Highlighted research on the USDA-ARS Central Plains Experimental Range (CPER) in Nunn, CO

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Welcome to the Shortgrass Steppe Research and Interpretation Center on the USDA-ARS Central Plains Experimental Range! In this document we have highlighted many of the important scientific studies that have contributed to our understanding of the shortgrass steppe ecosystem. The following study sites can be viewed from the county roads that transect the Central Plains Experimental Range. If you are interested in arranging a tour or receiving more information on research at the Central Plains Experimental Range, please email: sgsric@colostate.edu.

Background Information:

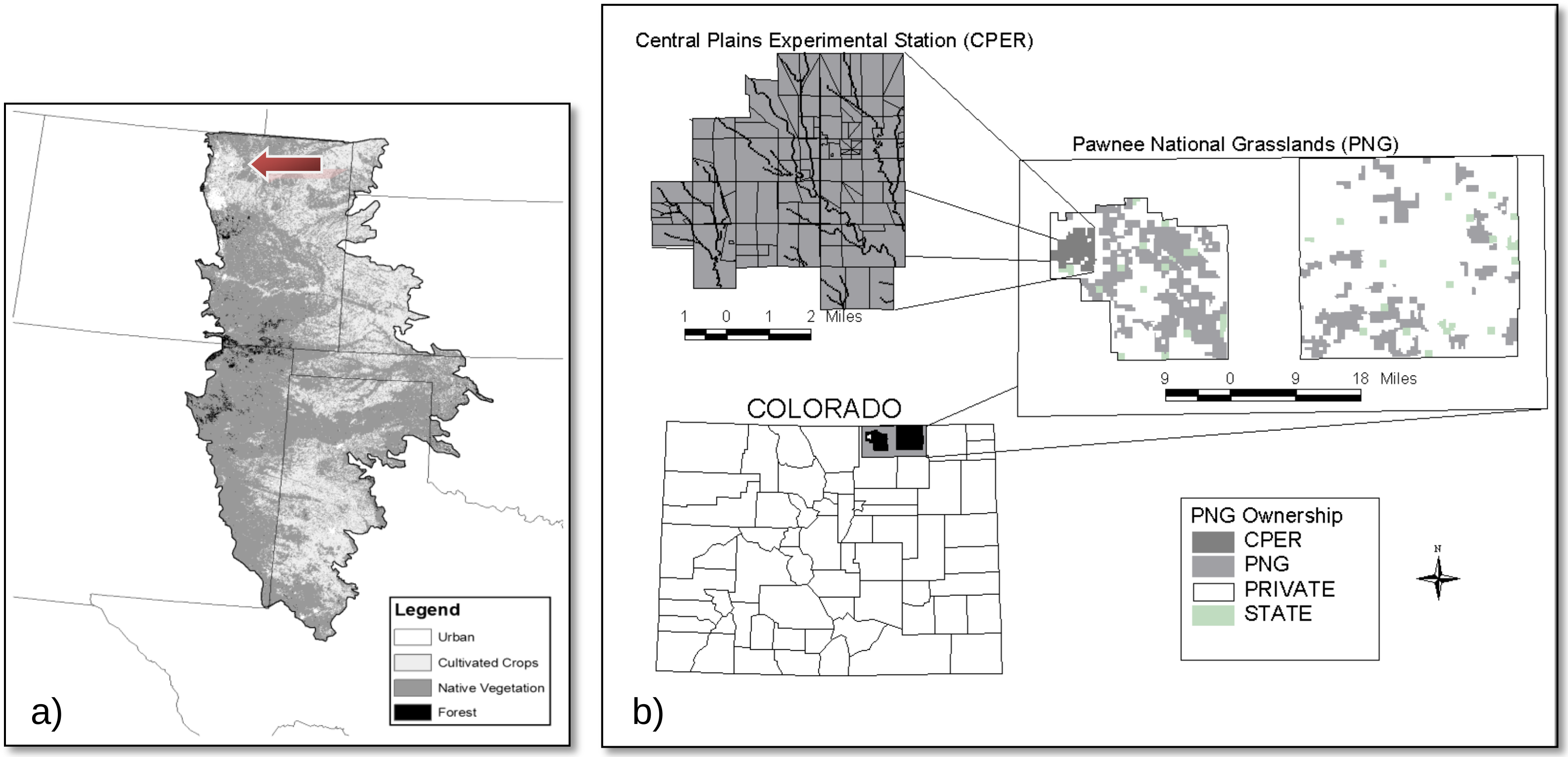
The United States Department of Agriculture (USDA)-Agricultural Research Service (ARS), and the Shortgrass Steppe Research and Interpretation Center support agricultural and ecological research, education and public outreach on the Central Plains Experimental Range. The site has a rich history of interdisciplinary research based onsite as host to the International Biome Program (1968-1974) and the Shortgrass Steppe Long-Term Ecological Research Program (1982-2014). Today, core sites within the National Ecological Observation Network and the Long-Term Agro-ecosystem Research Network are being established at the CPER. Researchers at the CPER have a history of contributing to long-term research networks, which are essential for detecting changes and understanding processes that occur at longer time scales.

