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# Effects of Historic Livestock Grazing on Vegetation at Chaco Culture National Historic Park, New Mexico

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**Abstract:** *Livestock grazing is the most ubiquitous land use in western North America, yet it rarely has been studied in a controlled manner because of the lack of large areas free of grazing. We compared the ecological effects of three grazing treatments—long-term protection, short-term protection, and currently grazed—at Chaco Culture National Historic Park in northern New Mexico. Chaco has a long history of human habitation and is now one of the largest grazing exclosures in the American West. We studied the effects of livestock grazing on the cover of plants, soil crusts, and plant species richness at six sites with different potential natural vegetation. Species richness was higher under long-term protection than under current grazing at all six sites. Trends in shrub and grass response varied significantly across the six sites. Shrub cover increased with long-term protection at four upland sites, and grass cover increased with protection at four sites. The response of Chaco vegetation to release from grazing varied significantly according to each site's ecological potential, determined in part by edaphic and topographic characteristics. These nuances in vegetation response represent natural ecological variation and contrast with the notions of widespread shrub "invasion" often inferred in the past.*

Efectos del Pastoreo Histórico de Ganado sobre la Vegetación en el Parque Histórico Nacional Cultura Chaco, Nuevo México

**Resumen:** *El pastoreo de ganado es el uso de suelo más generalizado en Norte América occidental, sin embargo rara vez ha sido estudiado de manera controlada debido a la ausencia de extensas áreas libres de pastoreo. Comparamos los efectos ecológicos de tres tratamientos de pastoreo - protección a largo plazo, protección a corto plazo y pastoreo actual - en el Parque Histórico Nacional Cultura Chaco, en el norte de Nuevo México. Chaco tiene una larga historia de presencia humana y ahora es una de las áreas libres de pastoreo más extensas en el oeste americano. Se estudiaron los efectos del pastoreo de ganado sobre la cobertura de plantas, corteza de suelo y riqueza de especies de plantas en seis sitios con diferente potencial de vegetación natural. La riqueza de especies fue mayor bajo protección a largo plazo que bajo pastoreo actual en los seis sitios. Las tendencias en la respuesta de arbustos y hierbas variaron significativamente en los seis sitios. La cobertura de arbustos incrementó con la protección a largo plazo en cuatro sitios elevados, y la cobertura de pasto incrementó con la protección en cuatro sitios. La respuesta de la vegetación de Chaco a la ausencia de pastoreo varió significativamente conforme al potencial ecológico de cada sitio, determinado en parte por características edáficas y topográficas. Estos matices en la respuesta de la vegetación representan una variación ecológica natural y contrastan con las nociones de "invasión" generalizada de arbustos, inferida a menudo en el pasado.*

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## Introduction

Grazing has long been the most widespread land use in western North America. Livestock were introduced into

the U.S. Southwest from Mexico in the early sixteenth century (Stewart 1936; Stoddart & Smith 1943). For almost a century and a half, grazing interests have been embedded in the political and social fabric of the West (Donahue

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1999; Fleischner 1999, 2002). For most of this time, grazing on public lands has been accepted without scrutiny. But, increasingly, a new ecological understanding—that livestock grazing often has serious consequences—has led to new management dilemmas. Determining how to manage grazing has become one of the most contentious issues facing land managers in the western United States.

We did not consider the social and cultural roles of ranching in the American West. Rather, we sought to assess the ecological effects of grazing in the semiarid shrublands and grasslands of the Colorado Plateau. According to studies reviewed by Fleischner (1994), grazing has reduced the density and biomass of species in a wide range of taxa, reduced biodiversity, aided the spread of alien species, interrupted ecological succession, impeded the cycling of the region's most important limiting nutrient (nitrogen), changed habitat structure, and disturbed elements of community organization. In addition to the more obvious biological effects of introducing large, heavy herbivores to dry ecosystems, such as reduction of standing biomass, grazing can damage soils and accelerate erosion. Concerns about such extensive ecological deterioration led the American Fisheries Society, the Society for Conservation Biology, and The Wildlife Society to call for a dramatic overhaul of grazing practices (Armour et al. 1991; Fleischner et al. 1994; The Wildlife Society 1996).

