of dung produced over the season (Table 1). Grazing pressure in Meadow 1 (28 g m^{-2}) was 46% greater than in Meadow 2, and 96% more than in Meadow 3. The change in vegetation height over the growing season was affected by treatment, but there were differences in the size of the effect among meadows (Table 3). There were significant differences in height between the exclosures and grazed quadrats for Meadows 1 and 2, but not for Meadow 3 (using post hoc tests), which is at higher altitude (Fig. 2). Overall, the difference in vegetation height was 11 cm between grazed and ungrazed quadrats (Table 2).

Discussion

Excluding grazing over one growing season resulted in changes in vegetation, including increases in above-ground biomass, vegetation height, cover of grasses, and reductions in litter for the three meadows. Overall, vegetation height and above-ground biomass were very sensitive to the removal of grazing in Aconcagua meadows, with 30% more biomass and vegetation height twofold taller over just one growing season. This likely reflects the high productivity of these meadows with moist deep soils of high vegetation cover and the concentrated nature of grazing during the peak period of vegetation growth.

Results found in Aconcagua are consistent with previous research in Andean meadows in Bolivia that found that vegetation responds rapidly to the removal of grazing, with increases in above-ground biomass, plant height, and palatable species after two years of exclusion (Alzérreca et al., 2001, 2006). In contrast to our results, two other studies in similar vegetation in the Andes found no changes in above-ground biomass in the short term (3–6 years). For Andean meadows in Cosapa, Bolivia, where grazing was by sheep and camelids, the lack of any effect on biomass from removing grazing was attributed to the dry conditions, low productivity, and long grazing history (7000 years) by camelids in these meadows (Buttolph and Coppock, 2004). In central Chile, the lack of vegetation differences with the cessation of grazing by camelids was attributed to the low intensity of grazing by these herbivores in the Andean meadows (Squeo et al., 2006b).

Among the three Aconcagua alpine meadows, there were no differences in vegetation height, biomass, floristic similarity, the overlapping cover of grasses, sedges, herbs, litter, species richness, or the cover of the two dominant species, *Deyeuxia eminens* var. *fulva* and *Carex* aff. *gayana*, despite differences in slope, altitude, and meadow size. There were also no differences in the size of the effect of grazing for all of these variables, apart from height, despite differences in grazing pressure among the meadows. The increase in vegetation height with the removal of grazing was greatest in one of the lower altitude meadows (3251 m a.s.l.). This meadow was subject to higher grazing pressure, which could sub-

TABLE 3

General linear mixed model on the effects of treatment (exclosure vs. grazed), meadow (Meadow 1, Meadow 2, Meadow 3), and the interaction between treatment and meadow for different vegetation parameters in alpine meadows in Aconcagua Provincial Park (d.f. = 17). * Log transformed, ** Arcsine square root transformed. Values in bold are significant at $\alpha = 0.05$.

	Meadow		Treatment		Meadow*Treatment	
	F	*P*	*F*	*P*	*F*	*P*
Change in height*	1.977	0.154	35.2	**<0.001**	4.833	**0.014**
Biomass*	1.035	0.377	13.388	**0.002**	1.391	0.276
Floristic similarity	2.628	0.101	0.010	0.920	0.006	0.994
Overlapping cover						
Grasses**	1.061	0.368	10.033	**0.006**	1.697	0.213
Sedges**	0.316	0.733	1.722	0.207	0.778	0.475
Herbs**	2.943	0.080	2.134	0.162	0.710	0.506
Deyeuxia eminens var. *fulva***	3.289	0.062	10.229	**0.005**	0.830	0.453
Carex aff. *gayana***	1.327	0.291	0.477	0.499	0.550	0.584
Litter**	2.448	0.116	6.926	**0.017**	1.758	0.202
Species richness	2.093	0.154	0.038	0.847	0.573	0.574

TABLE 4

Mean and standard errors of the overlapping cover of growth forms (grasses, sedges, rushes, herbs, mosses) and litter under vegetation and bare soil in March 2011 in exclosure and grazed quadrats in the three alpine meadows in Aconcagua Provincial Park. Cover = overlapping cover, q. = number of quadrats, T.q. = total quadrats.

