Trajectory and Rate of Desert Vegetation Response Following Cattle Removal

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Abstract—*Cattle have grazed continuously over the past three centuries in the Sky Island region and most work has focused on how these grazers have affected riparian and grassland habitats. I examined the effects of grazing on a fuller spectrum of desert habitats that occur in the close proximity to the San Bernardino Valley of Mexico and the United States. Plots in each of five habitats were placed in two adjoining areas: where grazing had not occurred for 25+ years and where grazing had only ceased 4+ years before this study. Vegetation responded quickly to removal of cattle in mesic environments and formed a species-poor, structurally diverse community. Grazing in more xeric communities did not affect vegetation cover but increased plant species richness. The differences in grazed and ungrazed areas of xeric habitats may indicate these areas were little affected by grazing or that the response after grazing ends is slower than captured by the time course represented here. Exotic species were essentially limited to recently grazed areas of the riparian habitat.*

Introduction

Vegetation changed dramatically during the late 1800s over large areas of the warm North American deserts, including the "Sky Islands" (sensu Warshall 1994), after a prolonged drought, coupled with large-scale cattle grazing period, followed by a period of unusually high precipitation (Bryan 1925; Hastings and Turner 1965). Rivers and streams that had coursed through uncut channels (1) incised the landscape lowering water levels and (2) changed rivers and streams from sources of perennial surface water to dry channels with flow present only after sufficient rains (Bryan 1928; Cooke and Reeves 1975). Valleys that had been grasslands were replaced by shrubs and subtrees (Bahre 1991; Bull 1999; Hastings 1959; Humphrey 1987). The contribution of cattle grazing to the change in vegetation over this period has been debated (Hastings and Turner 1965). Grazing had been widespread and stocking rates often high over much of the region since Spanish explorers first arrived in the 1600s (Wagoner 1952, 1960). However, the scant written description of this period leaves it difficult to interpret what early effect the large cattle herds had on vegetation. A lack of information on the early grazing impacts coupled with observations that dramatic vegetation changes occurred in the late-1800s in places cattle had never been suggests there is little support that grazing alone was the cause of abrupt vegetation change in the late-1800s. Some combination of climatic and human-caused factors likely coincided to bring about this change in vegetation (Hasting and Turner 1965). Empirical results from the present-day will provide further insights into this discussion.

Because of their importance to ranching and agriculture, the riparian and grassland habitats have received most attention regarding the effects of cattle grazing on vegetation communities (Stromberg and Tellman 2009, and references therein). However, these habitats cover a minority of the area in the present-day sky island region. Fewer studies have addressed how grazing affects desert scrub and other more xeric habitats that cover the largest expanse of North American warm deserts.

This study examined differences and rates of change of plant species richness, cover and composition after cattle grazing ended in five desert plant communities of the Chihuahuan desertscrub biome (Brown 1994). In addition to habitat, grazing histories also differed on adjoining areas; in one area cattle had been removed in 1979 after it had been purchased as habitat for endangered species (the present-day San Bernardino National Wildlife Refuge, Department of the Interior), and the other area had been ranched until 2000 when cattle were removed and agriculture was stopped (the present day Rancho San Bernardino, Fundación Cuenca de los Ojos). The difference in history of land use allowed me to compare floras at sites that had experienced recent cattle activity to floras at nearby sites that had no cattle present for 25+ years. Plant sampling sites were in five highly interdigitated habitat types in a small area (approximately 16 km^2). Close proximity of sites meant the same plant species could have potentially occurred in each habitat and differences in plant species richness and abundance due to rainfall, temperature, and other climatological conditions were minimized. Sampling designs such as these has been called "space for time comparisons" and are informative not only about how communities respond to disturbance but also the rate and extent of succession after disturbance (Fukami and Wardle 2009). Specifically, I asked the following three questions: (1) do plant species richness and cover increase in habitats with greater water availability and is this pattern the same where recent grazing has occurred as where it has not? (2) does the rate of vegetation change correspond to water availability? and (3) how does water availability influence distribution and species richness of non-native species?

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Methods

The study was done in the San Bernardino Valley, which runs north-south across the Mexico-United States border in northeastern Sonora, Mexico, and southeastern Arizona, USA. Elevation is approximately 1070 m and climate is xeric temperate with an annual average precipitation of 360 mm. Description of the climate and area are detailed in Minckley (2008).

