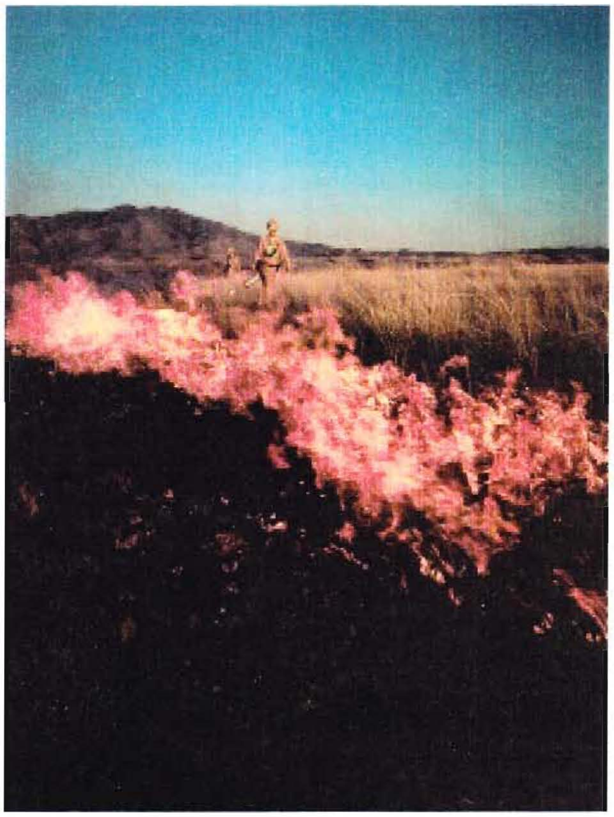
Experimental Studies of the Interaction of Climate, Fire, and Grazing on McKinney Flats

Annual Report to the Forest Service RMRS, 2004



Charles G. Curtin, Ph.D.
Arid Lands Project, P.O. Box 29, Animas, New Mexico 88020
ccurtin@earthlink.net/207-236-4118

Historical writings, old photographs and paintings, and paleo-ecological studies document changes typical of desertification (e.g. increases in woody vegetation and declines in grasses) throughout the arid regions of the southwest within the past 150 years (Hastings and Turner 1965, Cook and Reeves 1976, Grover and Music 1990, Bahre 1991). Data from long-term ecological studies and remote sensing indicate that these changes have continued, and in some cases accelerated, in the last 30 years (Ray 1995, Swetnam and Betancourt 1998, Curtin and Brown 2001). Within southwestern rangelands climate, fire, and grazing are considered the most frequent and important disturbances (McClaran and Van Devender 1995, McPherson and Weltzin 2000, Curtin and Brown 2001). Yet land managers have little guidance when it comes to understanding how key driving variables interact to structure rangelands (McClaran and Van Devender 1995, Ffolliott et al. 1995, Curtin et al. 2002).

To better understand the interaction of climate, fire, grazing, and herbivory by native species in 1998 we undertook replicated landscape level experiments on the McKinney Flats on the Gray Ranch in southwestern New Mexico. This long-term research forms one portion of a coordinated landscape-level research and restoration program being conducted in collaboration with the rancher-led Malpai borderland group and agency partners including the Forest Service Rocky Mountain Research Station and the Joint Fire Sciences Program (Curtin 2002b). In addition to the research described here over 200 vegetation monitoring plots using a comparable experimental design are distributed across the roughly million Malpai borderlands planning area providing a regional context for the landscape level experimental studies (Figure 1).