The scientists, technicians, educators, and students who work here are interested in the structure and function of the shortgrass steppe ecosystem, and how it is altered by natural processes and human activities. We are interested in identifying key ecological drivers and relationships within the shortgrass steppe. We think about how our understanding may be applied to land-use management, ecological theory, and conservation. We combine experimental and comparative approaches with long-term monitoring, cross-site studies and modeling. We seek to understand the inter-relationships between different components in the shortgrass steppe ecosystem, and to forecast responses of structure and function to regional and global change.

Timeline of Central Plains Experimental Range (CPER):

- **1937 CPER established in response to Dust Bowl crisis**
  - Many grazing exclosures erected to exclude grazing by livestock
- **1939 Developed long-term studies and partnerships**
  - Initiated long-term studies of impacts of grazing intensity (light, moderate, heavy)
  - Developed partnership with Crow Valley Livestock Cooperative, Inc
  - Installed rain gauges to monitor precipitation across the landscape
- **1953: CPER administered by USDA Agricultural Research Service**
- **1968: International Biological Program (US-IBP)**
  - Research focus on the biological basis of productivity and human welfare
- **1982: NSF Long-Term Ecological Research program**
  - Core areas of research focus on
    - Patterns of primary productivity
    - Inorganic and organic nutrient cycling
    - Dynamics of key species and communities
    - Key drivers and determinants of biodiversity and ecosystem function
    - Predictions under global change scenarios
- **2008: CSU Shortgrass Steppe Research and Interpretation Center**
- **2008: NSF National Ecological Observation Network**
- **2012: USDA Long Term AgroEcosystem Research Network**

Shortgrass Steppe Region and CPER Vicinity: a) Extent and land use of the shortgrass steppe ecosystem in the North American Great Plains. The location of the CPER is shown by the arrow. b) Research is conducted on the CPER, administered by the USDA-ARS, and the Pawnee National Grasslands, administered by the USDA- Forest Service. The map shows the mosaic of federal, state and private ownership.



CPER Management Details: Following European settlement of the plains, bison were replaced by cattle. During the 20th century grazing by large, migratory herbivores gave way to grazing by large resident (pastured) livestock. Management practices under study since 1937 at the CPER have focused on grazing treatments (intensity and seasonality) and the movement of cattle from one pasture to another, much as the native, migratory herbivores would have done. In more recent years, studies have focused on economic tradeoffs between various livestock production and conservation strategies and contemporary ecosystem services provided by the shortgrass steppe.

Cattle grazing, photo by D. Guenther

1. Inside the entrance to the Shortgrass Steppe Research and Interpretation Center is a soil monolith created from cores taken at the building site.