Of particular concern is the role of livestock in removing microbiotic (microphytic or cryptogamic) soil crusts, which provide critical ecosystem functions (Beymer & Klopatek 1992). Biological soil crusts provide fixed carbon on sparsely vegetated areas, which are common throughout the Colorado Plateau. Carbon contributed by these organisms helps keep plant interspaces fertile and aids in supporting other microbial populations (Beymer & Klopatek 1991). The availability of nitrogen is an important factor limiting primary production in arid habitats. In the Great Basin Desert it is second only to moisture in importance (James & Jurinak 1978). In desert shrub and grassland communities that support few nitrogen-fixing plants, such as those in Chaco Canyon, biotic crusts can be the dominant source of nitrogen (Rychert et al. 1978; Harper & Marble 1988; Evans & Ehleringer 1993; Evans & Belnap 1999). Nitrogen inputs are highly dependent on temperature, moisture, and species composition of the crusts (Belnap & Lange 2001); therefore, both prevailing climate and the legacy of disturbances influence fixation rates (Belnap 1995, 1996). In addition, crusts stabilize soils (Belnap & Gillette 1997, 1998), retain moisture, and provide seed-germination sites. Soil crusts are effective in capturing eolian dust deposits, contributing to a 2- to 13-fold increase in nutrients in southeastern Utah (Reynolds et al. 2001). The presence of soil crusts generally increases the amount and depth of rainfall infiltration (Loope & Gifford 1972; Brotherson & Rushforth 1983; Harper & Marble 1988; Johansen 1993).

Grazing can disturb soil crusts and other fundamental physical factors in landscapes. For example, climatologists and ecologists have attributed increasing soil surface temperatures and albedo in the Sonoran Desert to grazing-related land degradation (Balling et al. 1998). Grazing often leads to soil compaction, which reduces water infiltration and can lead to elevated soil temperatures (reviewed by Fleischner 1994; also see Yates et al. 2000).

Most of the American West is grazed: approximately 70% of the 11 western states supports livestock. Rock and ice peaks, urban areas, and lands devoted to crop agriculture comprise the primary exceptions to the ubiquity of livestock grazing in the region. It can be difficult to identify precise ecological relationships in grazed landscapes because few ungrazed ecosystems exist for comparison. There are virtually no representative sites left in the West that are truly ungrazed. As pointed out by Bock et al. (1993) and Noss (1994), grazing has amounted to a massive experiment without a control. Bock et al. (1993) called for the establishment of a federal system of large livestock exclosures to create a set of ecological benchmarks with which to study the effects of grazing. Whereas most of the handful of grazing exclosures throughout the West are on the order of 80 ha or less, the authors suggested that the minimum size for an effective exclosure should be about 1000 ha.

Chaco Canyon, in the San Juan Basin of northwestern New Mexico, was a major center of prehistoric Ancestral Pueblo (Anasazi) culture a millennium ago. Livestock were first introduced into the Chaco Canyon area in the last few decades of the seventeenth century by Pueblo Indians fleeing from the Spanish onto Navajo lands. Livestock husbandry was adopted by the Navajo, and large-scale cattle and sheep operations began in 1878 or 1879 (Judd 1954). Grazing by unknown numbers of sheep, goats, and, to a lesser degree, cattle continued in the area well into the twentieth century. Chaco Canyon National Monument was established in 1907 but did not affect grazing practices; in fact, the prehistoric ruins of the canyon were often used as sheep corrals. In 1933 park custodian Julien noted that lands in the monument were overgrazed and advised that livestock should be excluded. The U.S. National Park Service (NPS) began fencing the boundaries of the monument (8600 ha) in 1936, completing the task in 1948 (NPS 1995, 1998). In 1980 the monument was expanded and redesignated as Chaco Culture National Historic Park. Fencing of the four new parcels (amounting to 5000 ha) was completed from 1995 to 1999. Consequently, Chaco is currently one of the largest grazing exclosures in western North America—one of the few that meets the size criterion of the conservation biology proposal for exclosures. Thus, 8600 ha have been protected from grazing for over 50 years, and an additional 5000 ha have been protected for 5 years or less. The entire 13,600-ha exclosure is surrounded by lands that continue to be grazed by Navajo ranchers (although determining

the frequency, duration, and intensity of grazing or the class of livestock on these lands is problematic).