In fall 2003, eight sites were established in each of five habitat types; desert scrub, mesquite scrub along minor (upland) drainages, mesquite forest along major drainages, grassland, and riparian. The same sites were sampled again in spring 2004. These habitats are not discrete but do reflect a soil moisture gradient from highly saturated in the riparian zone along a permanent stream to more xeric in upland vegetation associations (creosote bush scrub, mesquite grassland, and mesquite forest) where cacti and desert shrubs occur such as *Acacia constricta* (whitethorn acacia), *Larrea tridentata* (creosote bush), and *Flourensia cernua* (tarbush). Grasses were common, but not dominant, in most of the grassland and were absent from the other upland vegetation types. Mesquite (*Prosopis juliflora*) occurred in both the grassland and mesquite forest, and creosote bush was the dominant perennial in the creosote bush scrub. For brevity, hereafter I refer to these vegetation types as follows; desert scrub, grassland, and riparian as written but mesquite scrub along minor (upland) drainages as bosque dry, and mesquite forest along major drainages as bosque wet.

In each habitat, half (4 of 8) of the sampled sites were located on ranchlands in Mexico that had been taken out of grazing 3 years before this study began. Cattle on this ranch had been stocked year-round when the cattle operation was active, and in the 2 years before cattle were removed (1999-2000), stocking density was approximately twice as high as recommended for long-term forage sustainability (J. Austin, pers. comm.). This area is referred to hereafter as the grazed area. The other sites in the United States had not experienced grazing since 1979 and are referred to hereafter as in the ungrazed area.

Vegetation was sampled using a multi-scaled sampling method developed and described by Stohlgren and colleagues (Barnett and Stohlgren 2003; Stohlgren et al. 1998). These plots are 20 m x 50 m and subdivided into two non-overlapping 10 m^2 and one 100 m^2 subplots. This size and rectangular shape of the plots provides a better estimate of vegetation heterogeneity in landscapes than smaller Daubenmire and Parker transects that have been traditionally used by field ecologists (Muller-Dombois and Ellenberg 1974). Stohlgren et al. (1998) found that approximately 45-80% more plant species and a greater proportion of rare, habitat specialist species are sampled in these plots than in the smaller plots. Where plots were located was determined using random numbers. Once the plot origin was fixed, the long axis of the plot was oriented to maximize number of species a plot included.

In each plot, the species composition, species frequency (= abundance) and cover of plants was measured. Plots were measured in all five vegetation types in the grazed and ungrazed areas for a total of 40 plots (4 plots x 5 habitats x 2 grazing histories). Each plant species was categorized as native or exotic based on information available through the United States Department of Agriculture (plants.usda.gov, accessed on 15 April 2012) and a species list for Sonora, Mexico (T. Van Devender, unpubl. data).

I first tested with a t-test if the plant species richness recorded in plots differed among the spring and fall samples. Secondly, I tested with a 2-way ANOVA for the effect of grazing on species richness by treating habitat and grazing history as main effects with species density as the variable. Third, I tested with a 2-way ANOVA for the effect of grazing on percentage cover by plants by treating habitat and grazing history as main effects with percentage cover as the variable. To gauge the level of heterogeneity among plots, habitats and grazing histories, I compared all habitat and grazing history combinations using Jaccard's similarity index.

Results

There were 147 plant taxa recorded from the plots, of which 133 were identified to species and 14 were considered uncertain identifications. This latter group was not included in the species number and cover estimates. There were more species in the spring than in the fall when calculated as total species (spring = 105 species; fall = 89 species), or if calculated as average species richness per habitat (fig. 1: spring = 18.7 ± 1.06 s.e., fall = 12.4 ± 1.06 s.e.; $p < 0.0001$). Only the riparian habitat did not have more plant species in the spring than in the fall sample. The seasonal difference in species number was particularly pronounced in the driest three habitats, desert scrub, bosque dry, and grassland (fig. 1). In all of the analyses, we tested both spring and fall data however, I limit the discussion to the spring data because there were no differences in the results among seasons and there were more species observed.

A complete list of the species will be available in the journal *Checklist* (www.checklist.org.br/) and made available as a Research Species list in Madrean Archipelago Biodiversity Assessment (MABA)/Southwest Environmental Information Network (SEINet) online database (Madrean.org).

Species Richness and Cover

Grazed habitats had significantly more plant species (mean = 21.75 ± 1.1 s.e.) than ungrazed habitats (mean = 15.65 ± 1.1 s.e.; t-test, $p = 0.0005$) and there were more species where grazing had occurred recently than where cattle had not been present for approximately 23+ years, in all but the bosque dry habitat (fig. 2). Tukey's test of all pairwise comparisons showed there were significantly more species in grazed areas of desert scrub, grassland, and riparian habitats than in ungrazed areas of more mesic riparian and bosque wet habitats.