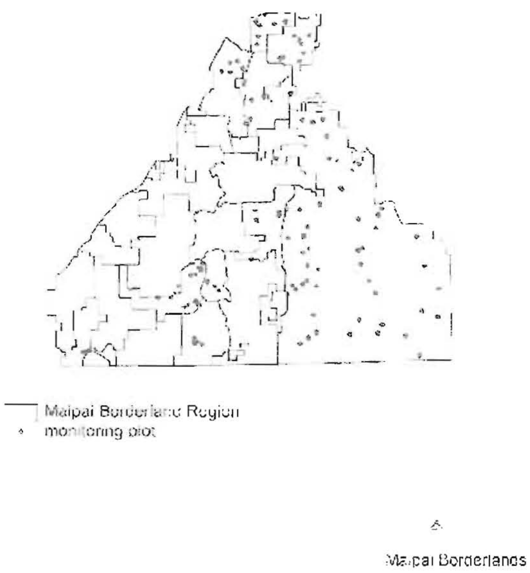


Figure 1. The experimental McKinney Flats project serves as a microcosm for understanding process occurring across the entire Malpai borderlands region. Over 200 vegetation plots provide a larger context for understand patterns detected with the experimental studies, while the experiments provide more detailed insights into the patterns detected at larger scales. The

McKinney Flats Project provides the cornerstone of an integrated landscape level research program in the borderlands and across the intermountain West.

The objective of this study is to determine the effects of climate, fire and grazing (native herbivores and livestock), both singularly and in combination, on the structure and composition of arid grasslands (Figure 2). Disturbance agents measure or manipulated include climate, fire, and grazing, with response variables measured include primary production (Vegetation), primary consumers (small mammals that are considered a keystone species in similar ecosystems), and secondary consumers (lizards) (Figure 2).

Figure 2. The left image depicts McKinney Flats looking East across the research area, in the foreground is a fire break around the Northwest treatment block. The right image looks south over the Southeast grazing exclosure with the Sierra San Louis Mountains in Mexico in the background.

An appreciation of the importance of scale has transformed ecology and natural resource management over the past several decades (Allen and Starr 1982, Allen and Hoekstra 1992, Weins 2002). With researchers increasingly questioning if results from small scale, short-term studies can be extrapolated to the larger scales needed to inform conservation and management (Carpenter 1996; Schindler 1998). The basic tenet of the McKinney Flats Project is to determine the minimum scale at which the interaction of the major variables affecting grassland plant and animal species can be studied at scales directly relevant to understanding landscape level processes. This results in what we believe to be a true landscape approach consisting of studies organized around a hierarchy of scales. This means we had to respond to the following constraints: 1) We needed an area large enough to mimic natural fire behavior, 2) We needed an area large enough to replicate the rotational grazing regimes considered sound livestock management in the region, 3) We needed a research site large enough to incorporate home ranges and foraging areas for investigating the interactions of a number of organisms including rodents

Figure 3. Repeat photos of one of several border monuments between Mexico and the US. at the south edge of the study area indicate that vegetation composition is largely unchanged over the last 110 years (Repeat photography by R. M. Turner and courtesy of the Animas Foundation).In contrast to many field sites in the southwest the study site is still primarily composed of native bunch grasses.

The fundamental underpinning of our research design was the need for independent replication of study plots (Hurlbert 1984, Hairston 1989). This means that there must be a minimum of four replicates of each treatment, and each treatment must, while being comparable to others in biotic and abiotic components, be independent of the others. Statistical analysis can be conducted through ANOVA with each study block and plot an independent replicate, or using a split-plot design. The research site is located on a northeast facing bajada at the base of the Sierra San Louis mountains. Study sites were placed on comparable sandy loam soils (Figure 4).

