REVISITING TRENDS IN VEGETATION RECOVERY FOLLOWING PROTECTION FROM GRAZING, CHACO CULTURE NATIONAL HISTORIC PARK, NEW MEXICO

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ABSTRACT

Livestock grazing has serious ecological consequences in the arid Southwest, leading to management dilemmas that become more problematic with global climate change projections. Management challenges can be illuminated by long-term monitoring studies, especially under varying climatic conditions. We revisited sites in Chaco Culture National Historic Park, where we had previously analyzed historic livestock grazing impacts under drought conditions (1999-2000). Two ages of grazing exclosures were created by fencing projects in the 1930s and 1990s, such that long-term protection (>60 years of exclosure), recent protection (≤12 years), and current grazing treatments were immediately adjacent at six sites. We compared plant species richness, cover of biological soil crusts, shrub density, vegetative cover, and plant community composition at these six sites. Our recent resurvey (2006) took place during a period of higher summer precipitation and temperature. The greatest differences between surveys were in forb characteristics. In all grazing treatments, forb density and cover was higher during the wetter season than during drought, and 77 forb species were recorded that had not been present in our earlier surveys (Floyd et al. 2003). Plant species richness continued to be significantly greater under long-term protection at all six sites. No differences among treatments in invasive plant diversity or cover were detected. The cover of black biological soil crusts was significantly higher under long-term protection at three of the four sites monitored; in the fourth, cover was highest under short-term protection. On Menefee Shales at Kin Klizhin, crust cover was six times higher with long-term protection than where currently grazed. These results affirm our earlier assertion that recovery of soil crusts can proceed rapidly with protection from grazing. Post-grazing trends were variable at the six sites with Fajada Gap (a grassland) having a significantly greater shrub density and cover in the currently grazed treatment than under protection. In contrast, at Mockingbird Mesa-top (a low shrubland) there was a significantly greater shrub density and cover in protected treatments. Thus plant community structure re-established itself differentially with protection from grazing depending on the inherent biotic potential of each site. This variable trend is an important management consideration.

INTRODUCTION

Livestock were introduced into the American Southwest in the early sixteenth century from Mexico (Stewart 1936; Stoddart and Smith 1943). Grazing by domesticated livestock, primarily cattle, has become the most ubiquitous land use in the western United States. Approximately 70% of the 11 westernmost states in the USA (those including and west of the Rocky Mountains) is grazed by livestock at least part of the year (CAST 1974; Longhurst et al. 1982; Crumpacker 1984), including approximately 90% of federal land in these states (Armour et al. 1991). Further, livestock grazing occurs in >75% of the ecoregions delineated by the World Wildlife Fund (Ricketts et al. 1999) in the American West. As such, it represents a primary ecological influence in more than half of these ecoregions (Fleischner, 2010).

Because of the ubiquity of livestock grazing, its ecological impacts can be difficult to discern. The primary method of studying grazing impacts has been comparison of areas exclosed to livestock (exclosures) and adjacent rangelands. These exclosures tend to be relatively small (≤80 ha), and a preponderance of them are in riparian habitats (e.g., Krueper et al. 2003). The lack of landscape-scale exclosures was noted by Bock et al. (1993), who called for an ecologically representative system of large livestock exclosures. Information on post-grazing recovery of dry uplands has been scarce because of the relative dearth of exclosures within these sites, and because recovery is inherently slower than in riparian habitats (Fleischner 1994).

Chaco Culture National Historic Park (CCNHP), New Mexico, situated in one of the longest continuously grazed regions of North America, is one of the largest and longest-term livestock exclosures in western North America (see Floyd et al. 2003 for details of grazing and management history). The U.S. National Park Service (NPS) began fencing the boundaries of Chaco Canyon National 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. Thus, 8600 ha have been protected from grazing for ≥60 years, and an additional 5000 ha have been protected for ≤12 years. The entire 13,600 ha exclosure is surrounded by lands that continue to be grazed by Navajo ranchers although it is not possible to accurately determine frequency, duration, and intensity of grazing, or class of livestock, on these lands.