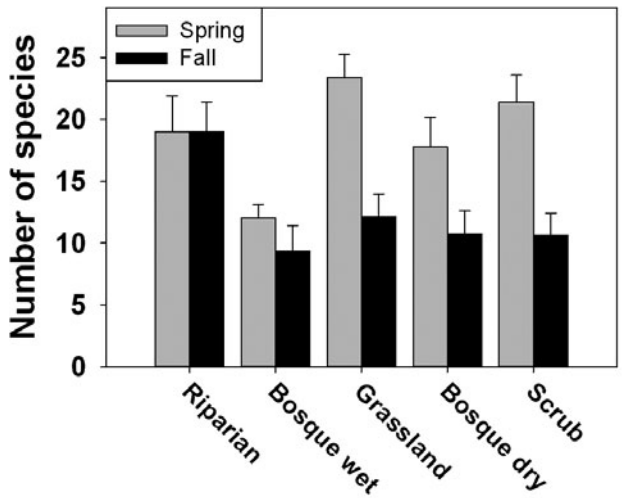

Figure 1—Seasonal differences in average number of plant species recorded from eight plots per habitat in five habitats. Each plot was sampled twice, once in spring 2004 and again in fall 2003. Significantly more species were recorded in the spring.

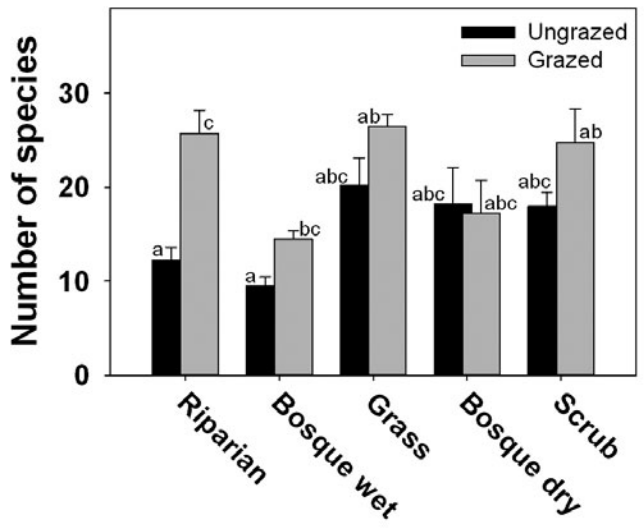

Figure 2—Mean plant species from plots in five habitats that had either experienced grazing ca. 5 years before this study or had not been grazed for 25+ years before the study. More plant species occurred in most habitats in the areas where cattle had been grazing recently. Letters above columns indicate significant differences.

However, in most habitats there was no significant difference in plant species richness when grazed and ungrazed areas were compared except for the riparian habitat where there were significantly fewer plant species in the ungrazed area than in the grazed area (fig. 2).

Mean percent cover did not change in response to grazing history. Post-hoc Tukey's test revealed only one comparison differed significantly; plots in ungrazed areas of grassland had less cover than in plots of the ungrazed area of the riparian habitat (fig. 3). Cover was not significantly different in any habitat when plots in grazed and ungrazed areas were compared.

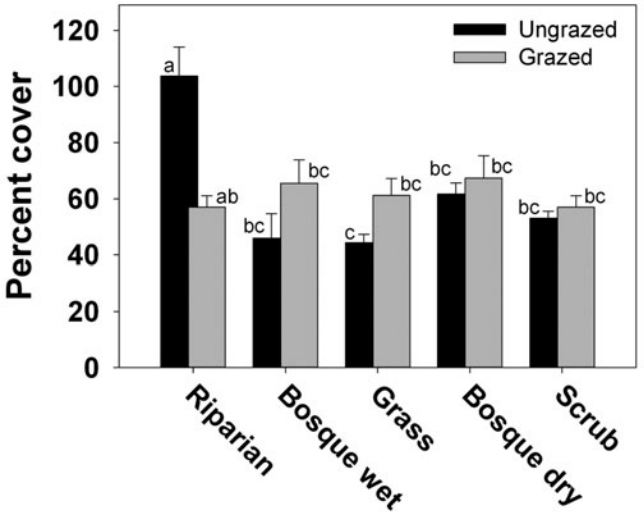

Figure 3—Mean plant cover from plots in five habitats that had either experienced recent grazing or had not been grazed for 25+ years. Cover in most habitats was similar in grazed and ungrazed areas except for the riparian zone. Letters above columns indicate significant differences.