Soil profile, photo taken by S. Sprague

The biotic, geological and geochemical processes of the shortgrass steppe interact to drive the development of soils and ecosystems over tens to hundreds of thousands of years. These processes have shaped the development and degradation of soils, the structure and biological dynamics of landscapes and the hydrological functioning of the ecosystem. Current physiography (e.g., soil developmental phase, landscape position and landforms) defines the geologic and pedologic template for the ecosystem and modifies the relationship between precipitation and soil water content, thereby affecting soil microbes, invertebrates, biogeochemical processes, and plant and animal communities. In addition to describing the spatial distribution of organisms and processes across different landscape elements, we study ecohydrological and pedological controls on water distribution, especially soil moisture, within and among landscapes and how landscape variability influences annual net primary production (aboveground biomass), species composition, key processes, and sensitivity of shortgrass steppe to forecasted climatic change.

2. In pasture 21SWS, the Ecosystem Stress Area allows scientists to make predictions about how shortgrass steppe will respond to resource enrichment (e.g. irrigation and fertilization) and disturbance. Our understanding is based on results from initial short-term experiments in the 1970s, long-term monitoring over the next 30 years, and a more recent application of carbon in forms of sugar, lignin and sawdust. This overlay of an historic and a newer manipulative experiment stresses the importance of long-term research in our understanding of how communities respond to disturbance.

As part of the US-IBP studies, in 1970, LTER researchers added water, nitrogen, and the two in combination to experimental plots, in amounts far exceeding what this ecosystem normally experiences. These applications continued for 5 years, and data on plant community composition were collected for each year of treatment. At the end of this experiment, the plots that had received excess water and water plus nitrogen had significantly higher biomass than the nitrogen only or control plots, but at that time no large differences in plant community composition between the treatments were apparent (Lauenroth et al. 1978). The researchers predicted a gradual reversion back to normal vegetation with the cessation of enrichment.

Seven years after the cessation of the treatments, researchers returned to these plots. Sampling from 1982 to 1991 showed a 10-fold increase in exotic weed species on the water plus nitrogen plots as compared to the controls (Milchunas and Lauenroth 1995), a community change has persisted on this site due to a chronic elevation of soil nitrogen caused by a plant tissue/soil organic matter feedback mechanism (Vinton and Burke 1995).

Visiting scientists examining the ESA plots in 2005, photo by L. Hartley

In 1997, it was hypothesized that decreasing nitrogen availability would create a disadvantage for the dominant exotic species and provide an advantage for the native species, returning the community to a vegetative structure more characteristic of undisturbed sites. Six new treatments were superimposed on the historic study site. The six new treatments were: control, sugar, lignin, sawdust, lignin and sugar, and sawdust and sugar. The additions provided 350 g carbon m-2 yr-1, resulting in 1,061 g m-2 of lignin, 777 g m-2 sawdust, and 833 g m-2 sugar being added to the study plots in from 1998 to 2004 (Lowe 2000). Labile C amendments would stimulate microbial activity and suppress rates of N mineralization, whereas complex forms of carbon (sawdust and lignin) could enhance humification and lead to longer-term reductions in N availability.

The five carbon treatments were continued for 8 years, but annual data collection continued. We found that C amendments, particularly sawdust and sawdust + sucrose, stimulated microbial activity in the field and reduced N availability. Over a decade of monitoring, we determined that such C treatments have a short term effect in remediating N additions although effects on vegetation are persistent. Carbon sources and concentrations applied did not help recover the dominant native species of grass, blue grama (*Bouteloua gracilis)*, they were effective in increasing another native species of carex (*Carex eleocharis)*. Consistent C additions or higher C concentrations are necessary to achieve persistent effects. Elevated N availability had a significant influence over community composition and nutrient cycling more than 25 yrs after cessation of increased N inputs. These results indicate that C addition may be a useful tool for restoring some native species in the shortgrass steppe, and their usefulness will depend on the restoration goals.

Small mammal communities responded to changes in vegetation and presumably, food resources, associated with the original treatments and the cessation of grazing. Prairie voles and western harvest mice invaded resource-enriched plots. The ecological changes that began >30 years ago persist today, with ESA treatment plots supporting higher densities and diversity of small mammals than undisturbed areas of shortgrass steppe grasslands (Stapp et al. 2008).

