Annual Report 2007: Activities and Findings

This has been a year of changing personnel, building new collaborations within and among other institutions, and increasing synthesis activities while maintaining our central focus of studying the structure and function of the SGS ecosystem and addressing broader scientific initiatives. We continue to initiate new experiments (in response to the comments from our 2005 site review) that will help form the basis for the next submission. This annual report provides a summary of our A) Research Activities, B) Information Management, C) Education, Outreach and Training Activities, and D) Project Management.
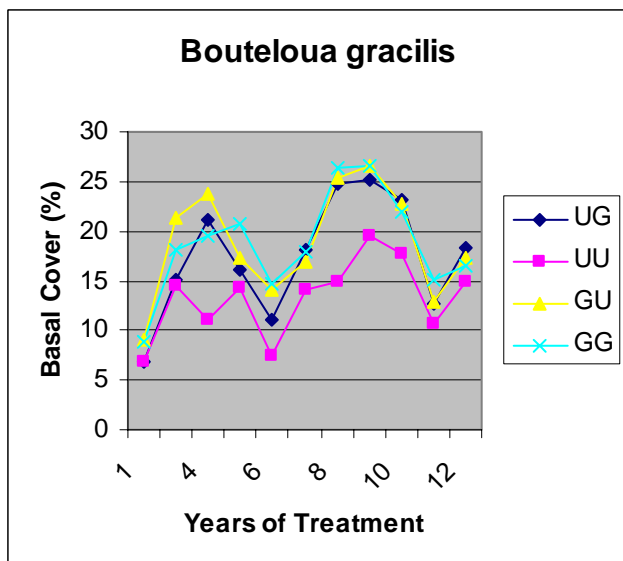
A. Research Activities

During the last year, we produced 27 papers in refereed journals, 18 book chapters, three dissertations, one thesis and 33 abstracts from national and international meetings. Fifteen additional papers have been accepted by refereed journals, and one for book chapters. **Twenty-one graduate students, 31 undergraduate students and three post-doctoral fellows** worked on research related to the shortgrass steppe LTER. We continue to sample our long-term projects, as well as initiating some new short-term experiments. Key research progress for 2006-2007 is presented below for each of our three core areas: population dynamics, biogeochemical dynamics, and land-atmosphere interactions, as well as for integrated, synthetic and cross-site work.

1. Population Dynamics

a. Plants

1) <u>Temporal Convergence after Shifts in Grazing Treatments</u>: Grazing exclosures and grazing intensity treatments at the CPER were established in 1939, but the temporal dynamics of the plant communities were not closely monitored at that time. We are conducting a long-term experiment that opens half of old long-term exclosures to grazing and creates new exclosures on long-term grazed areas. This will assess the dynamics of convergence of previously ungrazed communities (UG- previously Ungrazed, now Grazed) to grazed communities (GG- previously Grazed, still Grazed) and convergence of previously grazed communities (GU- previously Grazed, now Ungrazed) to ungrazed (UU- previously Ungrazed, still Ungrazed) (Figure 1). *Bouteloua gracilis*, the dominant species of the shortgrass steppe, is of particular interest in

Figure 1 Response in basal cover of Boutelous gracilis versus years of grazing treatment

response to these treatments because it is 70-80% of the plant community. Long-term results indicate that *B. gracilis* that is newly grazed will rapidly converge to the long-term grazed levels, but that newly ungrazed *B. gracilis* does not rapidly converge to long-term ungrazed levels. Larger differences between the UU and other treatments are observed during wet cycles of high abundance, but differences diminish during dry cycles. This suggests that the reaction to grazing may be more sensitive than the recovery from grazing, and that temporal increases in productivity within a system among years increases sensitivity to grazing similar to that predicted for local and global spatial scales among communities (Milchunas and Lauenroth 1993).

2) <u>Grazing of CRP to Speed Succession:</u> The shortgrass steppe of the Great Plains is an ecosystem that has evolved with grazing by large herds of bison. Current-day grazing by domestic livestock is a surrogate for this integral component of the system that favors endemic shortgrass fauna and flora, and reduces the abundance of invasive, ruderal, or 'weed' plant species. Planting of CRP lands with mid- and tall- grass species fragments native shortgrass steppe, and early seral stages have high densities of annual weed species. Relatively greater aboveground to belowground allocation ratios of these CRP fields compared to native shortgrass communities has additional implications for soil stability and carbon sequestration potentials of the two. A study was initiated to assess the potential for grazing (compared to the usual no grazing on CRP) to speed succession to native short grasses on seeded CRP land, to produce a physiognomy more favorable to endemic wildlife, and to increase recovery rates of soil organic matter that is depleted by previous plowing by selecting for late seral stage species that allocate relatively more belowground than to aboveground (Milchunas et al. 2005). The study includes both newly planted CRP fields (2 years old) and older CRP fields (10 years old) with grazed or mowed and ungrazed treatments. The new field was seeded, and allowed to establish for two years. Preliminary results indicate that new fields are nearly 100 percent dissimilar from native shortgrass (SG) and new ungrazed (NU), new mowed (NM), or new grazed fields (NG) show little difference after only one year of treatment. Old CRP fields grazed (OG) or ungrazed (OU) are approximately 60% different in species composition and initial (one year) treatments have not yet induced changes in the plant community. This system does not respond rapidly to aboveground disturbances, and changes due to treatments are not expected to occur initially.
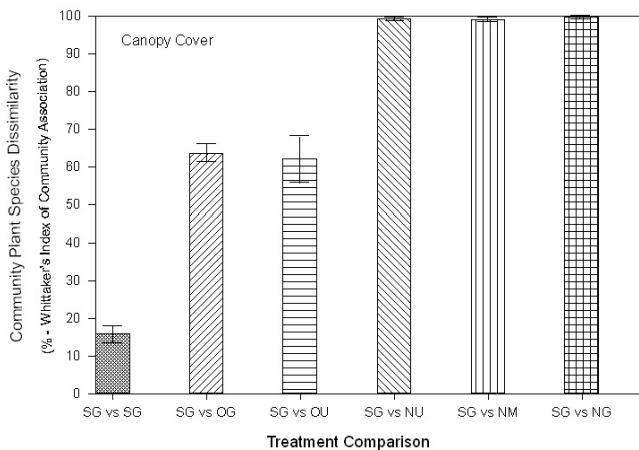

Figure 2 Disimilarity index of plant communities in CRP lands as a function of management. Shortgrass (SG) and new ungrazed (NU), new mowed (NM, new grazed fields (NG), old CRP fields grazed (OG) or ungrazed (OU).