	Overall $n = 20$					Casa de Piedra Meadow 1 $n = 5$				Casa de Piedra Meadow 2 $n = 5$				Plaza Argentina Meadow 3 $n = 10$			
	Exclosure		Grazed			Exclosure		Grazed		Exclosure		Grazed		Exclosure		Grazed	
Cover	q.	Mean ± S.E	q.	Mean ± S.E	T.q.	q.	Mean ± S.E	q.	Mean ± S.E	q.	Mean ± S.E	q.	Mean ± S.E	q.	Mean ± S.E	q.	Mean ± S.E
Grasses	19	64.6 ± 8.1	19	56.0 ± 9.0	38	4	57.6 ± 21.3	4	39.1 ± 23.0	5	86.4 ± 11.0	5	72.9 ± 17.6	10	57.3 ± 10.6	10	55.9 ± 11
Sedges	13	52.2 ± 11.9	14	47.4 ± 10.0	27	4	70.2 ± 30.8	4	60.0 ± 21.1	3	32.6 ± 18.4	3	30.4 ± 19.6	6	54.5 ± 16.5	7	49.6 ± 14.5
Rushes	3	9.8 ± 6.7	5	10.4 ± 6.7	8	1	19.8 ± 19.8	1	19.4 ± 19.4					2	9.7 ± 9.6	4	11 ± 9.8
Herbs	13	16.2 ± 6.7	16	7.2 ± 2.6	29	3	36.2 ± 16.4	4	15.2 ± 9.0					10	14.3 ± 9.6	12	6.7 ± 2.2
Moss	4	0.1 ± 0.1	1	0.3 ± 0.3	5	1	0.1 ± 0.1			1	0.2 ± 0.2	1	1.2 ± 1.2	2	0.1 ± 0.1		
Litter	9	7.9 ± 3.7	13	22.4 ± 6.6	22			2	1.0 ± 0	3	6.7 ± 2.6	4	14 ± 7.7	6	8.5 ± 4.5	7	33.3 ± 9.8
Bare soil	2	0.05 ± 0.05	5	0.22 ± 0.09	7			2	0.4 ± 0.2	1	0.2 ± 0.2	2	0.6 ± 0.4			1	0.3 ± 0.3

sequently have a greater effect, however, the difference could also be due to differences in site characteristics among the meadows, including altitude.

Grazing by pack animals in Aconcagua reduced the cover of tussock grasses, including *Deyeuxia eminens* var. *fulva,* but not sedges and herbs. Reductions in tussock grasses from grazing and neutral responses for sedges and herbs are consistent with other studies (Alzérreca et al., 2006; Niu et al., 2010). Although sedges in Aconcagua include palatable species such as *Carex* aff. *gayana*, they are able to tolerate grazing due to their rhizomatous architecture (Díaz et al., 2007). In contrast to other studies that have found less litter in grazed sites because of defoliation (Jutila, 1999; Wu et al., 2010), there was more litter with grazing in Aconcagua. This could be because of damage from trampling by the hard-hooved animals, which may result in a temporary increase in litter (Facelli and Pickett, 1991; Sun and Liddle, 1993).

In situations with heavy use of pack animals, trail incision could occur, altering water drainage and causing soil erosion (Raffaele, 1999), with changes in composition to a new "disturbance" flora. In Aconcagua, Andean meadows regularly trampled and grazed in the low alpine zone have been colonized by weeds (e.g., *Taraxacum officinale*) and natives (e.g., *Acaena magellanica*) adapted to drier conditions (Mendez et al., 2006; Barros et al., 2013).

As expected, given the short duration of the study, we did not find changes in plant composition, species richness, and floristic similarity with the removal of grazing. Most of the plants in Aconcagua are long-lived perennials, so there is likely to be a time lag between removing grazing and changes in the populations of some of these species (Colling et al., 2002). Numerous studies have found changes in composition after the removal of grazing, but only after several years of exclusion (Cole et al., 2004; Villalobos and Zalba, 2010).

The changes found in this study after the removal of grazing are likely to benefit native fauna that utilize the meadows. Taller vegetation may increase the habitat quality for some ground-nesting birds by decreasing the exposure of nests to predators and the risk of nests being trampled by pack animals as found in other regions (Zalba and Cozzani, 2004; Roodbergen et al., 2012). The increase in above-ground biomass and grass cover can increase food availability for guanacos. Previous studies in the dry Andes found that guanaco and livestock diets overlap, as both prefer to graze on meadows including perennial grasses such as *Deyeuxia* spp. (Puig et al., 2001, 2011). Despite guanacos being rarely present in the studied meadows and campsites, they can become more habituated to humans if there is no poaching (Malo et al., 2011). Enhancing meadow habitat by reducing grazing by pack animals may promote a larger spatial distribution of guanacos (Dirección de Recursos Naturales, 2009).

The results from this study could assist park managers in regulating grazing activities in alpine meadows. This includes establishing minimum acceptable levels of change in productivity and/or vegetation structure (e.g. 10%) as suggested for mountain meadows with recreational pack animals in North America (Spildie et al., 2000; Cole et al., 2004). To meet their conservation criteria, monitoring programs and management strategies including deferred grazing, rotating grazing areas between years, use of weed-free fodder for livestock, or establishing limits on the number and animal nights per meadow could be implemented (Moore et al., 2000).