By comparing three grazing treatments—long-term protection (>50 years), recent protection ( $\leq 5$  years), and currently grazed—we hoped to illuminate the effects of historic livestock grazing on biodiversity, the capacity for nutrient cycling, and vegetation structure and composition in the Chaco region. Within these three broad categories, we attempted to answer six questions: Does livestock grazing lead to a difference in (1) shrub density, (2) grass cover, (3) bare soil cover, (4) plant community composition, (5) plant species richness, or (6) cover of microbiotic soil crusts?

In the past few years, assertions about the deleterious effects of livestock grazing on native biodiversity have been drawn largely from reviews of literature (e.g., Fleischner 1994; Ohmart 1996; Belsky et al. 1999). To some observers, this has rendered the reviews' conclusions suspect and thus has added to the controversy rather than resolving it (e.g., Brown & McDonald 1995; Ferguson & Herman 1996; Fleischner 1996). Chaco provides an opportunity to test these assertions in the context of a large landscape unit, with an enclosure that is both large and old enough to yield meaningful results.

Chaco's location on the Colorado Plateau makes it a particularly valuable site for resolving questions about grazing ecology and management. The U.S. National Biological Service included ungrazed sagebrush steppe in the Intermountain West among the most "critically endangered" ecosystems in the United States—those with >98% decline (Noss et al. 1995). The World Wildlife Fund concluded that reform of grazing was one of the priorities for the Colorado Plateau Shrubland ecoregion (Ricketts et al. 1999). Recent paleoecological studies on the Colorado Plateau determined that the most severe vegetation changes of the last 5400 years resulted from livestock grazing during the last two centuries (Cole et al. 1997). One previous study (Orodho et al. 1990) examined the effects of grazing on Chaco vegetation at a single site. Because the vegetation and topography are heterogeneous (Floyd-Hanna & Hanna 1994), however, a single study site cannot provide a complete picture of the ecological transformations taking place after livestock are removed from an area for the first time in 300 years. Also, the intensity of grazing varied across the Chacoan landscape, and today's vegetation is a mosaic of variously disturbed pieces of land.

## Study Area and Methods

According to the biotic communities system of classification of Southwest vegetation (Brown 1994), Chaco Culture National Historic Park, in San Juan County, New Mexico, is located primarily in the Plains and Great Basin Grassland type. Continental-scale vegetation analy-

ses have classified the Chaco region within the Colorado Plateau Shrublands ecoregion (Ricketts et al. 1999), the Colorado Plateau Semidesert Province (Bailey 1995), and the Grama-galleta (*Bouteloua-Hilaria*) steppe (Kuchler 1985). Chaco vegetation has been described more closely by Jones (1972), who proposed six plant associations, and most recently by Floyd-Hanna and Hanna (1994), who delineated 13 vegetation communities.

We selected six study areas that represented the different geologic substrates (ascertained from Mytton & Schneider 1987) and plant communities (from Floyd-Hanna & Hanna 1994) in the park (Table 1). Where possible, we located the three grazing treatments (long-term protection, recent protection, and currently grazed) adjacent to one another, the treatments forming a T-juncture where two perpendicular fencelines intersected. However, at three of the study sites (East Canyon, Kin Klizhin, and Northern Sidecanyons), such an ideal configuration was not possible because factors other than grazing treatment, such as topography or substrate, coincidentally varied at a fenceline. In these cases, the currently grazed treatment was separated spatially from the other two treatments to eliminate variability of other ecological factors. Our study was made possible by the sequence of land acquisitions by the NPS that created, through fencing projects, T-junctures that separated active grazing from the two protected treatments. Replication of these T-junctures would be ideal, of course, but such replication of fenced points did not exist. Some replication is nonetheless available: two sites were in upland areas, and three were on bottomland. The Clys Headwaters site replicated an earlier study by Orodho et al (1990). Because of the ubiquity of grazing and the rarity of large, long-term enclosures in the western United States, sites on which to study grazing with full replication of all factors are virtually nonexistent. A fortunate coincidence of historical events, as described above, allowed us to test a fuller than usual set of grazing factors.