3) Livestock Responses to Very Heavy Stocking Rate Experiment: A new experiment was initiated in 2004 to evaluate the vegetation and animal responses to very heavy stocking. Previous grazing management research in the shortgrass steppe had largely addressed stocking rates within the constraints of the livestock production paradigm. Here, we implemented stocking rates that were double the recommended rate on shortgrass steppe. Individual animal responses in terms of average daily gains (gain per head per day) decreased by 15% (2004) and 24% (2005) in the first two years of the study, with marked reductions observed in 2006 (77% reduction) (Figure 3). Gains expressed on a per unit land area basis (kg/ha), however, show that the very heavy stocking rates produced more total gain over the summer grazing season in 2004 and 2005, but not in 2006. The greater gains per unit land area in 2004 and 2005 were manifest due to the doubling of the number of yearlings on the study pastures (Figure 4). The greater numbers of yearlings in 2006, however, did not compensate for the very marked reduction in livestock performance per individual animal. As a result, this suggests that short-term overstocking may be economically feasible for land managers, but continued implementation of this management practice has longer-term negative economic consequences. These results suggest that an ecological threshold in terms of animal performance was crossed in 2006, although forage production taken from temporary exclosures established prior to the grazing season did not differ between moderate (527 kg/ha) and very heavy (515 kg/ha) stocking rates. This experiment is planned to continue for 10 years with annual measurements of vegetation (cover, density, diversity, production) and animal (weight gains) responses.

Figure 3. Weight gain per individual animal for 2004, 2005, and 2006 under moderate and very heavy stocking rates.
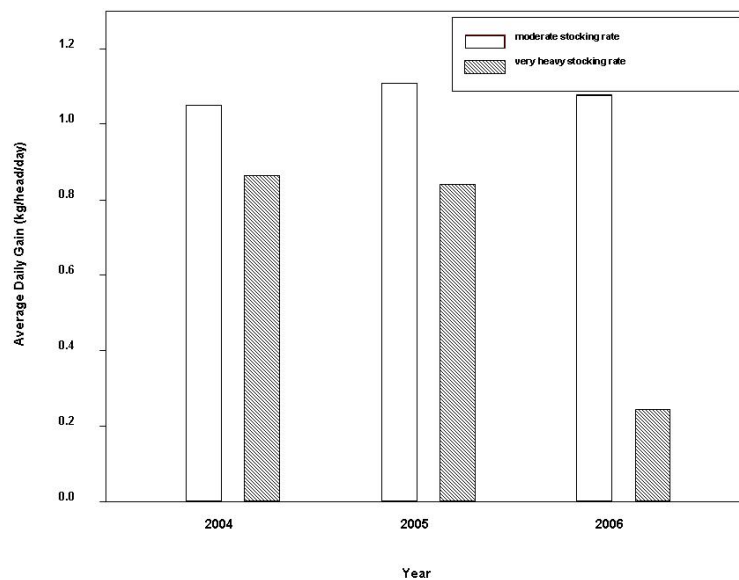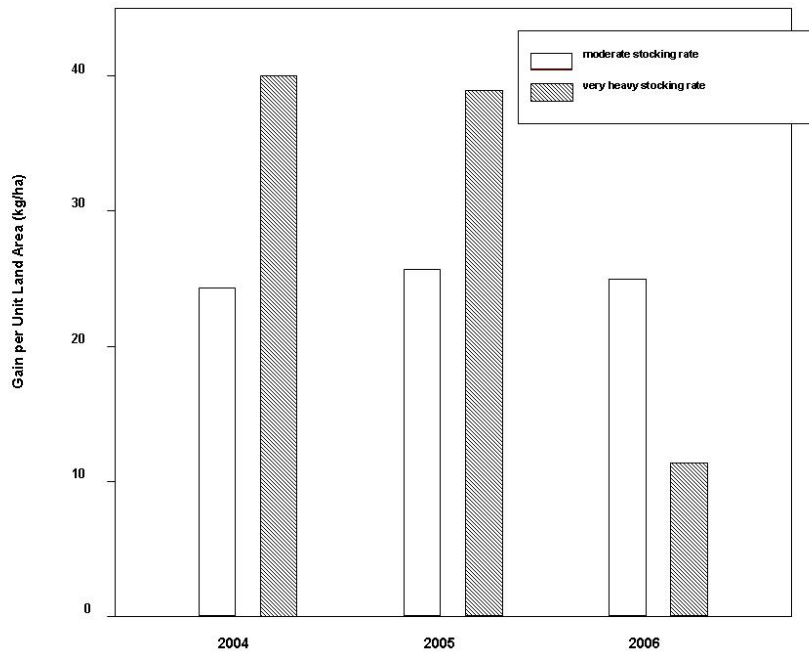
Figure 4. Weight gain per unit area for 2004, 2005, and 2006 under moderate and very heavy stocking rates.