Species Similarity

Vegetation composition varied considerably among habitats, most notably in the riparian habitat where cottonwood dominated the area that was ungrazed, but had not become established downstream in the 3 years after grazing had ended (figs. 4, 5). Approximately 30% of the vegetation coverage in habitats was by four perennial plant species (fig. 4), two that occurred in all habitats (mesquite and sacaton bunchgrass, *Sacaton wrightii*), one that occurred in all habitats except riparian (creosote bush), and one limited to the riparian habitat (cottonwood, *Populus fremonti*). Plant composition among plots was very heterogeneous, as is best exemplified by the low mean species similarities of the samples taken at different plots within the same habitat and grazing history (mean = 37.9%, range from 0.28 bosque wet grazed – 0.49 desert scrub ungrazed).

Exotic Species

There were six introduced species found in the plots; although only the widespread mustard, *Eruca vescaria,* occurred in desert scrub and

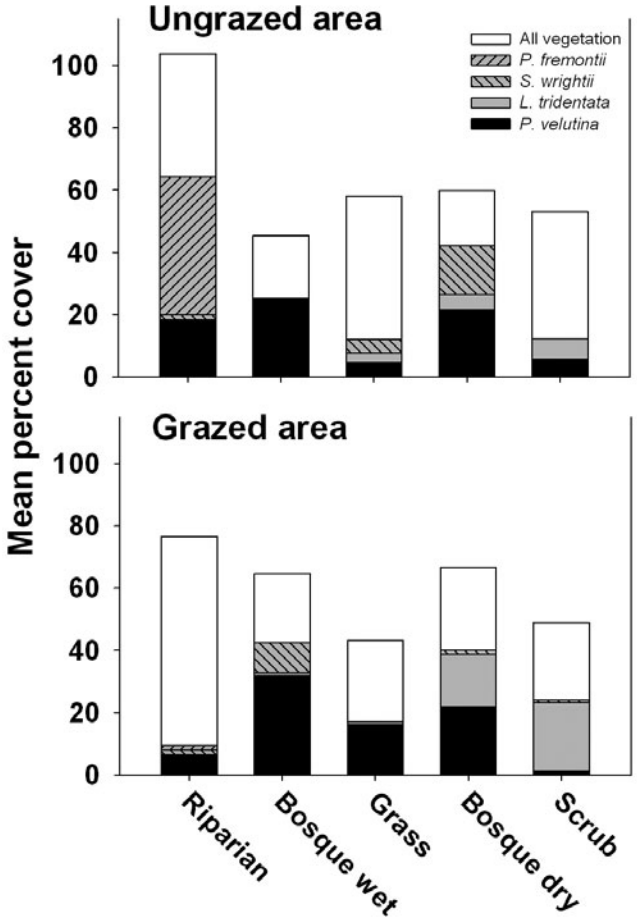

Figure 4—Differences in average cover of all vegetation, and of four perennial species in plots of five habitats that had either not been grazed by cattle for 25+ years or had experienced recent grazing.