During 1999-2000 we studied historic grazing impacts at CCNHP (Floyd et al. 2003). We compared the effects of three different livestock grazing treatments (long-term protection, short-term protection, and current grazing) on the cover of plants, biological soil crusts, and plant species richness at six sites with different potential natural vegetation. Plant species richness and cover of black (nitrogen-fixing) biological soil crusts were higher under long-term protection than under current grazing at all six sites. Trends in shrub and grass response varied with the site's potential. Shrub cover increased with long-term protection at four upland sites, and grass cover increased with protection at four sites.

Monitoring vegetation through cycles of climatic variation can provide more complete and accurate perspective on long-term trends. The National Park Service has recently implemented long-term monitoring in all parks as part of the Inventory and Monitoring Project. Because our data at CCNHP were collected during two years of drought (1999-2000), we were interested in comparing vegetation at the same sites during a year with greater precipitation. During May to September 2006, precipitation was roughly three times as great as during this period in 2000. Such biological comparison during different climatic regimes is especially important in the face of predicted global climate change--especially because vegetation change in the Colorado Plateau region is currently following the predictions of global climate change models (Breshears et al. 2005, IPCC 2007).

We are particularly concerned with the condition of biological soil crusts, which provide critical ecosystem functions (Belnap and Lange 2003), including fixing carbon in sparsely vegetated areas. Such carbon contributions help keep interspaces between vascular plants fertile and support other microbial populations (Beymer and Klopatek 1991). The availability of nitrogen is an important factor limiting primary production in arid habitats throughout the world. In the Great Basin Desert of the western USA, nitrogen is second only to moisture in importance (James and Jurinak 1978). In desert shrub and grassland communities that support few nitrogen-fixing plants, biological soil crusts can be the dominant source of nitrogen (Rychert et al. 1978; Harper and Marble 1988; Evans and Ehleringer 1993; Evans and Belnap 1999). Nitrogen inputs are highly dependent on temperature, moisture, and species composition of the crusts (Belnap and Lange 2003); therefore, both prevailing climate and the legacy of disturbances influence fixation rates (Belnap 1995, 1996). Additionally, crusts stabilize soils (Belnap and Gillette 1997, 1998; Warren 2003), 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 and Gifford 1972; Brotherson and Rushforth 1983; Harper and Marble 1988; Johansen 1993). Thus, biological soil crusts play critical roles regarding the two most important limiting factors in arid landscapes: water and nitrogen.

We compared the effect of three grazing treatments—long-term protection (≥60 years), recent protection (< 12 years), and currently grazed--on plant diversity, capacity for nutrient cycling, and vegetation structure and composition in Chaco Culture National Historic Park. Within these three broad categories, we attempted to determine if livestock grazing leads to a difference in: 1) shrub and forb density, 2) grass and forb cover, 3) bare soil cover, 4) plant community composition, 5) plant species richness, or 6) cover of biological soil crusts. We then compared these vegetation patterns from the wetter field season (2006) to data from earlier drought years (1999-2000) at the same sites to begin to tease out effects of climatic pattern on post-grazing ecosystem recovery.

METHODS

We sampled at the six sites reported in Floyd et al. (2003): Mockingbird Mesa-top, Clys Mesa-top, Northern Side Canyons, Fajada Gap, East Canyon, and Kin Klizhin (Figure 5.1). At each location, removal of fencing due to acquisition of NPS land had created T-junctions where 3 grazing treatments juxtaposed: long term protection (greater than or equal to 60 years), short term protection (less than or equal to12 years) and currently grazed land under jurisdiction of the Navajo Nation.

Within each treatment we sampled 6-10 points that were randomly selected with GIS software. At each sample point, we laid out 2 parallel 30 m transects, 10 meters apart. Shrubs were counted and tallied by species in the 10m x 30m area created by the parallel lines. Shrub cover was measured using the transects for line intercept sampling (Mueller-Dombois and Ellenburg 2003). We placed a point frame at each 10 m interval. This frame create 25 points and intersections of two lines defined ground substrate (bare soil, forb, shrub, grass, litter, biotic crust, physical crust, invasive forb, invasive grass, and dung). This was repeated 12 times at each sample point. Finally, a releve analysis was done once at each point, recording all plant species and their cover/abundance values using the Braun Blanquet scale (Mueller-Dombois and Ellenburg 2003). Data were analyzed using an ANOVA to determine significant differences in each cover and density variable between the three different treatments.