4) <u>Precipitation Manipulation Experiment</u>: Future climate scenarios for the central US include the potential for a shift to more extreme precipitation patterns in which growing season rainfall events will be fewer in number but larger in size. Within this region, a strong west-east precipitation gradient (350 to 850 mm) gives rise to three distinct grassland types – the shortgrass steppe, mixed grass prairie, and tallgrass prairie – which differ strongly in ecosystem structure and function. Aboveground net primary productivity (ANPP) is characteristically water-limited in each of these grasslands. A shift to fewer rainfall events is likely to alter soil water availability for plant uptake via changes in rates of evaporation, transpiration, and runoff. To investigate how ecosystem function may be impacted by shifts in precipitation patterns, we conducted a multi-site study in which growing season precipitation was manipulated through the use of small-scale rainout shelters (n=15 per grassland). Beneath these, we varied rainfall distribution through application of 12, 6, or 4 events/season, while maintaining cumulative amounts at 30-yr averages. Reducing event number had dramatic but opposite effects across the precipitation gradient. In tallgrass prairie, a reduction from 12 to 4 events resulted in a 15% reduction in ANPP (Figure 5). In contrast, an increase in ANPP of 30% and 70% was observed in short- and mixed- grass prairie, respectively, as event number decreased (but event size increased). Data suggest that changes in precipitation patterns strongly influence soil moisture dynamics and soil water content, which, in turn, drive ecosystem function.

Figure 5. ANPP vs rainfall events data for the SGS LTER site in 2006.

SGS 2006
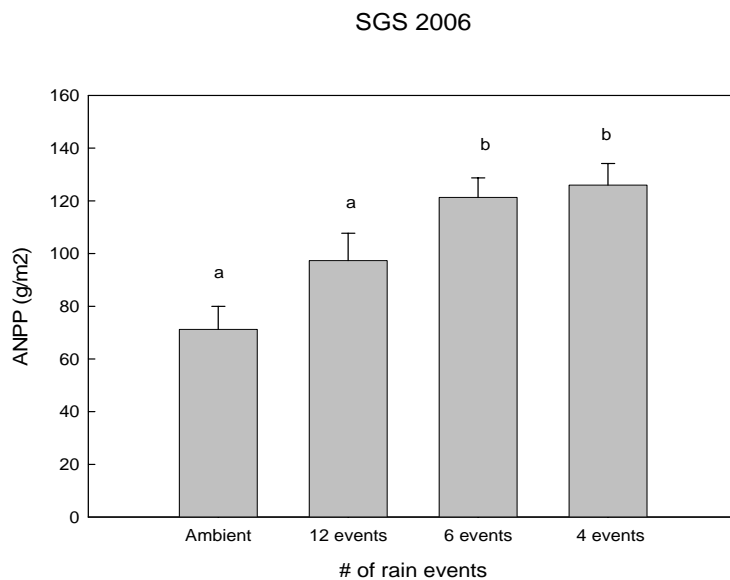
5) <u>Small Plot Burning Experiments</u>: Although fire is an important driver in grassland systems, comparatively little is known about the response of the shortgrass steppe. Based on comments we received from the NSF-LTER site review team we began a new experiment last year and report on this years findings. The goal of this study is to increase our understanding of the responses of the shortgrass steppe, not just to a single fire, but to a variety of fire frequencies. 20 m x 20 m plots were set up in an area in the Shortgrass Steppe LTER not grazed by cattle. Plots burned every year and every three years will be compared to unburned control plots. The first burn of both annual and triennial plots was conducted in early May 2006. ANPP was lower in the burned plots than the controls. This difference was due to a decrease in perennial grass productivity (Figure. 6). Species richness did not differ between treatments, although the relative cover of annual grass tended to be lower in burned plots. Soil moisture and temperature did not differ between burned and unburned plots. There was lower than average precipitation in 2006, which may affect how the system responds to burning.

Three individual cactus plants were marked in 2006 within each of the 4 replications of the 5 treatments (unburned, burned every spring, burned every fall, burned every third spring, and burned every third fall). All plots that had a burning treatment were burned in 2006, with the annual spring burning plots burned a second time in 2007. Plants were censused on June 14, 2007 with cladodes counted in the following categories: new, older (including injured cladodes) and dead, along with the number of flowers per plant. The values in the above graph represent means per treatment (n=12 plants). General trends include the following: a) New and older cladodes are greatest on plots not burned, and lowest on plots burned last fall, b) Number of flowers are greatest on plots not burned, and lowest on plots burned last fall and plots burned annually in the spring, c) Number of dead cladodes was greatest in the plots burned last fall and plots burned annually in the spring, whereas unburned and plots burned only in the spring of 2006 had the lowest numbers of dead cladodes.

Figure 6. ANPP (mean ± SE) of different plant types in control (black) and burned (gray) plots in 2006.
*** Difference between treatments is significant (P<0.001).
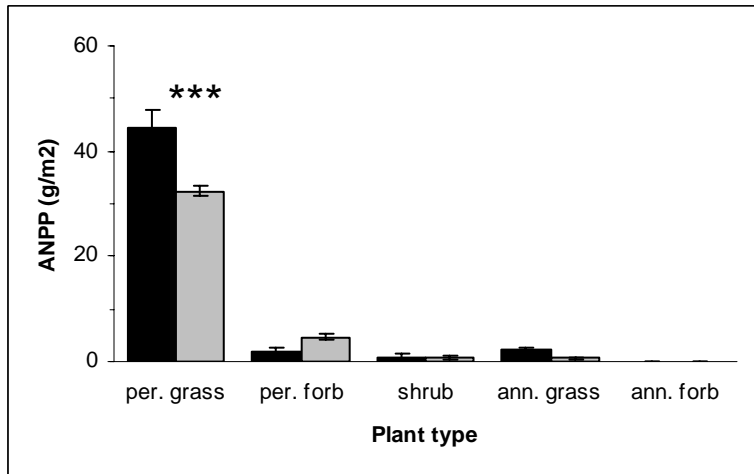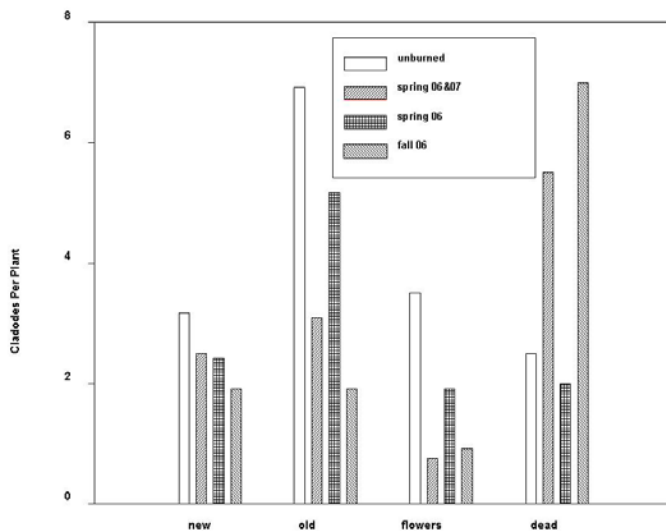