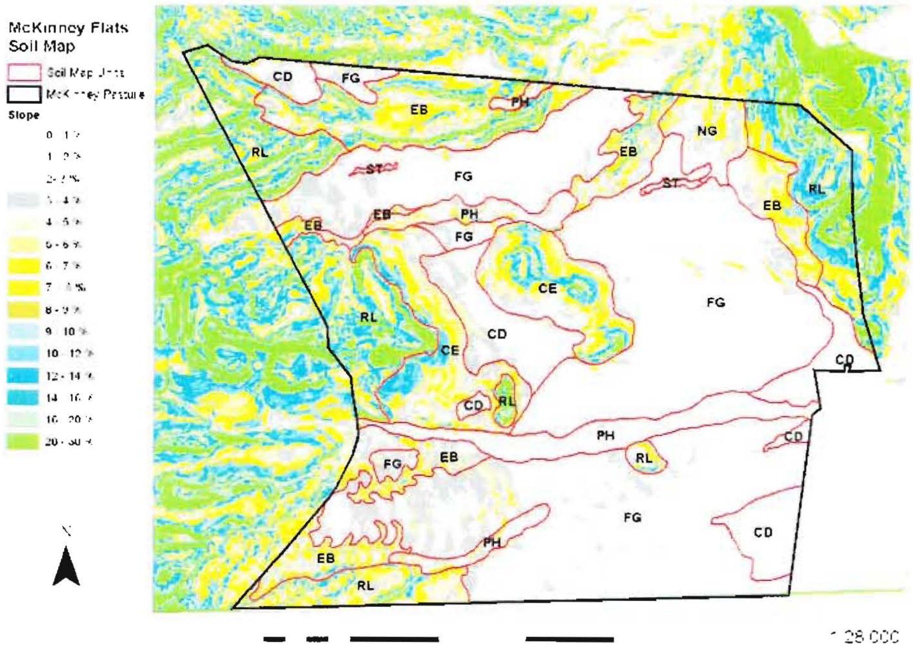


Figure 4. Slope and soil map of the McKinney Flats Research site. The study site is located on a NE facing bajada. All four-research blocks are located predominately oin Forrest Sandy Loam (Marked FG on the map).

We manage the research area as a four pasture, rest rotation system that is representative of progressive range management in the region. Each pasture serves as an independent grazing replicate (Figure 5). Burns are conducted in the context of each sub-pasture to attain replication of fire treatments. Experimental burns are conducted at three to four year intervals that are a timing similar to historical frequencies estimated from tree ring chronologies at the edge of grasslands (Swetnam et al. 2001; T. Swetnam pers. com. 1998). Burns are conducted in June after spring rains and before the summer monsoons when natural fire events and controlled burns primarily occur in our landscape, with the ignition patterns designed to mimic natural fire events. A 30% rainfall gradient across the pasture (7 to 12 in/19 to 30 cm) allows us to contrast the interaction of fire and grazing with precipitation. Because 10 inches (25 cm) of precipitation is often considered the boundary between grassland and desert ecosystems, examination of the interaction of fire and grazing at this threshold can provide important insights into how climatic variation affects recovery following fire, the effects of herbivory on that recovery, the role of climatic variability in creating landscape heterogeneity, and the impact of disturbance processes on desertification. Two hundred cattle (cow-calf pairs) graze the pasture for a targeted utilization of forage of 50% that is consistent with most range management in the region. Though separate assessments of vegetation biomass are conducted as part of the research studies, utilization of forage for range management purposes is conducted through traditional ocular or clipping approaches.

Within each of the blocks 1 x 1 km. study areas were established. In addition to the proximity to other plots, other constraints on plot placement were the selection of comparable soil and vegetation zones, topography, and distance to a water sources (to avoid this confounding variable we determine that the plots should be at least 1 km from permanent water). Within each block are four treatment plots: a) grazed-unburned, b) grazed-burned, c) ungrazed-unburned, and d) ungrazed-burned. Each of these 200 x 200 meter treatment plots were placed as close as possible to the center of the 500 x 500 m blocks to reduce edge effects and maximize distance between samples within each study area (Figure 5).

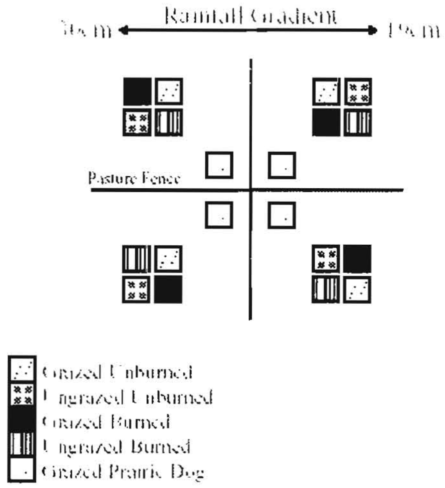


Figure 5. Schematic diagram of the McKinney Flats design depicting the four Pasture rest-rotation system that results in four replicated treatment blocks. Each block (pasture) has four separate fire/grazing treatments and a Prairie Dog translocation treatment. A rainfall gradient across the pasture allows examination of the interaction of treatments with climatic effects.