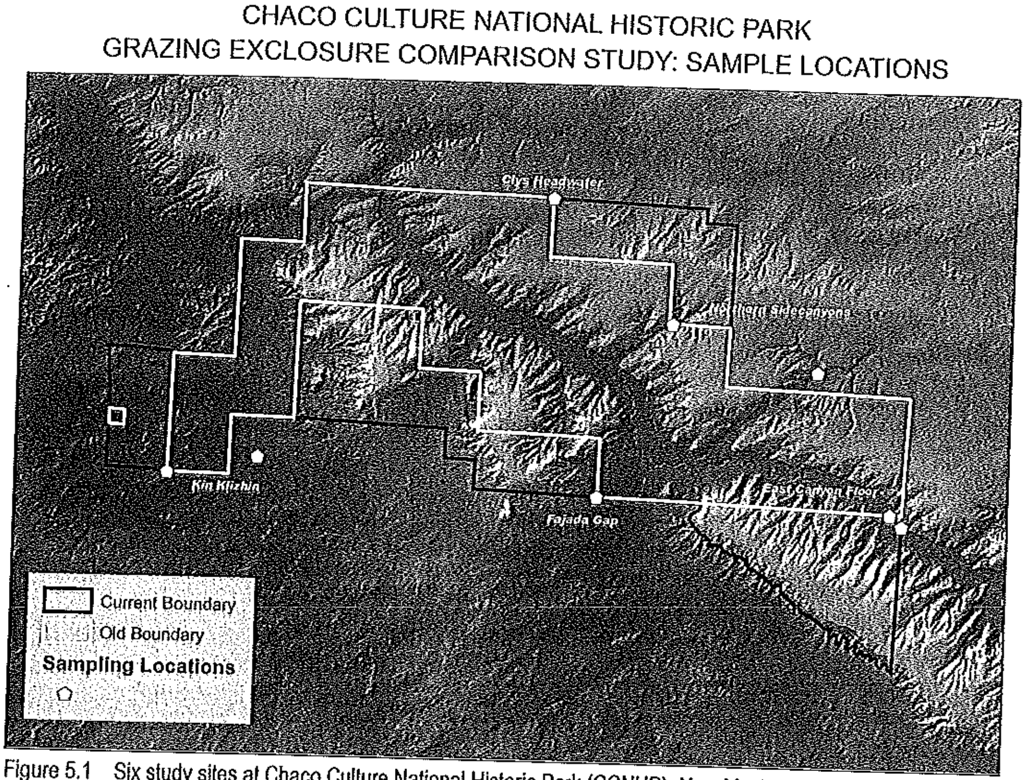

Figure 5.1 Six study sites at Chaco Culture National Historic Park (CCNHP), New Mexico.

	2000	2006
Fajada	2.01 (5.1)	5.56 (14.1)
Pueblo Bonito	1.62 (4.1)	4.02 (10.2)
Visitor Center	1.64 (4.2)	5.97 (15.2)

Table 5.1 Total precipitation from May through August 2000 and 2006 in inches (cm) at three gauging stations, CCNHP.

Site Location	Current	Short-Term	Long-Term	Significance
Clys Mesa-top	31 (2)	33 (3)	31(3)	ns
East Canyon	62 (5)	44 (5)	32(5)	F= 7.5, p=.001
Fajada Gap	72 (3)	77 (4)	61 (5)	F=5.4, p=.006
Kin Klizhin	67 (5)	49 (6)	23 (4)	F=19.5, p<.001
Mockingbird Mesa-top	39 (3)	24 (3)	35 (4)	F=7.0, p=.001
North Side Canyons	62 (6)	42 (7)	40 (6)	F=3.7, p=.03

Table 5.2 Bare soil cover, mean % (SE) of bare soil at 6 study sites in 3 treatments (currently grazed, short-term protection, and long-term protection) CCNHP, September 2006.