Figure 7. Response of cactus (Opuntia polyacantha) to burning in 2006.

b. Fauna

1) <u>Long-term mammal studies</u>: This year we continued our long-term studies of small mammals and carnivore populations on the site, which now consists of 14 years of monitoring. In an effort to take advantage of this growing dataset, we organized a Working Group at the LTER All-Scientists Meeting (LTER-ASM) in Estes Park to bring together LTER scientists working in arid and semi-arid grasslands to discuss opportunities for cross-site comparisons. We received funding from the Network Office for one meeting in February 2007 in Albuquerque to facilitate data synthesis and analysis for research across four LTER/ILTER sites (Shortgrass Steppe, Sevilleta,

Jornada, Mapimi). Preliminary results of these cross-site analyses were presented a part of a special symposium at the American Society of Mammalogists meeting on long-term studies of small mammals in arid and semi-arid environments. Work from this symposium will be published in a Special Feature in the *Journal of Mammalogy* in 2008. We published 1 manuscript in 2006 based on our long-term studies.

2) Ecology of shortgrass steppe in relation to prairie dogs and plague: This year we continued our estimates of prairie dog densities, based on mark-resight methodologies. Our own analyses indicate that previous estimates based on indices from visual counts on survey grids, developed by Severson and Plumb (1998; Wildl. Soc. Bull. 26:859-866) have been useful to a limited extent (E.g. Derner et al. 2006), but lack estimates of reliability and error. The first reassessment of these estimates is in press (Magle et al., J. Wildl. Manag., *in press*), but further analyses are currently underway in collaboration with the CSU department of Fisheries, Wildlife and Conservation.

We work closely with the PNG staff to monitor activity of prairie dogs on the both the PNG and CPER (SGS work), by GPS measurements of prairie dog size. Data are currently updated to 2006, with the following general trends, including plague outbreaks on all five major prairie dog towns on the CPER (27, 22, 5, 29, 30).
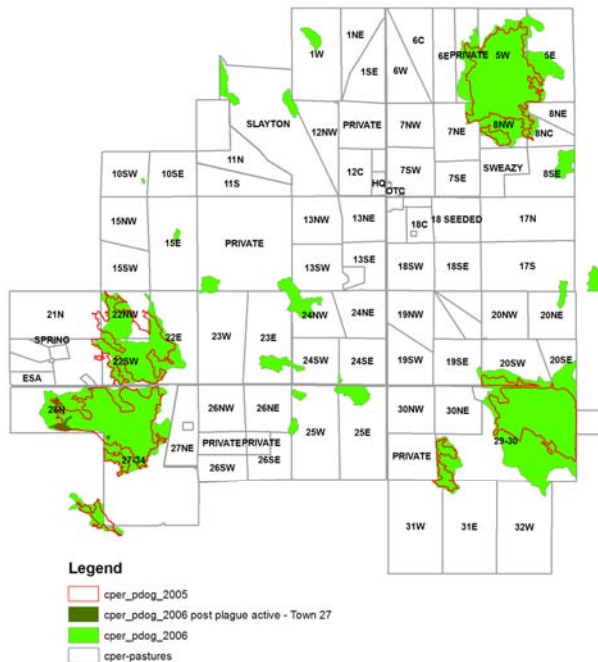

Figure 8. Distribution of prairie dog towns on the CPER. Updated with surveys from 2006

The long-term trend (1981-2006) follows two patterns: a general increase in area during the last 10-15 years, with recent declines because of plague. The number of prairie dog towns has also increased greatly during this time (Figure 9). At the same time, the average size of colonies has decreased, as expected when the largest towns are

extirpated by plague but many new towns are colonized at the same time (Figure 10). The data are being incorporated into a dynamic metapopulation model (Webb, Unpublished). The model was presented at the 5th Ecology and Evolution of Infectious Diseases Conference in Ithaca, NY (May 30-June2, 2007) as a poster:
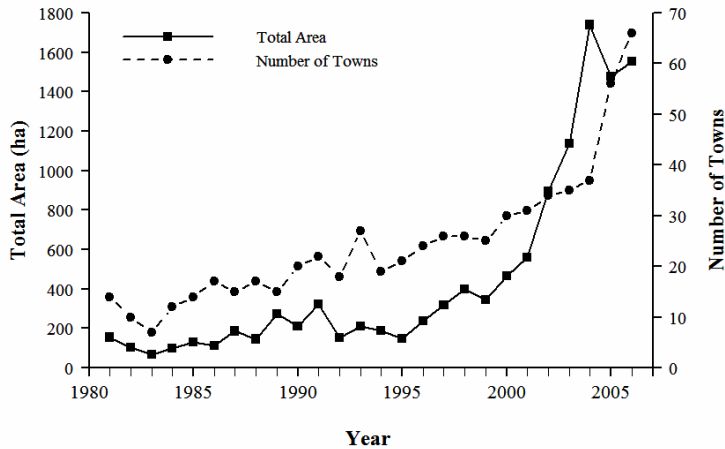