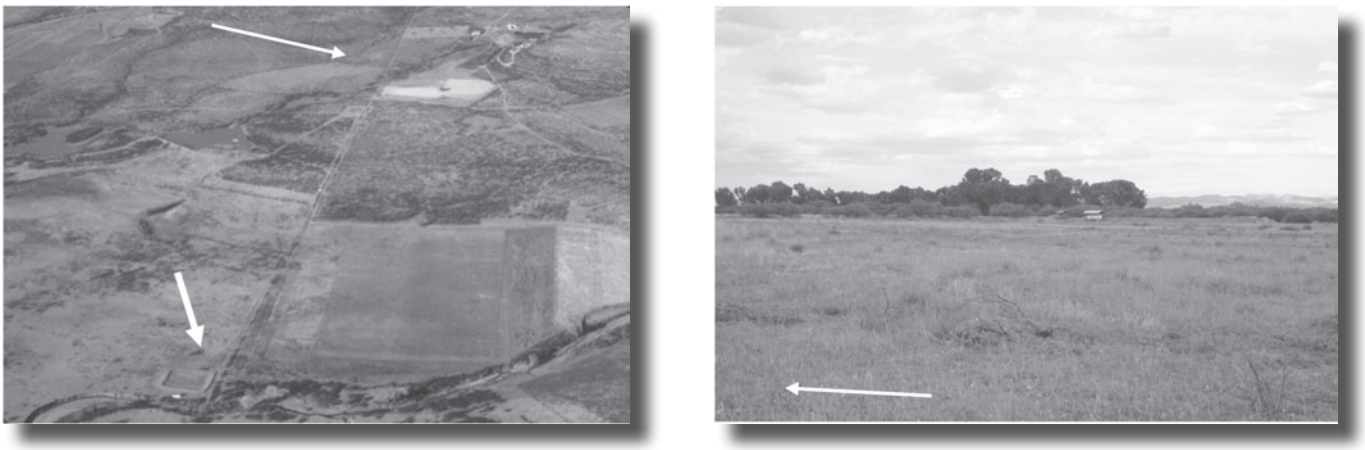

Figure 5—The rapid response of riparian vegetation after the San Bernardino National Wildlife Refuge was established is evident from these photographs from 1979 (left) and 2002 (right) of the Rio San Bernardino (= Black Draw) at the United States-Mexico border. The longer and narrower white arrows in both images indicate north, and the heavy short arrow in the left hand image indicates the approximate source and direction that the image on the right was taken. The United States-Mexico border is distinct in the right hand photo by the continuous line extending from the top to the bottom of the aerial photograph and is less distinct in the left hand photos where it runs from the left to right and traverses the river at the last *Populus fremontii* on the Rio San Bernardino (-Black Draw). The aerial photograph from 1979 shows an unvegetated, exposed riverbed on both sides of the border with few *P. fremontii.* Along the river in the left photo is found an almost continuous forest that has grown since 1979 and is yet to establish along the river in Mexico, where grazing occurred until 3 years before the photo.

bosque dry habitats and only tumbleweed, *Salsola tragus*, occurred in the grassland habitat (table 1). All exotic species occurred in the grazed riparian habitat, but only two of these species occurred in the riparian habitat that was ungrazed. The amount of cover represented by exotic species was less than 5% in all habitats except the riparian habitat with the lowest coverage in the desert scrub habitat. Coverage of introduced species in the riparian habitat was 7-fold greater in the grazed area (25.4%) than in the ungrazed area (3.4%).

Discussion

Despite considerable differences in vegetation among plots within habitats, in the five habitats, and in the 23+ year difference in grazing history, the pattern of vegetation response showed water availability affected how the community composition changed and how quickly such changes occurred. The difference was most marked in the riparian habitat where a cottonwood-dominated gallery forest is now

Table 1—Distribution and identity of exotic species in spring, 2004. Four plots were sampled per habitat and grazing history type. Percent cover is the average for each exotic species in the four plots and percent cover of exotics is the percentage cover by exotic species of all vegetation (not percentage of entire plot). The greatest species richness and overall cover of exotic species occurred in the riparian ungrazed habitat. Exotic species were rare or absent in drier habitats.

Habitat, grazing history	Plant species	Num. plots (of 4 max)	% Cover	% Vegetation cover by exotics
Bosque dry, grazed	–	–	–	–
Bosque dry, ungrazed	*Eruca vescaria*	2	0.1	0.2
Bosque wet, grazed	*Eruca vescaria*	1	0.1	
	Cynodon dactylon	1	0.5	0.9
Bosque wet, ungrazed	*Eruca vescaria*	2	0.3	
	Cynodon dactylon	1	0.2	
	Salsola tragus	2	0.2	1.5
Grass, grazed	*Salsola tragus*	1	0.2	0.5
Grass, ungrazed	–	–	–	–
Riparian, grazed	*Eruca vescaria*	2	0.3	
	Cynodon dactylon	4	11.8	
	Melilotus indicus	3	2.6	
	Salsola tragus	2	0.6	
	Sorghum halepense	1	4.1	
	Tamarix ramosissima	1	0.03	25.4
Riparian, ungrazed	Cynodon dactylon	2	1.5	
	Sorghum halepense	4	2.0	3.4
Scrub, grazed	Eruca vescaria	2	0.3	0.6
Scrub, ungrazed	Eruca vescaria	1	0.4	0.8

present where cattle had been removed in 1979 (fig. 5). Although in this habitat the cover was the greatest of any habitat sampled (fig. 3), species richness was the lowest (fig. 2). Xeric shrub and grassland habitats in the San Bernardino Valley are high in species number, and rivaled only by grazed riparian habitat where cottonwood forest had not become established. Shrub and grassland habitats in grazed and ungrazed areas differed much less in the species found there (fig. 2) and the percent cover (fig. 3) than was observed in the riparian habitat, indicating low water availability does not limit species richness but slows the rate vegetation responds once grazing is reduced.