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Precipitation and Floristic Trends in 2006

While the annual precipitation in 2006 was not appreciably different from 1999 and 2000, Chaco received far greater precipitation during the summer months of May-August (Table 5.1).

This promoted germination of 77 forb species that had not been present in our plots in the earlier study (91 species were recorded in 2000, 168 in 2006).

Vegetative recovery after protection from grazing can be assessed by monitoring residual bare soil (unvegetated) surfaces. In five of the six sites there was significantly greater cover of bare soils in currently grazed treatments (Table 5.2). In the one site, Clys Mesa-top, where no significant difference occurred, the primary cover was provided by Bouteloua gracilis and Gutierriza sarothrae, species known to be tolerant of grazing (and diversity was low at the grazed treatment).

Shrub Density and Cover

At two sites we found significant differences in shrub density and cover (Table 5.3). At Fajada Gap (a grassland with sandy, often-shifting soils, on level terrain), there was a significant difference in shrub density (F=7.4, p<.008) and cover (F=8.0, p=001); the highest shrub density occurred in the currently grazed treatment. In contrast at Mockingbird Mesa-top (a low shrubland) there was a significant difference in shrub density (F=7.56, p=.005) and cover (F=4.89, p=.009); the greatest shrub density occurred in the long term treatment and the highest cover in the short-term treatment. At the other four sites we could detect no difference in shrub density. However, there was a significant difference in shrub cover at Clys Mesa-top (F=4.4, p<=.014) and Kin Klizhin sites (F=4.3, p=.016); in both sites, the greatest shrub cover occurred in long-term protected sites.

Forb and Grass Cover

At Fajada Gap, there was a significant difference (F=3.8, p=.026) in forb cover between all treatments , with cover highest in the long-term treatment (Table 5.4). A similar trend occurred in grass cover (F=4.6, p=.012) at this site. At Mockingbird Mesa-top, forb cover was also significantly higher (F=3.6, p=.03), in the long-term protection treatment (Table 5.4). At this site, grass cover was also significantly different across treatments (F=4.14, p=.018) with cover highest in the short-term protection treatment. No differences in forb or grass cover were detected at the other four sites.

Biological Soil Crusts

The cover of black, nitrogen fixing, biotic crusts differed across treatments in three of the six study sites (Table 5.5). At East Canyon, a significant difference in black crust cover occurred (F=12.9, p<.001) with crusts most heavily developed in short and long term treatment with no differences between these protected sites. At Fajada Gap, significant differences in black crust cover occurred (F=30.9, p<.001) with the highest cover in the short-term protected sites. At Kin Klizhin, a site with the most prolific biotic crust growth in Chaco Canyon NHP, significant differences occurred (F=31.4, p<.001) with the greatest crust cover in the long term protection treatment, where crust cover was six times higher than on the adjacent currently grazed treatment.

Plant Species Richness

In all sites, considered collectively, there were greater numbers of plant species found in long-term protected treatments; overall, we recorded 124 species in currently grazed treatments, 123 species in short-term protected areas, and 168 species in long-term protected sites. At each of the six study sites in Chaco Canyon, we tallied the total number of plant species in three grazing treatments

Site Location	Current	Short-Term	Long-Term	Significance
Shrub Density (#/300 m²)				
Clys Mesa-top	91 (23.2)	95 (45.6)	151 (37)	ns
East Canyon	48 (4.9)	41 (4.2)	44 (2.9)	ns
Fajada Gap	121 (41.9)	1 (43.9)	12 (19)	F=7.4, p=.008
Kin Klizhin	82 (26.4)	72 (24.0)	58 (16.6)	ns
Mockingbird Mesa-top	37 (15.2)	37 (15.2)	48 (15.7)	F=7.5, p=.005
North Side Canyons	51 (5.3)	79 (17.9)	62 (9.7)	ns
Shrub cover				
Clys Mesa-top	4.2 (.9)	3.0 (.4)	7.2 (1.2)	F=4.4, p=.014
East Canyon	24.8 (3.4)	17.8 (2.0)	21.0 (2.5)	ns
Fajada Gap	7.6 (.9)	0	15.2 (4.2)	F=8.0, p=.001
Kin Klizhin	3.4 (.6)	5.9 (.6)	6.8 (.8)	F=4.3, p=.016
Mockingbird Mesa-top	4.5 (.8)	7.8 (1.2)	4.7 (.6)	F=4.8, p=.009
North Side Canyons	7.7 (2.5)	16.8 (2.3)	19.6 (2.8)	F=2.9, p=.056

Table 5.3 Shrub density and shrub cover, mean % (SE) in 6 sites in 3 treatments (currently grazed, short and long term protection from grazing), CCNHP, September, 2006.