Vegetation Monitoring: Our vegetation sampling protocol is based on scaling and data collection exercises conducted to determine when sample sizes asymptote and analysis of optimal sampling intensities. In addition, field analysis of commonly used range monitoring protocols and our sampling design, supported by the Turner Foundation, indicates that our protocol is relatively robust and accurate at detecting change in grassland communities (Traphagen and Sundt, Unpublished). Based on these baseline studies, our sampling protocol entails using 40 x 40 cm. quadrates set at two-meter intervals along five 150-meter sampling lines within each sampling plot. Relative frequency data is obtained for each 150m transect by using a series of 75 quadrates systematically placed at 2m intervals along the transect. Relative cover data is obtained by using the four corners of each frequency quadrate as one point-intercept data point resulting in 300 points per transect and 3000 points per 150 x 150 m plot (Figure 6). Vegetation sampling is conducted once a year following the summer rains. Vegetation biomass was measured at 30 m intervals along the 150 m transect lines within 0.40 m^2 square quadrates using techniques developed by the USDA ARS research center in Tucson, Arizona. In this technique representative samples are clipped and weighted until the samplers ability to estimate cover is consistently accurate with less that 5% variation. After the sampler's eye is trained the technique is applied to measurements taken within the study plots. Samples are periodically retested to assure that the ability to estimate cover is consistent throughout the sampling period. Though less accurate than weighing and clipping every sample, the variance in ocular estimates is considerably lower than the variation in cover due to placement of sampling frames. Because this is a long-term study where repeated measures are sought through time from the same plots, nondestructive approaches to sampling were our only option to assure the continuity of the project.

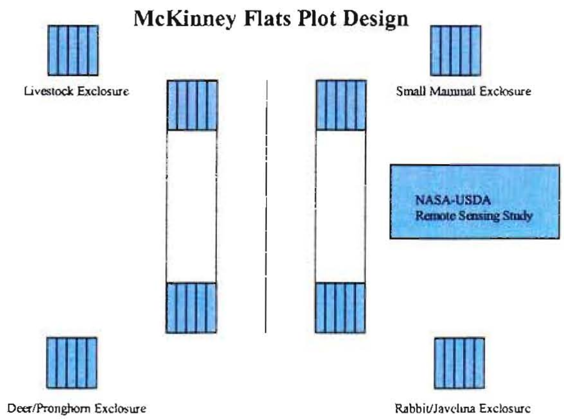


Figure 6. Vertebrate and vegetation sampling is arrayed along five 150 transects within each treatment block. In addition to the core sampling there are 36-m2 herbivore exclosures containing four 30 m vegetation transects situated in the grazed plots. Also measured in the course of baseline sampling efforts to determine optimum vegetation sampling are four 30m2 vegetation sub samples collected at the corners of the main study plots. In a NASA funded companion study research from the University of Arizona and ARS in Tucson has a remote-sensing study of vegetation change on plots adjoining the study areas.