Grant, W.E., N. R. French and D. M. Swift. 1977. Response of a small mammal community to water and nitrogen treatments in a shortgrass prairie ecosystem. Journal of Mammalogy 58:637-652.

Lauenroth, W. K., Dodd, J. L. and P. L. Sims. 1978. The effects of water and nitrogen induced stresses on plant community structure in a semiarid grassland. Oecologia. 36:211-222.

Lowe, P. N. 2000. Nitrogen availability effects on exotic, invasive plant species. M. S. Thesis. Colorado State University.

Milchunas, D. G. and W. K. Lauenroth. 1995. Inertia in plant community structure: state changes after cessation of nutrient-enrichment stress. Oecologia. 5:452-458.

Vinton, M.A., and I.C. Burke. 1995. Interactions between individual plant species and soil nutrient status in shortgrass steppe. *Ecology*. **76**:4 1116 – 1133

Stapp, P., B. Van Horne and M.D. Lindquist. 2008. Ecology of mammals of the shortgrass steppe. Pp. 132-180 in: Ecology of the shortgrass steppe: a long-term perspective (W. K. Lauenroth and I. C. Burke, eds.). Oxford Univ. Press.

3. In pasture 22W, Black-tailed prairie dogs are ecosystem engineers whose activities significantly modify plant species composition, vegetation structure, nutrient dynamics and available habitat for other species. Plague, an introduced bacterial species (*Yersinia pestis*) that is spread by fleas, can decimate prairie dog colonies, causing dramatic changes in vegetation and plant and animal communities (Stapp et al. 2004).

Images Clockwise from upper left: Prairie Dogs, photo by D. Guenther; Rattlesnake eating horned lizard, photo by A. Yackel Adams; Burrowing owl on prairie dog mound and swift fox, photos by M. D. Lindquist

The ecological effects of ecosystem engineers such as black-tailed prairie dogs in shortgrass steppe differ from more productive grasslands because both flora and fauna are adapted to herbivory and short vegetation (Stapp 1998). However, burrows constructed by prairie dogs are a locally abundant and persistent source of refuge belowground and, in semi-arid grassland like shortgrass steppe, prairie dogs themselves are important prey for top-level predators.

Plague is an exotic disease caused by the bacterial pathogen *Yersinia pestis* that spread into the range of the black-tailed prairie dog in the 1940's. Because of the high mortality of black-tailed prairie dog within local colonies, plague has resulted in a classic metapopulation dynamic of black-tailed prairie dog where colonies die off and then are recolonized within several years. With black-tailed prairie dog altering plant communities toward a higher proportion of forbs by selectively grazing the dominant C_4, warm-season grasses,(e.g. blue grama) the ecological effects of plague on black-tailed prairie dog have community effects that include other rodents, flowering plants and their pollinators, and large herbivores. Genetic analyses of the plague pathogen and black-tailed prairie dog, along with modeling efforts, have demonstrated that this alternative state for black-tailed prairie dog can persist because of the metapopulation structure rather than large-scale disease pandemics that sweep across the landscape. Thus, an introduced pathogen can be shown to have led to a persisting alternative state for black-tailed prairie dog and associated species.

In section 22 W, a grid is set up to observe prairie dog grazing and cattle interactions at a site where prairie dog populations vary with an expansion and then subsequent contraction caused by plague. Measurements of the ecosystem responses to these variations include vegetative cover and plant species composition were collected following a 2006-07 plague epizootic at CPER. Other key response variables in the ecosystem being measured are livestock behavior, which is categorized by creating maps of movement by cattle wearing GPS collars, as well as their weight gains, wind erosion rates, small mammal density and species composition, arthropod density and species composition, and Mountain Plover density. Grid 22W is one of 4 sites across the CPER being monitored.

Stapp, P., M.F. Antolin and M. Ball. 2004. Patterns of extinction in prairie-dog metapopulations: plague outbreaks follow El Niño events. Frontiers in Ecology and the Environment 2:235-240.