At each of the six study sites, slope, aspect, topography, and substrate were similar in all three grazing treatments. Time since grazing was isolated as the only variable. Within each of the three grazing treatments at each of the six study sites, 6–10 sample points were selected randomly. Each point was 100 m plus a random distance in a randomly selected direction from the previous point. At each of the 130 sample points we recorded the relative frequency (estimate of cover) of plant life forms and substrate types, shrub density, and forb density, and we inventoried all plant species and their relative cover and abundance. The 2 years of this study—1999 and 2000—were characterized by unusually low precipitation in the spring. Therefore, although we measured forb density, data were not representative of normal spring growth patterns, and we do not report them here. We calculated species richness for each of the three grazing treatments at each of the six sites.

**Table 1.** Characteristics of six study sites at Chaco Culture National Historic Park, New Mexico.

Study Site	Geologic substrate	Slope (degrees)	Topography	Vegetation community
Clys Mesa-top	sheetwash alluvium	1.6–2.2	mesa top	<i>Artemisia nova</i> - <i>Gutierrezia sarotbrae</i> - <i>Chrysothamnus greenii</i>
Fajada Gap	deep alluvium	1.3–3.1	broad canyon bottom >500 m	<i>Hilaria jamesii</i> / <i>Sarcobatus vermiculatus</i> - <i>Bouteloua gracilis</i> - <i>Oryzopsis hymenoides</i>
East Canyon	deep alluvium	1.1–1.2	broad canyon bottom >500 m	<i>Sporobolus airoides</i> - <i>Atriplex canescens</i>
Kin Klizhin	menefee shale	1.2–2.4	open basin	<i>Sarcobatus vermiculatus</i> - <i>Lycium pallida</i> - <i>Sporobolus airoides</i> / <i>Atriplex gardenieri</i>
Mockingbird Mesa-top	sheetwash alluvium	1.0–1.4	mesa top	<i>Artemisia nova</i> - <i>Gutierrezia sarotbrae</i> - <i>Chrysothamnus greenii</i>
Northern Side Canyon	alluvium with sandstone outcrops	3.0–8.1	narrow canyon bottom <200 m	<i>Sarcobatus vermiculatus</i> / <i>Atriplex canescens</i> / <i>Hilaria jamesii</i>

We measured shrub cover by establishing two parallel 30-m transects 10 m apart, with line-intercept methods (Mueller-Dombois & Ellenburg 1974). We conducted two relevé analyses in 10 × 10 m plots. Using the Braun-Blanquet scale (Mueller-Dombois & Ellenburg 1974), we assigned each species a cover-abundance value. Taxonomy followed that of Weber and Wittmann (1996) and Welsh et al. (1987). Using a 25-point frequency frame, we measured the relative frequency of each plant life form and substrate type (bare soil, rock, biotic crust, forb, grass, shrub, small tree). At each sample point, we placed the frame 10 times at randomly selected distances from the line-intercept transects described above. Microbiotic soil crust cover was measured in 10 0.5 × 0.5 m quadrats. The positions of quadrats were randomly selected. We estimated both total crust cover and cover of black crusts. The latter (consisting of the lichen *Collema* spp., several species of cyanobacteria, and the mosses *Tortula canineruis* and *Didymodon topbaceus*) are considered most likely to be nitrogen fixers (J. Belnap, personal communication).