Figure 9. Total area and number of prairie dog towns 1981-2006
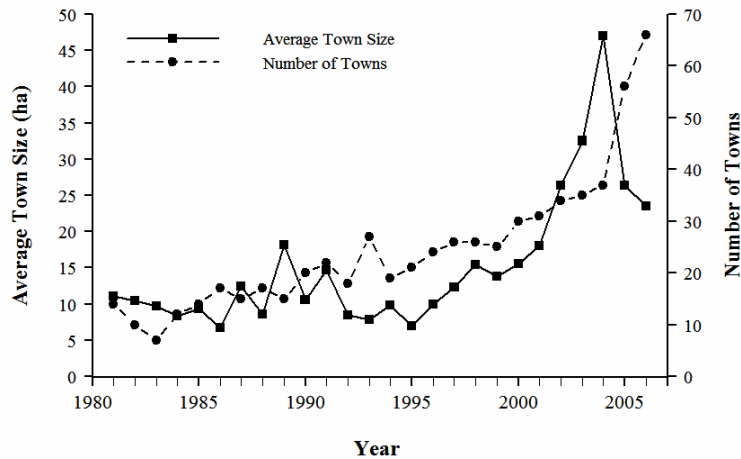
Figure 10. Trend in average size of prairie dog towns over time.

2) Flea transmission studies: Two fleas are thought to be important in plague epizootics among black-tailed prairie dogs: *Oropsylla hirsuta* and *Oropsylla tuberculata cynomuris* (Siphonaptera: Ceratophyllidae). Both are competent vectors of *Y. pestis* and commonly harbor infections in the wild, but evidence of their role in plague epizootics is conflicting. Prior studies of vector efficiency of these two fleas showed they are relatively inefficient vectors, suggesting they are incapable of supporting epizootic spread among prairie dogs. We examined transmission efficiency of *O. hirsuta* and *O. tuberculata*

cynomuris in the laboratory using naïve mice to groups of potentially infectious fleas from 1 to 4 d post-infection (early-phase). In contrast to traditional ideas of flea-borne transmission, the results show that both fleas are infectious soon after exposure to a bacteremic host. These conclusions offer an alternative mechanism for flea-borne epizootic spread in prairie dogs that is more consistent with the rapid spread observed in plague epizootics than traditional flea-borne transmission after a prolonged incubation period The two flea species are separated seasonally, with *O. tuberculata cynomuris* dominating in late winter and spring, and *O. hirsuta* abundant in summer and early fall.

3) Prairie dog parasite studies: Prairie dogs, are commonly parasitized by coccidians in the genus *Eimeria.* The study was conducted from September 2005 to October 2006, and revealed four *Eimeria* species: *E. callospermophili, E. cynomysis, E. lateralis,* and *E. morainensis*. Samples from 222 prairie dogs were collected from 8 active towns that included plague or no plague present. Parasite prevalence, abundance, intensity, and species diversity were related to mean air temperature and presence of plague in towns. These results support the hypothesis that plague, which also has infection dynamics driven by temperature, affect the animals' immune systems and allow higher numbers of other parasites to invade or persist.

A PhD project entitled "Functional genetic diversity and pathogen resistance in black-tailed prairie dogs" will examine how host genetic diversity may play an important role in buffering populations against infectious disease. The genes encoding the major histocompatibility complex (MHC) of the vertebrate immune system are highly polymorphic and well-characterized for many species, and have thus been an attractive target to discern relationships between genetic diversity and disease. However, evolutionary dynamics of MHC remain unclear, likely because other immune system genes are also important in responses to pathogens and parasites. Recent immunogenetic discoveries make it practical to isolate immune system genes besides MHC in wildlife, and examine responses of specific immune system genes to different types of pathogens and parasites. An extensive literature search for parasites of black-tailed prairie dogs, revealed 37 pathogen and parasite species, primarily coccidia and arthropods, but also two zoonotic bacteria and several helminth species. Given the potential parasite diversity in black-tailed prairie dogs, evidence of disease-induced decline, their taxonomic relationship to several species of conservation concern, extensive knowledge of their life-history and ecological traits, and our previous studies of populations in northern Colorado, prairie dogs are an excellent model for associations between pathogen resistance and functional genetic diversity in mammals. The project is moving beyond the single-pathogen single-gene approach by investigating the relationship between allelic diversity (heterozygosity) in three functionally different immune system genes and the entire parasite community of black-tailed prairie dogs. Currently we have PCR-cloned the *DRB* gene (10 alleles in Colorado), and with development of markers for the chemokine receptor interleukin-10 and toll-like receptor-2 underway.

4) Burrowing owl studies: Burrowing owls (*Athene cunicularia*) are a state listed threatened species in Colorado, declining across most of their range in the Americas.

Burrowing owls on the PNG are associated with the metapopulation of black-tailed prairie dogs where periodic local town extinctions are caused by plague (*Yersinia pestis*), providing a system for studying multi-species dynamics in the presence of an introduced pathogen. We are locating nests and monitoring abundance, apparent nest success, and fledging success for owls on the PNG, and making use of owl count data collected by the Forest Service from 1998 – present. In collaboration with CDOW, banding efforts increased in 2007 with the major goal of estimating fledging success, which has never measured for burrowing owls in natural burrows and will require new estimation techniques. We are using models to investigate the existence of a threshold in prairie dog town area lost, beyond which owl populations may decline. The burrowing owl is a species of conservation concern in the state of Colorado.