Stapp, P. 1998. A reevaluation of the role of prairie dogs in Great Plains grasslands. Conservation Biology 12:1253-1259.

4. In pasture 27 there is a standard meteorological station. In a semi-arid grassland characterized by both inter-annual variation in precipitation (i.e. periodic drought) and grazing by livestock, many ecosystem components, including the amount of of ecosystem respiration versus carbon storage, are influenced by the timing and size of rainfall events.

Summer storm and rainbow, photo by M.D. Lindquist

We know that annual aboveground biomass is more sensitive to variations in precipitation than to long-term differences in grazing treatments (Milchunas et al. 1994), an important consideration when making management decisions about livestock grazing in shortgrass steppe. Recently, our work has focused on understanding the influence of the timing and size of precipitation events. For instance, precipitation events of <5 mm in size result in respiration, but not carbon uptake, especially after extended periods without precipitation when soil moisture becomes depleted. The hypothesized mechanism is through activity of soil microbial communities relative to the ability of grasses to become photosynthetically active. With climate change resulting in altered seasonal patterns of precipitation in the shortgrass steppe ecosystem on the western Great Plains, the effects could scale to large changes in carbon balance across the area.

Soil moisture, the driving abiotic determinant of productivity in shortgrass steppe, is dependent on highly seasonal and pulsed nature of precipitation, as well as with interactions between the biota and physiography, and soil properties. Biological, geological and geochemical processes have interacted to shape the development and degradation of soils, topographic variation and the hydrological functioning of the ecosystem over tens to hundreds of thousands of years. Changes in the magnitude and timing of precipitation that will accompany anticipated climate change will alter the spatial distribution and temporal availability of soil moisture, and therefore net primary productivity, on the landscape.

Rainfall totals and PET (photosynthesis, evaporation and transpiration) have been recorded here in pasture 27 since 1969 using a rain stick gauge and lysimeter, respectively. A series of pulsed rainfall experiments also have been designed to examine effects of pulsed events on scales from local microbial and soil arthropod communities within in situ gas exchange chambers to large-scale measure of land-atmosphere exchanges with Bowen ratio towers.

Milchunas, D.G., J.R. Forwood, and W.K. Lauenroth. 1994. Productivity of long-term grazing treatments in response to seasonal precipitation. *Journal of Range Management*. **47**:2 2133 – 139

Mean Monthly Conditions:
(calculated from daily values collected from 1969-2010 IBP/LTER Dataset)

Month	Mean ppt total mm (in)	Mean Maximum Temp C (F)	Mean Temp C (F)	Mean Minimum Temp C (F)
January	5.76 (.23)	6.09 (43.0)	-1.5 (29.3)	-9.26 (15.32)
February	6.14 (.24)	8.05 (46.50)	0.25 (32.45)	-7.6 (18.32)
March	17.50 (.69)	11.65 (52.97)	3.83 (38.90)	-3.99 (24.82)
April	36.68 (1.44)	16.27 (61.28)	8.35 (47.03)	0.43 (32.78)
May	55.40 (2.18)	21.00 (69.81)	13.28 (55.91)	5.57 (42.03)
June	53.79 (2.12)	26.61 (79.90)	18.39 (65.10)	10.20 (50.35)
July	52.53 (2.10)	30.80 (87.45)	22.16 (71.89)	13.55 (56.38)
August	43.09 (1.70)	29.80 (85.65)	21.24 (70.23)	12.70 (54.86)
September	30.39 (1.20)	24.95 (76.91)	16.27 (61.29)	7.62 (45.72)
October	19.34 (.76)	18.17 (64.71)	9.83 (49.69)	1.50 (34.71)
November	9.73 (.38)	10.69 (51.25)	3.13 (37.63)	-4.44 (24.01)
December	5.17 (.20)	6.53 (43.76)	-1.01 (30.17)	-8.61 (16.50)

Other programs have monitoring equipment in pasture 27 at the CPER, including:

The National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu/) has maintained monitoring equipment here since 1979 to collect a long-term record of wet deposition of acids, nutrient and base cations across the nation and in this area from along the frontrange.