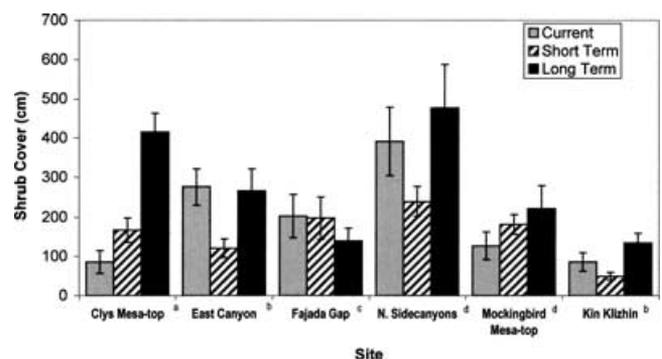
In all analyses, we combined data from both years of field study (1999–2000). Data were tested for normality prior to analyses. Frequency data (relative estimates of plant cover) were transformed with square-root arcsine transformations, as is appropriate to normalize data (Sokal & Rohlf 1981). Using SPSS software (Norusis 1993), we analyzed data with two-way analysis of variance (ANOVA) (Sokal & Rohlf 1981). We tested for differences in each dependent variable across the six study sites (“site”) and across three grazing treatments (“treatment”). We ran post hoc least-significant-difference (LSD) tests when significant differences among treatments or sites were detected with ANOVA (Sokal & Rohlf 1981).

## Results

Shrub cover differed significantly among the grazing treatments ( $F = 8.0$ ,  $p < 0.05$ ) and among sites ( $F = 9.6$ ,

$p < 0.05$ ). The interactive ANOVA term was also significant ( $F = 5.4$ ,  $p < 0.05$ ), indicating that the specific nature of shrub responses to release from grazing pressure was variable across the six sites (Fig. 1). Long-term protection favored shrub regeneration at four sites (Clys Mesa-top, Northern Sidecanyons, Mockingbird Mesa-top, and Kin Klizhin). This was particularly clear at Clys Mesa-top, which exhibited nearly a fivefold increase in shrub cover compared with the currently grazed area. Yet, at the two canyon-bottom sites with deep alluvial soils, grazing treatment either had no effect on shrub cover (East Canyon) or shrub cover was significantly reduced in the long-term protected area (Fajada Gap).

Bare soil exposure differed significantly among grazing treatments ( $F = 28.1$ ,  $p < 0.05$ ) and among study sites ( $F = 19.3$ ,  $p < 0.05$ ). There was also a significant interaction between the effect of the two independent variables ( $F = 3.5$ ,  $p < 0.05$ ). Currently grazed areas had



**Figure 1.** Total cover of shrubs at six sites at Chaco Culture National Historic Park, New Mexico, under three grazing treatments: long-term protection (>50 years rest), short-term protection (2–5 years rest), and currently grazed. Lines represent standard error. Post hoc least-significant-difference tests are indicated with letters adjacent to site names (significant differences have different letters).

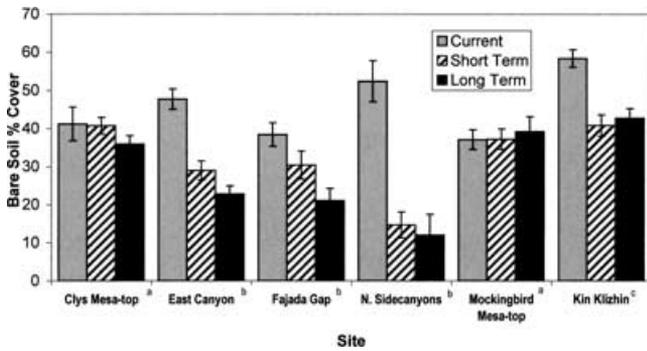


Figure 2. Bare soil exposure (mean percent cover) at six sites at Chaco Culture National Historic Park, New Mexico, under three grazing treatments: long-term protection (>50 years rest), short-term protection (2–5 years rest), and currently grazed. Lines represent standard error. Post hoc least-significant-difference (LSD) tests ( $p < 0.05$ ) are indicated with letters adjacent to site names (significant differences have different letters). The LSD tests confirm that each treatment was significantly different ( $p < 0.05$ ) from the other two treatments.

greater exposure of bare soil than areas under protection from grazing at all but one site (Mockingbird Mesa-top). This grazing effect was particularly pronounced at three sites: East Canyon, Fajada Gap, and Northern Sidecanyons (Fig. 2).