In addition to the large scale sampling effort, at the corners of each 150 x 150 m grazed/burned and grazed/unburned plot are six 36 x 36 m mammal exclosure plots containing four 30 m transect lines. The studies in addition to directly addressing the role of native herbivores and providing additional replication of treatments at a smaller scale, were designed to be comparable to studies being conducted on the Jornada and Sevilleta Long-term Ecological Research Sites in New Mexico, the Armendaris Ranch in New Mexico, and the Mapimi Biosphere reserve in Durango, Mexico (Figures 6). They also form the cornerstone of cross-site studies in collaboration with The Nature Conservancy that examines the interaction of grazing and fire across ranches distributed across the intermountain West. These mammal exclosures involve the following treatments: 1) small mammal exclosures (hardware cloth), 2) rabbit/javelina exclosures (Chicken Wire), 3) Deer and antelope exclosures (three-strand barbwire), 4) cattle exclosures (five-strand barbwire), and 6) Control plots. The plots are sampled through 6, thirty-meter sampling lines with 40 x 40 m quadrates spaced at 2 m intervals. Point intercept data at the corners of the quadrate results in data on plant basal cover from 60 points per line and 360 points per 36 m square exclosure (our baseline studies have determined that 300 to 400 points per plot is optimal for sampling areas of this size).

Small Mammals: Small mammals are considered engineering or keystone species with arid ecosystems with their effects often greater than those of livestock (Curtin and Brown 2001). Because of their strong influence on ecosystem structure and function an understanding of rodent response to fire provides insights into the effects of fire on the ecology of our system, and a assay of resource concentrations. Three times a year Sherman traps are placed at 30 m intervals along the five 150 meter transects within each study plot. We have found that to ensure the traps are all picked-up by the heat of the day, that only one-half of the site will be trapped at a time (240 traps per night). The duration of trapping will be for three days in each location. Due to relatively high mammal densities and diversities on the site (roughly 12 species on the site at a given time and two to ten captures per 200 x 200 m sampling area), this approach is proving effective at documenting small mammal species composition. This trapping is done at the same time as lizard sampling to allow direct comparison between these organisms. In both lizard and mammal sampling we incorporate a interm program with local high school students and college students from around the country. This communicates the importance of research and the utility of the scientific approach to local students, while informing future resource management professionals about the value of ranching and other forms of active resource management (Figure 7).

Figure 7. The McKinney Flats project brings researchers from around the country together with local students to study native flora and fauna and its response to disturbances such as drought, fire, and climate.

Reptiles/Amphibians: Herpetologists have expressed concern over the effects of fire on reptiles and amphibians. The New Mexico Department of Game and Fish is involved in this facet of our study through the participation of State Herpetologist Charlie Painter who serves as a technical advisor for the reptile studies. Given the political ramifications of these studies, it was important to have a herpetologist of regional and national standing involved in our study to ensure our results have credibility. Pit-fall traps are censused three times yearly for nine days each. These periods include early summer, after adults emerge and become active prior to the monsoon (early June), in July after the monsoon (when heat and drought sensitive species are likely to be active), and in August after the young of the year become active. Starting this spring University of Arizona herpetologist Cecil Schwalbe and associates have begun mark recapture and transmitter studies of snakes. This work over the next three years will provide important information on the effects of these predators on other study organisms on the research pasture .

Physical Factors: Rainfall gauges records for the vicinity of the study exists since 1991, with regional rainfall records extending back to the 1800s. We established rainfall gauges on the research area in 1999. In each research block a weather station collects data on air temperature, humidity, rainfall, soil moisture, and wind. To record the spatial distribution of rainfall, gauges also exist at each research plot resulting in 20 gauges distributed across the research area. We added four full weather station on the site in April 2004 to document the interaction between local climate and soil moisture. Soil scientists from the Jornada Experimental Range completed a preliminary soil analysis in 2002 to determine soil composition (depicted in figure 3). Prior to prescribed burns heat sensitive paints on tile are placed at each sampling stake to document burn intensity.

PRELIMINARY RESULTS: Though the project is designed to be a long-term study, significant results have been documented.