In this study area, grazing depressed recruitment of cottonwoods in the riparian habitats resulting in eventual extirpation of the species where permanent water was present. Cottonwoods present today were largely absent in this area when cattle grazing was first discontinued in 1979 (fig. 5). The absence of a cottonwood canopy in the grazed riparian area enabled numerous shrubs and annual species to colonize and persist there, many of which were found otherwise in xeric habitats. Both the lack of sunlight and excess soil moisture exclude some plant species from riparian habitats where continuous forest canopy occurs. Upon cessation of grazing in riparian habitats, cottonwoods and other fast growing mesic-adapted plants become established and eventually displace other, lower-growing, species.

In comparison to riparian habitat, the effect of grazing on desert scrub and grassland habitats is more difficult to interpret because it is not possible to disentangle if (1) grazing had little effect on these habitats, or (2) if grazing had a large effect and the rate vegetation responded in these habitats was slower. Though rarely considered, the first hypothesis is not implausible given grazing density and duration for more distant habitats is reduced because cattle remain within a few kilometers of sources for water, especially when air temperatures are high. In the San Bernardino Valley, grassland, desert scrub, and bosque dry habitats are often further from permanent water than riparian and bosque wet habitats. Stock tanks in the grazed area hold water ephemerally today (author, personal observation) and probably behaved the same in the past. Therefore, the more xeric habitats may have experienced lower grazing intensity than riparian and bosque wet habitats. If grazing did have little effect on desert scrub and grassland communities in the San Bernardino Valley, these data suggest that grazing results in greater plant species richness and little change in composition.

Alternately, if grazing had a strong effect of vegetation in desert scrub and grassland, this study is consistent with the conclusion that after grazing ends the species richness declines gradually, and the response by vegetation is slow. The 25-year span of vegetation change represented in this study is not long enough to distinguish which hypothesis (or others) is most reasonable. Further monitoring of the sites studied here and others is needed.

Exotic species were most diverse and represented the greatest coverage where soil moisture was greatest and sunlight was not impeded by a cottonwood canopy (riparian, grazed habitat). The lack of exotic species in xeric habitats is consistent with observations of other studies (Tellman 2002). Furthermore, there are clear management implications of this pattern given that the habitats where exotic species are concentrated are the most localized of any habitat in the region; management to repress the establishment and spread of exotic species may be sometimes feasible even if resources are limited.

Although only eight plots were sampled per habitat in this study, and half of these were in areas that had been recently grazed or not grazed for 25+ years, the comparisons suggest grazing influences vegetation in most, if not all, habitats and these effects may be positive or negative. Where surface water occurs, vegetation responds rapidly to reduced grazing and generates a distinctive low-diversity community dominated by trees. These same habitats are grazed most intensively when cattle have access to them, which results in greater species richness and changes in vegetation composition that approached those observed in adjacent xeric habitats. In xeric habitats, such as desert scrub, the long-term effects are more difficult to establish based on data in this study. It is possible these habitats are little changed other than the increased species richness related to physical disturbance of soils and better penetration or improved emergence by seeds. If they did change substantially when grazed, the rate of recovery appears slow. Either way, the differences in vegetation among habitats here illustrate the complexity managers of biodiversity are confronted with; is grazing maintained to promote local biodiversity or should grazing be discontinued and fewer species maintained locally?

Although cattle removal leads generally toward lower plant species richness, particularly in the mesic habitats, cattle removal has a disproportionate effect in the functional diversity of the whole ecosystem (Petchey and Gaston 2002; Svenson and Enquist 2009). Habitats with great vertical development (gallery forests of cottonwoods) not previously found, or barely present in the grazed area, add ecological complexity to the natural setting. In the mesic sites with low specific diversity, the capture of carbon in thick tree trunks is greatly increased, and the litterfall and carbon addition to soils and watercourses is increased manifold. These factors, mainly associated to increased functional diversity might increase the overall ecosystem functioning and the beta and gamma diversity.

Finally, although this study was done in 1 year, the patterns match those recorded during a vegetation survey in 2000 (Minckley and Burquez, unpublished report), the year after cattle were first removed from the grazed area of this study. This matching pattern supports the conclusion that the effects reported in this study are still related to grazing despite a 3-year lag after grazing ended in the ungrazed area and a 25+-year lag after grazing ended in the ungrazed area.

Acknowledgments

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