Grass cover differed significantly among treatments ( $F = 28.1, p < 0.05$ ) and among sites ( $F = 19.3, p < 0.05$ ). There was also a significant interaction between treatments and sites ( $F = 3.5, p < 0.05$ ). At Fajada Gap, East Canyon, Clys Mesa-top, and Kin Klizhin, grass cover increased with short- and long-term protection from grazing. Only at Fajada Gap was grass cover significantly greater under long-term than recent protection (Fig. 3). Exceptions to this pattern were evident at the remaining two sites. At Mockingbird Mesa-top, the currently grazed treatment had the greatest grass cover and long-term protection had the least. The currently grazed site supported only one grass species, *Bouteloua gracilis*, whereas the long-term treatment supported numerous bunchgrasses, including *Oryzopsis hymenoides* and *Stipa comata*, and a much higher abundance of forbs and cover of shrubs. At Northern Sidecanyons the currently grazed and long-term protected treatments were statistically indistinguishable, whereas recent protection supported significantly less grass cover.

Black biotic crust cover differed significantly among grazing treatments ( $F = 19.6, p < 0.05$ ) and study sites ( $F = 14.6, p < 0.05$ ). Black crust cover was greatest under long-term protection at all sites, but the magnitude of black crust differed among sites ( $F = 2.0, p < 0.05$ ). The most well-developed crusts were on the Menefee shale substrate at the Kin Klizhin site. At this site,

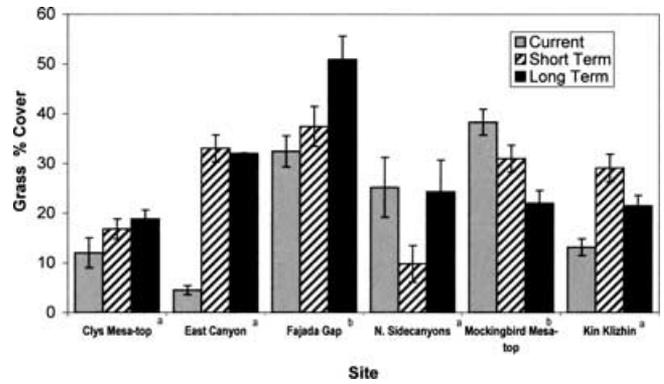


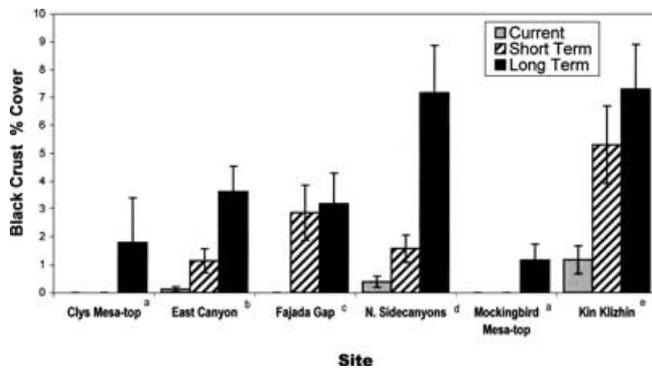
Figure 3. Mean percent grass cover at six sites at Chaco Culture National Historic Park, New Mexico, under three grazing treatments: long-term protection (>50 years rest), short-term protection (2–5 years rest), and currently grazed. Lines represent standard error. Post hoc least-significant-difference (LSD) tests ( $p < 0.05$ ) are indicated with letters adjacent to site names (significant differences have different letters). The LSD tests confirm that the currently grazed treatment is significantly lower than either protection treatment.

the cover of crusts was indistinguishable in the recent protection treatment and the long-term protection treatment, suggesting rapid recovery. Black crusts at Northern Sidecanyons and East Canyon, although present in the short-term enclosure, were dense only in the long-term treatment, suggesting a slower recovery. Black crusts were virtually absent at Clys Mesa-top and Mockingbird Mesa-top, the sites with the poorest soil development, but were found at very low densities under long-term protection (Fig. 4).

At each of the six study sites, plant species richness was higher in the protected areas than in the grazed areas (Fig. 5). Exotic species, including *Kochia scoparia*, *Bromus tectorum*, *Salsola iberica*, *Halogeton glomeratus*, and *Carduus nutans*, were found in all three treatments. Each study site supported between 24 and 40 species of vascular plants; the proportion of exotic species varied from 20% to 33% of the total flora in different sites and treatments. The proportion of exotic species did not differ significantly among treatments.