UV-B Monitoring and Research Program at Colorado State University (http://uvb.nrel.colostate.edu/UVB/index.jsf)
High energy ultraviolet solar radiation can significantly damage plants, crops, animals, and ecosystems, alone or in combination with other environmental stress factors such as temperature and moisture. To address these concerns, in 1992 the USDA established the UV-B Monitoring and Research Program at CSU to provide cost-effective monitoring of UV-B levels over wide geographic areas of the United States. This is one of 37 stations in the national network of UV-B monitoring instruments that delivers high quality data products in support of agricultural research describing the geographic distribution of UV-B solar irradiance, effects of increased or diminished UV-B on crops, native and invasive plants, and animals, and provided data input to climate and crop models.

The **U.S. Climate Reference Network (USCRN**) **(http://www.ncdc.noaa.gov/crn/)** consists of 114 stations developed, deployed, managed, and maintained by the National Oceanic and Atmospheric Administration (NOAA) in the continental United States for the express purpose of detecting the national signal of climate change. The USCRN instrument suite on the CPER was installed in 2003 and measures the following climate related parameters:

- Air temperature
- Precipitation
- Solar radiation
- Wind speed
- Surface temperature
- Relative humidity (2004/2005)

5. In pasture 24, you can see the long-term grazing strip. The shortgrass steppe is unique among North American grasslands for its long evolutionary history of intense selection by both drought and herbivory, resulting in an ecosystem that is well adapted to withstand grazing by livestock, the predominant land-use in a region where precipitation is both low and highly variable.

Looking north, cattle outside the long-term grazing strip, photo by D. Milchunas

The boundaries of the grazing strip run one mile north of WCR 114. The center of the grazing strip has been excluded from grazing since 1937. To the east, the vegetation is moderately grazed and to the west it is heavily grazed. On either side of the grazing strip the vegetation is dominated by two species of low-growing, warm-season perennial grasses (blue grama, buffalograss) that are resistant to grazing and short-term drought. Biological activity is concentrated belowground, as reflected by the large allocation of nutrients for plant growth as roots and the high rates of energy flow through belowground food webs. Most biologically active elements in the shortgrass steppe are protected from natural disturbances by being stored in soil organic matter. Removal of grazing results in plant communities which are more similar to disturbed areas than are heavily grazed pastures.

6. In pasture 25, since 1994, small mammals have been live trapped in upland grassland and lowland shrubland (saltbush) sites at the CPER (saltbush-dominated areas are apparent in the Owl Creek drainage that parallels, then intersects WCR 37). Scientists also monitor changes in the abundance of prey species, such as insects, as well as changes in plant community and vegetation structure. Rabbit populations are monitored by spotlight counts along the main roads (WCR 114, 37, 108) on the CPER once per season. Collectively, these studies monitor consumer populations over the long-term, as well as their interactions between climate and habitat and resources, where findings describe the potential responses of animals to climate change and disturbance.

Ord's Kangaroo Rat, Deer Mouse, Prairie Vole, and Thirteen-lined ground Squirrel, photos by P. Stapp

Because of the low productivity and lawn-like features of shortgrass steppe vegetation, factors that influence the structure of the vegetation or access to belowground refuges have a large influence on faunal populations and biodiversity. The shortgrass fauna is dominated by omnivorous, seasonally-active generalists whose biogeographic locations are within adjacent prairie and montane areas. In the harsh climate characteristic of shortgrass steppe, the presence of taller, cool-season grasses and shrubs provide critical cover, resources and habitat for many species, including some of regional conservation concern. Changes in climate, CO_2 or land-use that alter the distribution of these plants, especially the presence of shrubs and seed-bearing plants, will have profound effects across multiple trophic levels.

Stapp, P., B. Van Horne and M.D. Lindquist. 2008. Ecology of mammals of the shortgrass steppe. Pp. 132-180 in: Ecology of the shortgrass steppe: a long-term perspective (W. K. Lauenroth and I. C. Burke, eds.). Oxford Univ. Press.