5) Swift fox studies: The purpose of this project is to contribute to our growing understanding of swift fox behavior and the relationship between a northeastern Colorado swift fox population and black-tailed prairie dogs. Specifically, we investigate seasonal changes in swift fox spatial and temporal movement patterns, habitat use, den site selection, and diet in relation to the distribution of prairie dog towns on the CPER by radio tracking of individual foxes. Home ranges of foxes are being compared from times before plague outbreaks on prairie dog colonies (data acquired from 2003 – 2006) compared to post-plague event home ranges (2007 – 2008). Before the plague epizootic foxes denned on or in close proximity to prairie dog towns, but little is known how foxes shift with respect to a plague outbreaks. The swift fox is a species of conservation concern in the state of Colorado.

6) Pollinator studies: Black-tailed prairie dogs' intensive herbivory, vegetation clipping, and burrowing greatly modify colonized patches, and the increase in bare ground and forbs affects pollinating insects. We sampled six prairie dog towns and six similar uncolonized sites for bare ground and forb cover, inflorescence and open flower density, and insect floral visitation in 2003 and 2004. Bare ground, forb cover, and total number of inflorescences and open flowers on prairie dog colonies were approximately double that on uncolonized sites in both years. Diurnal insect visitors, primarily pollinators, visited flowers at twice the rate on towns as off, indicating preferential use of prairie dog towns for foraging. The most-visited plant species had denser inflorescences and insect diversity was related floral resource diversity. These results are evidence for a terrestrial tri-trophic interaction with consequences for conservation of shortgrass steppe flora and insects, and further substantiates prairie dogs role as ecosystem engineers.

7) Harvester ant studies: Social animals contribute to habitat heterogeneity by building long-standing dwellings that house many individuals for extended periods of time. These habitat alterations and disturbances change resources for other available that exploit engineered habitat. Two conspicuous ecosystem engineers occur on the Colorado shortgrass steppe are the mound-building black-tailed prairie dog and the nest-building western harvester ant (*Pogonomyrmex occidentalis*). These taxa overlap in much of their ranges ant nest densities are similar on and off prairie dog towns, but on-town nests were significantly larger. Mounds and nests were significantly aggregated on the landscape; a striking 22% of nests overlapped mounds, which covered only 1.2% of

prairie dog towns. Mounds supported more vegetation than nests on and off colonies; in particular, a native forb (*Sphaeralcea coccinea)* and an exotic forb (*Salsola iberica)* were associated with mounds but not nests. Beyond mounds and nest perimeters, there were few differences in vegetation cover, diversity, or height that can be attributed to harvester ant activity. Instead, differences in vegetation characteristics were manifested at the town scale as a likely response to prairie dog grazing.

8) Effects of prairie dog dynamics on vegetation: Plague causes periodic die-offs of prairie dog towns, and during periods of inactivity vegetation may recover from the effects of heavy grazing.   During the previous 25 on the PNG, most colonies (97%) experienced plague outbreak within 15 years of activity, and that over half (55%) were inactive for at least five years after an outbreak. Further, the probability of a town attaining its pre-outbreak size within 5 years was low (28%). Comparing towns of different ages before and after outbreaks showed that average plant canopy cover and functional groups (forb, grass, shrub, cactus) did not differ between on- and off-town either before or after outbreaks. However, average grass biomass was lower on towns before outbreaks, but not after, while forb biomass did not differ either before or after outbreaks. Herbivore exclosure cages demonstrated that cattle and prairie dogs had similar and additive effects on plant biomass. Cattle consumed about the same amount of plant biomass on- and off-towns, total aboveground plant production was did not differ between on- and off-colonies, but graminoid production decreased and forb production increased with prairie dog grazing. Total plant species richness was greater only on old and plague-extirpated towns, and greater species richness was due to greater numbers of forb species rather than graminoid species. Shoot N concentrations of the dominant grass (*Bouteloua gracilis*) and forb (*Sphaeralcea coccinea*) were significantly greater on active towns. However, total standing crop N was lower on active towns because aboveground biomass was lower. Prairie dog mounds on active colonies had greater rates of N mineralization compared to off-colony or intermound spaces, suggesting that mounds may be sites of high nutrient turnover. Soil organic matter pools (total C and N, particulate organic matter C and N) appear to be relatively unaffected by prairie dogs, with differences seen only in the older colonies. Both mound and intermound areas on-colonies had lower total organic C than off-colonies.   The introduction of plague to North America may be altering the role of prairie dogs in shaping ecosystem structure and function because plague-extirpated towns were rarely different than off-colony sites. Effects of prairie dogs appear to increase with colony age, but because of plague, few colonies now persist for multiple decades.

2. Biogeochemistry

Among our new efforts, we have 1) evaluated the role of fungi vs bacteria in controlling trace gas fluxes, 2) analyzed the relationships between soil microbial ecology and methane uptake, and 3) invested in cross-LTER-site activities to address the large-scale and regional scale controls over decomposition. In the latter case, we have conducted 3 major syntheses.

1) Soil respiration and N_2O emissions under patches dominated by C_3 and C_4 grasses, and forbs in the short grass steppe: Influence of fungal and bacterial activity: Microbial