This study was able to assess the short-term effects of excluding grazing by large animals under current grazing conditions. To evaluate structural and functional changes on vegetation, however, long-term controlled grazing trials are necessary. Factors such as years of exclusion from grazing combined with grazing intensity, type of grazers, and climate variability can shape the response of vegetation (Milchunas and Lauenroth, 1993; Erschbamer et al., 2003). Also, changes found in this study, including height and biomass, could be homogenized over winter because of compensatory mechanisms (Briske et al., 2003). Plant production, however, may be more limited under chronic grazing, as they are not able to allocate more resources to carbon and nutrients (Turner et al., 1993).

Despite the logistical and resource difficulty in undertaking this type of research in the Andes, it is important to continue this work and include longer term monitoring. Although the Andes accounts for 13% of all mountains worldwide (Körner et al., 2011), there are few studies on the alpine flora, including grazing, for this region compared to Northern Hemisphere mountain areas (Körner, 2009). Therefore, assumptions about ecological processes, including impacts of grazing, based on literature from the Northern Hemisphere may not accurately reflect what happens in the Andes or other Southern Hemisphere mountains. It is important to determine if livestock, recreational use, and other types of human activity in the high Andes have similar impacts to those found elsewhere, or if ecological ecosystem differences mean that lessons learned elsewhere may not apply.

Conclusions

This study shows that excluding grazing on meadows in Aconcagua Park, even for a single growing season, results in increases in vegetation height, above-ground biomass, and cover of some species, which is likely to improve the habitat quality of the meadows for native wildlife. Given the increasing numbers of pack animals in mountain protected areas in the dry Andes and their preference for foraging on meadows, their grazing should be monitored to promote the conservation of these plant communities.

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APPENDIX

TABLE A1

Mean and standard errors of the overlapping cover of species in paired exclosure and grazed quadrats in March 2011 in the three alpine meadows in Aconcagua Provincial Park. T. = total, q. = number of quadrats.

	Casa de Piedra								Plaza Argentina				
	Meadow 1				Meadow 2				Meadow 3				
	Exclosure		Grazed		Exclosure		Grazed		Exclosure		Grazed		
Overlapping cover	q.	Mean ± S.E	q.	Mean ± S.E	q.	Mean ± S.E	q.	Mean ± S.E	q.	Mean ± S.E	q.	Mean ± S.E	T. q.
Deyeuxia eminens var. *fulva*	3	42.8 ± 23.5	2	38.2 ± 23.4	4	58.8 ± 23.5	4	53.3 ± 22.4	3	8.5 ± 4.6	3	4.0 ± 2.5	19
Deyeuxia crysostachya					1	19.6 ± 19.6	1	18.5 ± 18.5	5	41.3 ± 15.1	5	38.9 ± 14.1	12
Deyeuxia velutina									1	4.3 ± 4.3	1	7.3 ± 7.3	2
Festuca dissitiflora									1	3.3 ± 3.3	1	5.7 ± 5.7	2
Hordeum comosum					1	8.0 ± 8.0	1	1.20 ± 1.20					2
Puccinellia argentinensis	1	14.8 ± 14.8	1	0.8 ± 0.8									2
Carex aff. *gayana*	4	43.2 ± 15.6	4	40.2 ± 18.2	3	32.6 ± 18.4	3	23.6 ± 19.3	6	46.2 ± 13.6	7	49.6 ± 14.5	27
Eleocharis pseudoalbibracteata	3	27.0 ± 18.8	1	19.8 ± 19.8			1	6.8 ± 6.8	1	8.3 ± 8.3			6
Oxychloe bisexualis									2	9.7 ± 9.6	4	11.0 ± 9.8	6
Patosia clandestina	1	19.8 ± 19.8	1	19.4 ± 19.4									2
Werneria pygmaea									3	11.4 ± 9.8	3	2.2 ± 1.8	6
Gentiana próstata									5	2.9 ± 1.5	7	4.5 ± 1.8	12
Cardamine glacialis	2	17.6 ± 11.5	2	5.4 ± 4.3									4
Hypsela reniformis	1	13.6 ± 13.6	2	4.8 ± 4.5									3
Mimulus luteus	1	5.0 ± 5.0	1	5.0 ± 5.0									2
Bryophyta	1	0.1 ± 0.1			1	0.2 ± 0.2	1	1.2 ± 1.2	2	0.1 ± 0.07			5