Site Location	Current	Short-Term	Long-Term	Significance
Clys Mesa-top	1.1 (.4)	.44 (.26)	.11 (.1)	ns
East Canyon	0	27 (.18)	1.3 (.7)	ns
Fajada Gap	3.3 (1.4)	.67 (.3)	4.5 (1.3)	F=3.8, p=.026
Kin Klizhin	1.7 (.7)	2.1 (.9)	3.4 (1.5)	ns
Mockingbird Mesa-top	.22 (.15)	.22 (.2)	1.3 (.5)	F=3.6, p=.03
North Side Canyons	0	8.0 (3.0)	5.3 (5)	ns

Table 5.4 Forb cover, mean % (SE) in 6 sites in 3 treatments (currently grazed, short and long term protection from grazing), CCNHP, September, 2006.

Site Location	Current	Short-Term	Long-Term	Significance
East Canyon	0	5.7 (1.5)	11.3 (1.6)	F=12.9, p<.001
Fajada Gap	.16 (.1)	10.5 (1.9)	0	F=30.9, p<.001
Kin Klizhin	4 (.9)	8 (1.3)	24 (2.5)	F=31.4, p<.001
North Side Canyons	4 (1.9)	.4 (.4)	1.7 (.8)	ns

Table 5.5 Biotic crust cover. Mean % (SE), shown for 4 of the 6 sites where crusts occur at CCNHP in 2006.

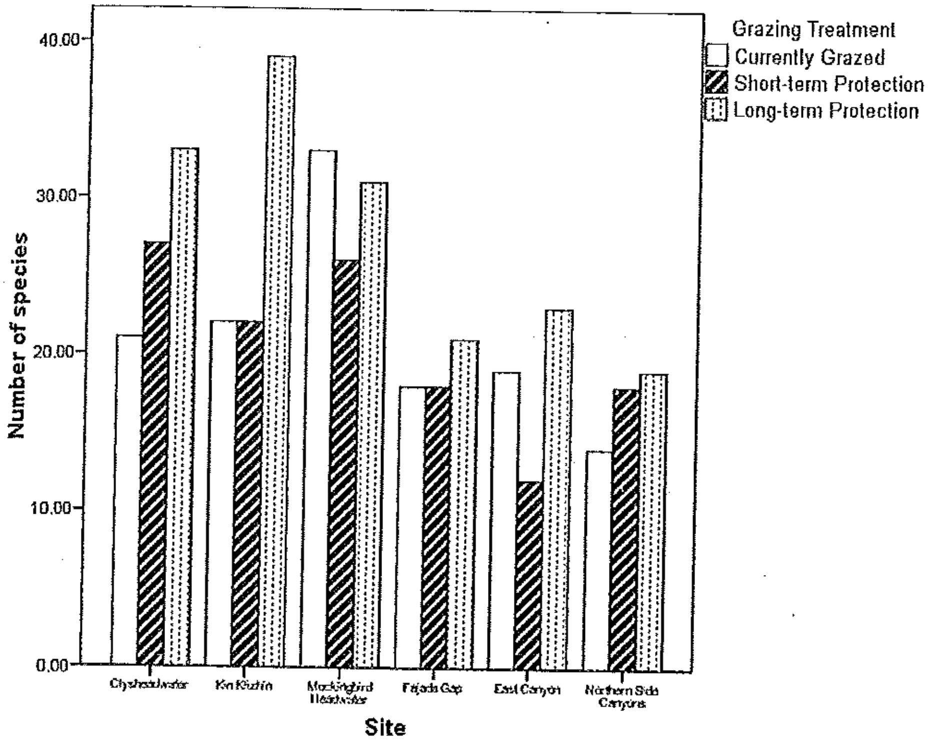

Figure 5.2 Plant species richness in three treatments at six sites, CCNHP.