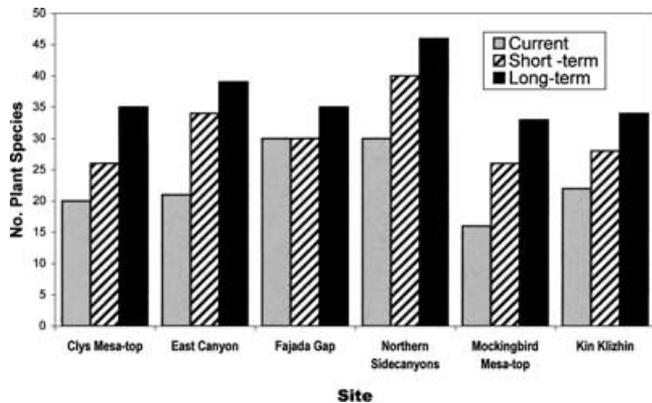
## Discussion

The ecological effects of historic livestock grazing were most evident in terms of plant diversity and biotic soil crusts. Plant species richness was consistently higher under long-term protection than under current grazing at all six sites. Similarly, biotic crusts consistently responded to protection from grazing: cover of the probable nitrogen-fixing black crusts was significantly greater under



**Figure 4.** Mean percent black biotic crust cover at six sites at Chaco Culture National Historic Park, New Mexico, under three grazing treatments: long-term protection (>50 years rest), short-term protection (2–5 years rest), and currently grazed. Lines represent standard error. Post hoc least-significant-difference (LSD) tests ( $p < 0.05$ ) are indicated with letters adjacent to site names (significant differences have different letters). The LSD tests confirm that each treatment was significantly different ( $p < 0.05$ ) from the other two treatments.

long-term protection at all six sites. On one site, rapid recovery of crusts into the short-term treatment was documented. Invasive plant species were present in all treatments at all sites, demonstrating how firmly they are established in the landscape. This pattern exemplifies the tenacious presence of invasive species in the arid West: exotic species are maintained even in long-term grazing exclosures. This is partly because of the aridity and slow growth of plants in this ecosystem, which leave open patches of bare soil decades after disturbances create them. Such openings tend to act as refugia for the invasive



**Figure 5.** Plant species richness at six sites at Chaco Culture National Historic Park, New Mexico, under three grazing treatments: long-term protection (>50 years rest), short-term protection (2–5 years rest), and currently grazed.

species. Plant and ground cover exhibited more heterogeneous responses to protection from grazing. Shrub cover increased with protection at all four upland sites, whereas this was not true at two sites on the deeper alluvial soils of the canyon bottom.

Range managers have often judged grazing practices by reference to a single criterion, the relative increase or decrease of grass cover. At four of our six sites, grass cover was greater with protection than with current grazing. At Fajada Gap, the site with the highest grass cover, currently grazed and recently protected treatments showed no significant difference, but grass cover was significantly higher under long-term protection. This site, on alluvial soils of the canyon bottom, most closely resembled a true grassland community type, with over 50% cover of grasses under long-term protection. The other canyon-bottom site with deep alluvial soils, East Canyon, also showed dramatic recovery of grasses under protection, but there was no significant difference between the two protection treatments. At Cly's Mesa-top, the site with the lowest overall grass cover, both protected treatments exhibited significantly higher grass cover than did the currently grazed treatment. The two anomalous sites in terms of grass cover were Northern Sidecanyons and Mockingbird Mesa-top. At the former, the currently grazed and long-term protection treatments showed no significant difference, whereas the recently protected treatment had the lowest grass cover. At Mockingbird Mesa-top, grass cover was highest under current grazing and lowest under long-term protection. This site was dominated by *Bouteloua gracilis*, known to be resilient to grazing (Ruyle & Young 1997). However, grass diversity (including *Stipa comata*, *Aristida purpurea*, and *Oryzopsis hymenoides*) was greater under long-term protection.