Vegetation Response to biotic/abiotic Interactions: Examination of the interaction of climate, fire, and grazing on native bunch grass black grama (Bouteloua eriopoda) in the NE study block illustrates how these factors interact to structure rangelands (Figure 8). Over the last five years the region has faced a severe drought with rainfall declining from 203 mm (8.02 in) in 2000, 2004 mm (8.05 in.) in 2001, to 181 mm (7.14 in.) in 2002, and 172 mm (6.81 in.) in 2003. Initial results of the interaction of climate, grazing, fire show that climate is of overwhelming importance accounting for 55% percent of variation. While grazing had a statistically significant positive impact on vegetation cover accounting for 10% percent of variation, fire alone did not (Figure 9). Grazing and fire did have a significant interaction, though considerably smaller than grazing alone accounting for 2.6% percent of variation (percent of variation accounted for = 73.7% percent, $R2 = 0.737$, $p < 0.05$)(After M. Traphagen 2004, unpublished). The results illustrate that researchers and land managers cannot consider these variables in isolation, but should consider them within the context of other factors. That single factor studies at best miss much of the dynamics of the system, and can be extremely misleading. For example in the case of the bunch grass black grama studies from the 1950s and 1960s indicated that black grama declined following fire (Reynolds and Bohning 1956, Cable 1965). Because black grama grasses are frequently the dominant grass in desert grassland this data was considered to be evidence that this species was not fire adapted, and therefore fire was not a part of desert grasslands (McClaran and Van Devender 1995). Yet subsequent analysis of fire data from McKinney Flats and from monitoring plots from other portions of the Gray Ranch indicate that these results are climatically mediated. During wet periods black grama maintains it's population or increases following fire, whereas during drought it did not. This data is now illustrating that fire has a significant role in maintaining Chihuahua desert grassland.

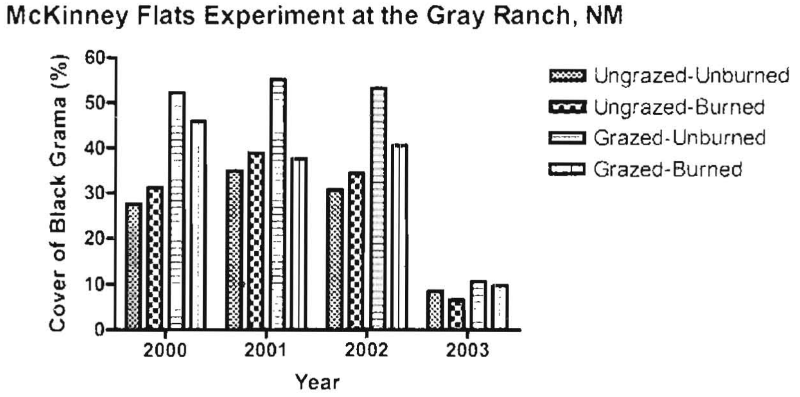


Figure 8. Climate, represented by the yearly variation in results, overwhelms the other key variables including fire and grazing. Yet interactions between variables are frequently considerably more important that the effects of the variables by themselves. The interaction of fire and grazing consistently resulted in the greater Black grama cover than any of the variables in isolation. Thresholds and timing are clearly important in this system. Though the rainfall in 2003 was only 9 mm lower than 2002 the grass cover collapses across all plots.

Role of cattle in desert grasslands: For more than a century conservationists, land managers, and scientists have debated the role of livestock grazing in the degradation of rangelands (Powell 1878, Leopold 1924,USDA 1936, National Research Council 1994, Laycock 1994, Donahue 1999, Curtin et al. 2002, Knight et al. 2002). This debate has peeked in recent years as conservationists and researchers increasingly view ranching and the associated livestock grazing as either a crucial conservation strategy (Starrs 1998, Knight et al. 2002, Maestas et al. 2002), or a major threat (Fleischner 1994, Donahue 1999, Wuerthner and Matheson 2002). While it is impossible to after the fact tease-out the precise effects of a century of grazing, or how the introduction of cattle may have altered the land at the time of European settlement. Landscape level studies can provide important insights into the current effects of livestock. The fundamental hypothesis tested in the coarse of recent analysis of data from McKinney Flats asks: Do cattle reduce the abundance and diversity of key taxa in a desert grassland? Acceptance of the hypothesis would be the result of demonstrably lower biomass and diversity, rejection of the hypothesis would be the result of no effect or demonstrably higher biomass and diversity following reintroduction of cattle.