7. In pasture 26NW and NE, scientists set out to determine if patch burning which is currently used in mesic rangelands, can be extended to semi-arid rangelands as a management tool. In 2007 this study site was established to explore the interactions between burning and grazing. One quarter of the pasture is burned each year, and compared to pastures not burned but grazed at the same stocking rate. This study concluded in 2012. Can you still see sign of the burn?

Prescribed burn on the shortgrass steppe, photos by M.D. Lindquist

The shortgrass steppe ecosystem evolved with and has adapted to grazing by large herbivores and fire. Native migratory bison have been replaced by managed resident livestock and wild fire has been suppressed. Scientists are interested in the sensitivity of the shortgrass steppe to different climates, grazing regimes and management practices, fire management, and other disturbances. Researchers will determine the effects of summer burning with grazing on productivity, composition, diversity, nutrient cycling, vegetation heterogeneity (spatial patchiness and variability), and livestock gains and behavior. They will also determine the consequences of increasing heterogeneity within a pasture with regards to landscape pattern and key ecological processes (water balance, carbon exchange). Measurements collected on the burned areas and control areas include grasshopper numbers, density, species composition, vegetation structure, cover, and composition, forage quality and quantity, cattle behavior and weight gains, cactus population dynamics, soil water and temperature, greenness index (NDVI), fuel loads and fire temperatures, wind erosion rates, small mammal (ground squirrel) density, grasshopper density, mountain plover and grassland passerine densities.

8. In pasture 7SW, a long-term grazing experiment was installed in 1991. Long-term ungrazed from 1937 were maintained as areas closed to livestock grazing. Some long-term ungrazed exclosures were opened to being grazed by livestock. Some long-term grazed areas were closed to grazing, and long-term grazing areas remained open to grazing. These installments created 4 grazing treatments over 6 sites. Three of these 6 sites have the paired small-mammal exclosures as seen in pasture 7SW.

Exclosure ungrazed since 1937 on the left pictured beside a long-term grazed area, photo by D. Milchunas

This study reverses long-term grazing treatments to assess how the shortgrass steppe transitions among states (state and transition models) and to conduct long-term monitoring of system behavior in response to seasonal and annual climatic fluctuations and trends. Numerous hypotheses are being tested: 1) Grazing does not shift this system to an alternate state (contrary to Natural Resource Conservation Service models) and convergence to long-term grazed (opened to livestock since 1937) and long-term ungrazed (closed to livestock since 1937) conditions will be rapid. 2) Grazing at moderate intensities does not affect the recovery of the system from drought, a co-force in the evolution of this system (contrary to US Forest Service management). 3) Grazed communities will fluctuate less than ungrazed communities through weather cycles. 4) As shown for communities around the world (Milchunas and Lauenroth 1993) and for topographic positions within the shortgrass steppe (Milchunas et al. 1989), grazing will have less effect on plant community composition and productivity during dry than wet periods. 5) Nitrogen concentrations and yields (forage quality) will fluctuate less that than primary productivity (forage quantity) through wet-dry cycles, and less on grazed than ungrazed treatments. 6) Grazing will stabilize the system response to changing climate in part due to suppression of exotic and opportunistic species, 7) Grazing will and by maintaining the dominance of belowground allocation, the impact of the belowground allocation on configuration of the soil community, and important nutrient feedbacks from the soil community to the plant community (Moore et al. 2003).

Milchunas, D.G. and W.K. Lauenroth. 1993. A quantitative assessment of the effects of grazing on vegetation and soils over a global range of environments. *Ecological Monographs*. **63**: 327 - 366

Milchunas, D.G., W.K. Lauenroth, P.L. Chapman, and M.K. Kazempour. 1989. Effects of grazing, topography, and precipitation on the structure of a semiarid grassland. *Vegetation*. **80**: 11 – 23

Moore, J.C., K. McCann, H. Setala, and P.C. de Ruiter. 2003. Top-down is bottom-up: Does predation in the rhizosphere regulate aboveground production. *Ecology*. **84**: 846 – 857