The interrelationships of these responses—cover of shrub, grass, soil crust, bare ground—to the removal of livestock from the six regions of Chaco Canyon underscore the ecological nuances involved in recovery from long-term, human-related disturbance in semiarid landscapes. There was no one-pattern-fits-all phenomenon; rather, post-grazing succession at each site depended on residual plant propagules, the degree to which the site had been disturbed by grazing and other land-management practices, edaphic characteristics, and other habitat conditions. In short, release from grazing in some Chaco habitats (alluvial canyon bottoms) favored grasses, in others (upland sites) it favored shrubs, and in still others (sites with shale substrate) it favored biotic soil crusts. Throughout western North America, it is common to find sites with different ecological potentials closely adjacent. Thus, caution should be exercised when evaluating the effects of grazing: rarely will a single variable (e.g., grass cover) or a single site provide a clear picture.

Shrub “invasion” of grasslands has been noted in the Southwest for decades and is the focus of a great deal of management controversy. Branson (1985) referred

to “the widespread change of semidesert grassland to shrubland...one of the most impressive examples of vegetation modification to be found on western rangelands.” In southern Arizona and New Mexico, mesquite (*Prosopis* spp.) increased as grass cover decreased (York & Dick-Peddie 1969; Bahre 1991; Bahre & Shelton 1993). Throughout the Intermountain West, juniper (*Juniperus* spp.) woodlands have increased in both density and distribution since Euro-American settlement (Miller & Wigand 1994). It has been repeatedly suggested that overgrazing by livestock, often in conjunction with lengthening of fire intervals, has been a primary cause of woody plant encroachment (Branson 1985; Archer 1994).

Shrubs are not necessarily “invading,” however, when they increase on a site in the arid West. Because the regional vegetation in the Chaco area is a mix of desert grassland and shrubland, woody vegetation is “normal” at many sites. Rowlands and Brian (2001), studying a relict site in the Grand Canyon, suggested that in many cases woody plant increases should be viewed as “reoccupation” rather than invasion and that, in some cases, populations of particular species, such as juniper, increase and decrease over long-term cycles. The general trend we observed—shrubs increasing in uplands and decreasing in the canyon bottom—demonstrates the different inherent ecological potentials of sites with different soils, drainage patterns, and water-infiltration capacities. Broad canyon bottoms, with deeper, more recently developed alluvial soils may be more naturally inclined toward grassland conditions than are upland sites, which tend more toward shrubland. In southern Arizona desert grasslands, after 18 years of enclosure, Brown (1950) found that shrubs increased more on protected areas than on currently grazed sites. This is similar to what Orodho et al. (1990) and we observed at upland sites in Chaco Canyon.

One site, Kin Klizhin, on Menefee shale, was characterized by a rapid increase in biotic crust cover. This is an especially hopeful trend. Biotic crusts favor nitrogen input and, in some ecosystems, deter non-native species (Belsky & Gelbard 2000). Although exotic species are present on protected treatments in Chaco, preliminary data suggest that the cover and abundance of exotic species is lower.

Past land-use activity can result in long-term modifications to biodiversity and reverberations in ecosystem dynamics. For example, researchers in eastern North America discovered that land-use practices 40 years in the past were more accurate predictors of stream ecosystem conditions within a watershed than was current management (Harding et al. 1998). This is undoubtedly true on arid rangelands as well. Fleischner (1994) reviewed studies documenting that initial impacts from livestock grazing—often long in the past—caused the most dramatic changes to ecosystems. Branson (1985) suggested that the loss of topsoil may impede efforts to re-establish former grasslands affected by livestock. Changes that result from

the establishment of exotic species exacerbate this situation (Mack 1981; D’Antonio & Vitousek 1992; Hobbs & Huenneke 1992). Consequently, projects to restore arid lands degraded by grazing have met with limited success (Allen & Jackson 1992). It is unsurprising that Chaco, which was grazed longer than most parts of the American West, recovers slowly, and it may never regain pregrazing conditions. From this perspective, the conspicuous and consistent increase of biotic crust and plant species richness with protection from grazing can be seen as an encouraging sign of healing.

## Acknowledgments

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