	Grazed	Ungrazed	P-Value
Plant Biomass	-	+	0.04
Plant Diversity	+	-	0.03
Mam. Biomass	+	-	0.01
Mam. Diversity	+	-	0.02
Lizard Biomass	-	+	NS.
Lizard Diversity	+		NS

Figure 9. At a landscape level the reintroduction of cattle to a landscape ungrazed for a decade resulted in higher diversity of plant and mammals on grazed plots. Analysis over the long-term will examine is this pattern persists through time and across different climatic epochs.

Data on vegetation and vertebrates indicate that response to the reintroduction of cattle to an arid/semi-arid grassland is neutral or positive (Figure 9). A significant difference in the vegetation biomass in grazed and ungrazed portions of the research area (P = 0.0001) existed with mean biomass per 0.40 m^2 quadrate 41.6 (SD = 28.6) and 61.9 (SD = 37.6) gms in grazed and ungrazed plots, respectively. These recorded differences are conservative because fall rains caused some vegetative regrowth prior to sampling. Following a season of rest from livestock the mean biomass of grazed (30.5 gms., SD = 19.9) and ungrazed (29.9 gms., SD = 1.4) plots were not significantly different (P = 0.77). Vegetation richness was not significantly different between grazed and ungrazed plots in 1999 and 2000 prior to livestock reintroduction (P = 0.69 and 0.18, respectively), was significantly higher on grazed plots in 2001 following reintroduction (P = 0.03), and returned to non-significant levels in 2002 after a season of rest (P = 0.84). Climatic factors correlate with greater change than grazing effects with species number in 1999 prior to the drought in the low 30s, whereas by 2002 species number had dropped by a third to the low 20s (and during 2001 were in the mid-teens). Increases in species number on grazed plots were not the result of colonization of exotic species for no detectable shift in species composition occurred during, or following, implementation of the grazing treatments. Small mammal biomass was not significantly different between plots in 1999 and 2000 prior to livestock reintroduction (P = 0.34), yet was significantly higher on grazed plots in 2002 following reintroduction (P = 0.01). Small mammal richness (species number) was also not significantly different prior to livestock reintroduction (P = 0.61), but was significantly higher on treatment plots following reintroduction (P = 0.02). Mammal biomass increased during the sampling period presumably is association with the drought, while diversity declined ($P < 0.05$). Response to grazing by lizards was non-significant with biomass 341.8 gms (SD = 204) in grazed, and 408.8 (SD = 262) in ungrazed treatments (P = 0.78). Species richness per plot averaged 5. 2 (SD = 1.3) in grazed and 4.6 (SD = 0.9) in ungrazed treatments(P = 0.32).

Role of prairie dogs in desert grasslands: In 1902 one of the country's most influential mammalogists C. Hart Merriam estimated that prairie dogs reduced forage for cattle by reducing range productivity by 50 to 75% percent. This estimate and others contributed to the long-standing perception that pastoral land uses and prairie dog conservation were fundamentally incompatible (Miller et al. 1994, Williams 2000). In contrast to these long-held beliefs there is a growing body of literature indicating that prairie dogs have no demonstrable negative impacts, and can have measurable benefits to cattle and other large herbivores (Whicker and Detling 1988, Weltzin et al. 1997). Because the majority of prairie dog research has been conducted on the Great Plains, with the majority of herbivore interaction studies focusing on bison, there is little direct experimental evidence of the effects of prairie dogs on desert grasslands, or of the interaction of prairie dogs with domestic cattle.