(Figure 5.2). While the greatest number of species was found consistently in long-term protected sites, no significant differences were detected among the short-term and currently grazed treatments, suggesting that conditions suitable for establishment of many species (especially forbs in 2006) require decades of recovery after grazing disturbance ceases.

Invasive plant species

We encountered only four invasive species in the study plots: the grasses *Bromus tectorum* and *Chloris varigatus*, and the forbs *Kochia scoparia*, *Halogeton glomeratus*, and *Salsola kali*. There were no detectable differences in the distribution of these species across the treatments. Nearly every treatment included the ubiquitous *Salsola kali* among its flora, and each treatment at each site had present at least one invasive plant species.

DISCUSSION

An earlier study examining trends in post-grazing recovery at Chaco Canyon National Historic Park (Floyd et al. 2003) found different trends in vegetation trajectories depending on biotic potential of the site-- a potential dictated by geology, soils, and other site conditions. Lacking a "one size fits all model," some sites returned to grasslands when grazers removed, while in others shrub density increased with release from grazing pressure. However, we were unable to investigate trends in forb populations because the original study took place during extreme drought (1999-2000).

Due to increased summer precipitation, forb germination in 2006 was prolific in all treatments relative to the previous study. We observed prolific growth of plant species which had been absent for many years, such as *Solanum jamesii*, a wild potato perhaps facilitated by prehistoric farmers in the region (Yarnell 1965). However, in only two of the four sites can we attribute increases in the cover of forbs to protection from grazing. Long-term protected grasslands at Fajada Gap and protected low shrublands at Mockingbird Mesa-top supported greater forb cover than at currently grazed sites. And, as in Floyd et al. 2003, the diversity of plant species was consistently greater in the long-term protected treatments at all six study areas, including an additional 44 plant species in the long-term protection treatments (124 species in currently grazed, 123 species in short-term protected, and 168 in long-term protected). Many of these additional species were annual forbs that were absent in the earlier study; in 1999/2000 Floyd et al. (2003) documented 91 species, while in 2006 we documented 168 species. Most of the new species were forbs whose appearance is tied to increased precipitation.

While we hypothesized that there would be a potential reduction in invasive species in long-term protected sites, this was not the case in 2006. There was no difference in invasive plant diversity or cover when we compared the currently grazed sites to those with long or short term protection.

One of the most startling effects documented by Floyd et al. (2003) attributed to removal of grazers was the re-establishment of black, potentially nitrogen-fixing, biotic crusts within 5-6 years of protection. This was especially pronounced on Menefee Shale substrates at the Kin Klizhin site. We continue to see this pattern in 2006 at East Canyon and Kin Klizhin locations where there was greater crust cover in protected (long and short term) than in currently grazed treatments but no significant difference among the crust cover in the two protection treatments. This suggests rapid recovery in the short-term, followed by stability of these crust populations thereafter. The importance of these microbial communities cannot be overstated (Belnap 1995, 1996, Belnap and Gillette 1997, 1998, Belnap and Lange 2003, Reynolds et al. 2001).

SUMMARY

After 60 years, the legacy of grazing at Chaco Culture National Historic Park continues to influence patterns of plant distribution and abundance. However, there are signs of ecological recovery. While trends in shrub and perennial grass cover are similar to drought conditions in 1999-2000, we detected greater forb diversity and cover with the increased summer moisture in 2006. Another sign of recovery was that of black crust abundance and plant biodiversity, which were significantly greater in long-term protected treatments. While several species of invasive grasses and forbs occur in Chaco Canyon, their abundance and cover is similar in protected and currently grazed treatments. Long-term monitoring of vegetation communities at Chaco Canyon National Historic Park (effectively a 13,600 ha grazing exclosure) will contribute to our understanding of the influence of changing climate (drought and rising temperatures) in high desert shrubland and grasslands unhindered by the overlying influences of grazing disturbance.

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