nitrogen transformations via nitrification and denitrification contribute about 70% of the annual global emissions of N_2O. Nitrification is the main source of N_2O in the short grass steppe, where water contents do not exceed 24%, and it could be carried out by autotrophic bacteria or heterotrophic microorganisms. Previous work in grasslands and semiarid soils has shown that N_2O emissions were related to heterotrophic activity, but the source has been unknown in shortgrass steppe. Our first objective were to estimate respiration rates of fungi and bacteria in patches dominated by different plant functional types (C_3 and C_4 grasses, and invasive forbs) in plots under control and resource addition treatments (Figure 11). These resource addition treatments included nitrogen + water addition plots, which were fertilized and watered 30 years ago. The second objective was to evaluate N_2O emissions during lab incubations, and determine whether fungal or bacterial biomass was the most important source. We incubated soils collected monthly during the growing season. Respiration and N_2O emissions were lower in June, when the precipitation was relatively low, and they increased during consecutive months when precipitation increased. Field trace gas fluxes were variable in time and space. We did not find consistent differences between plant functional types or resource additions. In general, fungal inhibition significantly decreased respiration and N_2O emissions. Carbon dioxide and N_2O emissions were higher under higher precipitation. Future analyses will help determine whether N_2O emissions were mainly determined by nitrification or denitrification. This work will be presented at ESA this summer.
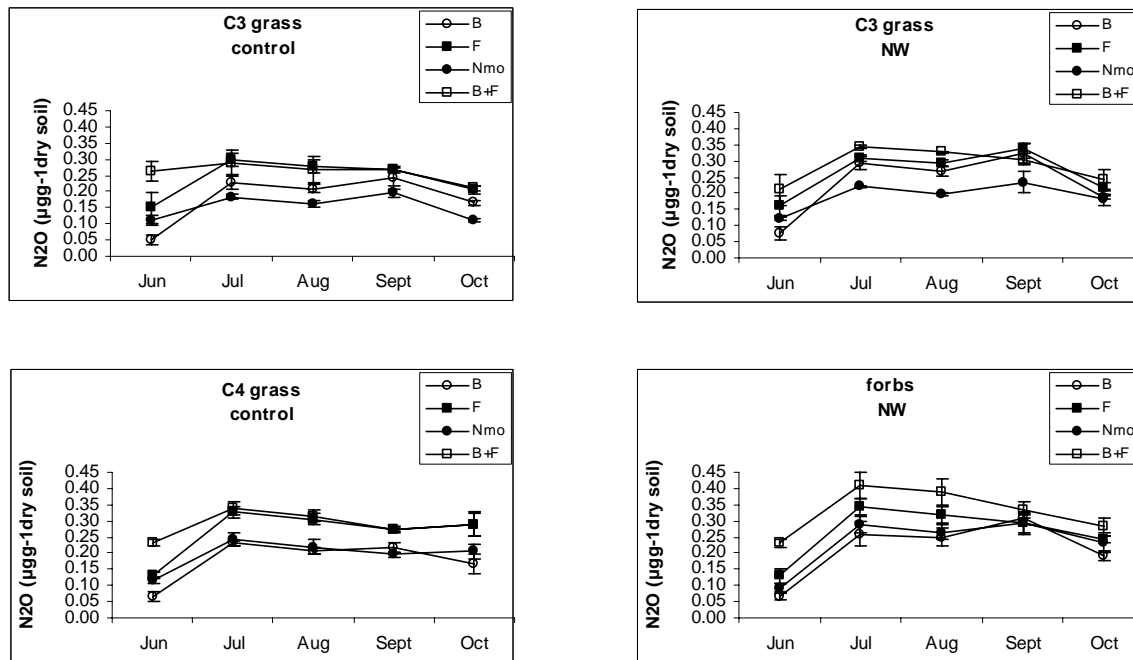

Figure 11: Monthly patterns of N_2O flux on a grazing exclosure (control), and plots that were fertilized and watered 30 years ago (NW) under patches of different functional types: C3, C4, and forbs. Soils were incubated in the laboratory with antibiotics to discriminate microbial activity: B: cycloheximide was applied and only bacteria were left; F: streptomycin was applied, and only fungi were left; Nmo: both antibiotics were applied, and neither bacteria nor fungi were left; B+F: control without antibiotics and with both bacteria and fungi present.

2) <u>Linking soil microbial ecology with ecosystem function</u>: There is fundamental interest in understanding how soil biogeochemical processes relate to functional traits of soil microbes and environmental controls of their activity. For many biogeochemical processes, understanding the linkage to microbes is complicated by the myriad types of organisms and multiple environmental controls. In contrast, methane consumption in upland soils (i.e., well-drained, oxic) is relatively simple: methane molecules diffuse from the atmosphere into the soil, where they are consumed by methanotrophic bacteria, a phylogenetically cohesive group of organisms.

We have developed a new biogeochemical model to describe methane consumption dynamics. This model both provides insight into methane consumption, and it serves as the basis for a new method for determining soil methanotroph activity that does not require laboratory incubations of soils, but uses field measurements using flux chambers. This work was submitted to the Journal of Geophysical Research – Biogeosciences.

The methane consumption model describes how soil diffusivity (i.e., the capacity of the soil to conduct gas movement) and methanotroph activity yield methane uptake rates. The model solution (illustrated below) reveals a surprising, non-linear relationship between soil diffusivity, methanotroph activity and methane uptake rates: doubling microbial activity or soil diffusivity leads to only a √2 increase in flux rate, not to a doubling of flux as might be expected (Figure 12). This relationship has important implications for interpreting measures of methanotroph community size or activity in lab incubations.
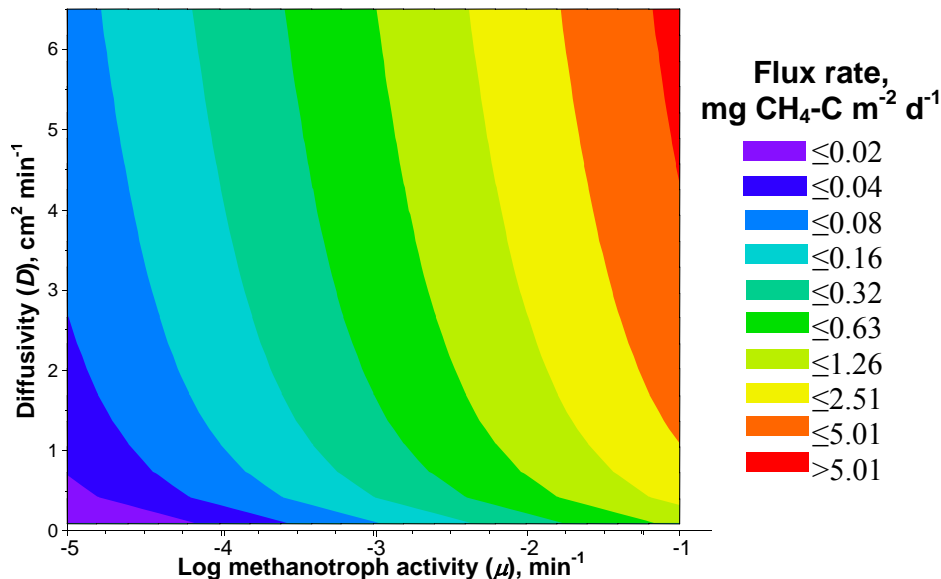