Prairie dogs had mixed effects on the composition of major functional groups within the reintroduced colonies (Figure 10). From 1999 through 2002 vegetation biomass was significantly higher on the prairie dog towns ($P < 0.0001$), with mean dry weight of vegetation matter per 40 cm^2 sampling plot was 50.3 grams (SD = 38.6) on the prairie dog colonies, versus 37 grams (SD = 26.1) on the grazed control plots. Species richness (number) was significantly lower on the prairie dog towns than grazed control plots ($P < 0.001$), with mean number of species per study plot 19.7 (SD = 5.1) versus 27 (SD = 6.8) on grazed control plots. No statistically significant change in species composition occurred with the proportion of forbs, grasses, and sub-shrubs remaining constant during the four years following reintroduction. From 1999 through 2002 the mean number of species of small mammals (not counting prairie dogs) was significantly lower on the prairie dog colonies, versus grazed control plots ($P < 0.01$), with the mean number of species 3.6 (SD = 1.7) per plot on the prairie dog towns, versus 4.9 (SD = 2.1) in the grazed control plots. Mean mammal biomass was not statistically different ($P < 0.14$), with 242 gms (SD = 263) on the prairie dog colonies, versus 321 gms (SD = 238) on the grazed control plots. The number of small mammals was significantly lower on the prairie dog towns ($P < 0.04$), with 7.2 (SD = 7.7) on the prairie dog colonies, versus 9.6 (SD = 7.4) in the grazed control plots. In contrast, the number of lizard species from 1999 to 2002 was higher on the prairie dog towns ($P < 0.03$), with mean species number per plot 5.6 (SD = 1.4) on the colonies versus 4.7 (SD = 0.6) in grazed control plots. Biomass was significantly higher on the prairie dog colonies ($P < 0.0002$), with 450.7 gms of lizard biomass (SD = 202) on the prairie dog towns, versus 360.7 (SD = 258) in the grazed control plots. The number of lizards was also significantly higher on the prairie dog colonies ($P < 0.01$), with a mean of 76.4 (SD = 25.5) on the colonies, versus 63 (SD = 47.9) in the grazed control plots.

	PDog		Cattle	P Value
Plant Biomass		>		0.0001
Plant Diversity		<		0.001
Mam. Biomass		<		NS.
Mam. Diversity		<		0.01
Lizard Biomass		>		0.0002
Lizard Diversity		>		0.03

Figure 10. Prairie dogs had diverse impacts across a range of taxa predominantly resulting declines of mammals and increases in lizards. Vegetation biomass increase, whereas diversity declined. From a North American perspective perhaps the most unusual result was the increase in biomass. While this is not been documented in North America, it is consistent with vegetation responses to herbivory documented in East African "grazing lawns." Though as yet not tested we have postulated that the differences between our results and those in other North American grasslands is that our pastures are rotationally grazed allowing recovery after herbivore interactions, whereas many prairie dog town are grazed the entire growing season.

The preliminary results suggest that in many ways the benefits of prairie dog restoration are as tangible for the ranching as for conservation. In addition to increasing biomass, numerous studies document higher nutrient content on prairie dog towns. Our work and that of others (Weltzin et al. 1997) indicate that prairie dogs remove shrubs from grasslands. While cattle and other large grazers disproportionately forage on the colonies (Curtin and Brown, In Review). All of these results suggest that rather than there being a fundamental conflict between prairie dogs and ranching, that prairie dogs could actually be used to assist in the restoration of degraded rangelands. The essential point of the prairie dog studies and the other portions of the McKinney Flats project is that large-scale studies that experimentally document the interaction of driving variables provide fundamentally different insights into the structure and function of natural systems compared to traditional short-term, small-scale microcosm approaches.

FUTURE DIRECTIONS: Preliminary analysis has primarily focused on analysis of single factors such as fire, grazing, or prairie dogs. Additional years of data will give us more power to examine the abundance and distribution of different species in increasingly greater detail. But the most exciting aspect of the next few years is that we are beginning to have enough years of data to have the statistical power to focus on spatial and temporal interactions between variables (as illustrated by preliminary analysis in figure 9). Over the next five years analysis will increasingly be directed at exploring the interactive effects of driving variables and interactions between response variables. As time passes we will increasingly be able to factor in climatic effects because the rainfall gradient across the pasture allows examination of the individualistic response of different parts of the landscape to climatic variation. While linkages to monitoring plots across the million acre Malpai planning area and cross-site studies distributed across the intermountain West allow a regional and continental context to develop.

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