Figure 12: *Modeled relationship between soil diffusivity, methanotroph activity and methane flux (consumption) rate from von Fischer et al. (submitted). Note log scales on methanotroph activity and flux rates.*

Because the relationship between methane flux and its controls is quantified with this mathematical model, the model can also be used to determine the methanotroph activity from field measures of soil diffusivity and the methane flux rate made from traditional gas flux chambers. Results from application of this field technique illustrate the temporal changes in methanotroph activity in response to changing environmental conditions. For example, between July 11 and August 9, we observed a 98% reduction in methanotroph activity, as soils dried and became hotter over the summer.

We have begun using molecular tools to relate these field measures with the distribution and abundances of methanotrophic bacteria. Preliminary results reveal that methanotroph abundance falls off sharply with depth in the soil profile ; methanotrophs are 40% less abundant in the 10-20cm depth than they are in the 0-10cm. Although methanotroph activity varies with topographic position and soil texture, we found no changes in methanotroph abundance, so we are investigating variability in methanotroph community composition by sequencing the methane monooxygenase gene from methanotrophs from these different sites.

3) Global Scale Patterns in N Dynamics during Decomposition: Our SGS scientists have been extremely involved in the LIDET synthesis work (Parton et al. 2007, Adair et al. in press, Bontti et al. submitted). The LIDET experiment has been the first experiment to be conducted across all LTER sites (as well as several others). Parton et al. (2007) found interesting patterns across all sites with respect to N dynamics during decomposition. Litter decomposition provides the primary source of mineral nitrogen (N) for biological activity in most terrestrial ecosystems. The 10-year decomposition experiment data from at 21 sites from seven biomes found that net N release from leaf litter is dominantly driven by the initial tissue N concentration and mass remaining
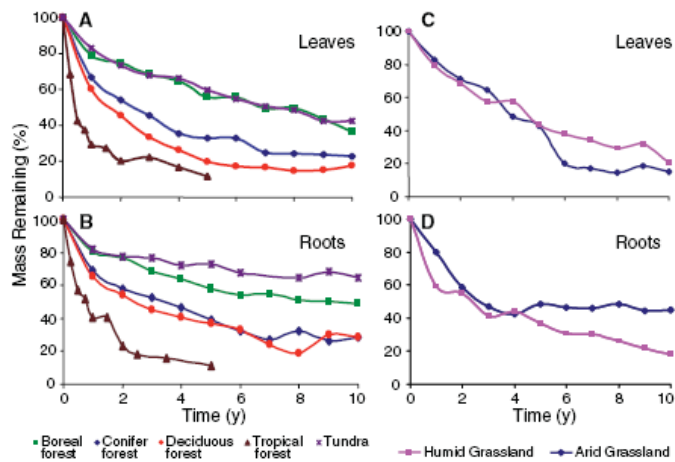
regardless of climate, edaphic conditions, or biota (Figure 13). Arid grasslands exposed to high UV radiation were an exception, where net N release was insensitive to initial N. Roots released N linearly with decomposition and exhibited little net N immobilization. We suggest that fundamental constraints on decomposer physiologies lead to predictable global-scale patterns in net N release during decomposition.

Figure 13. Average mass remaining as a function of time for LIDET core leaf (n = 5 to 6 species) and root (n = 3 species) litters decomposed in 21 sites. (A) Leaf litter decomposed in forest and tundra biomes; (B) root litter decomposed in forest and tundra biomes; (C) leaf litter decomposed in humid and arid grasslands; (D) root litter decomposed in humid and arid grasslands. Each species and litter type was decomposed in replicate bags and collected at multiple time points. Results show that leaf and root litter decomposition rates generally increase as the CDI increases (Table 1). In arid grasslands, leaf litter decomposed more rapidly than expected (based on the CDI), possibly due to photodegradation.

In a separate study, our investigators evaluated the extent to which the LIDET data could be modeled using simple approaches (Adair et al in press). As atmospheric CO_2 increases, ecosystem carbon sequestration will largely depend on how global changes in climate will alter the balance between net primary production and decomposition. The response of primary production to climatic change has been examined using well-validated mechanistic models, but the same is not true for decomposition, a primary source of atmospheric CO_2. We used the Long-term Intersite Decomposition Experiment Team (LIDET) data set and model selection techniques to choose and parameterize a model that describes global patterns of litter decomposition. Mass loss was best represented by a three pool negative exponential model, with a rapidly decomposing labile pool, an intermediate pool representing cellulose, and a recalcitrant pool. The initial litter lignin/nitrogen ratio defined the size of labile and intermediate pools. Lignin content determined the size of the recalcitrant pool. The decomposition rate of all pools was modified by climate, but the intermediate pool's decomposition rate was also controlled by relative amounts of litter cellulose and lignin (indicative of lignin-encrusted cellulose). The effect of climate on decomposition was best represented by a composite variable that multiplied a water stress function by the Lloyd and Taylor (1994) variable Q_{10} temperature function. Although our model explained nearly 70% of the variation in the LIDET data, we observed systematic deviations from model predictions. Below- and aboveground material decomposed at notably different rates, depending on the decomposition stage (Figure 14). Decomposition in certain ecosystem-specific environmental conditions was not well represented by our model; this included roots in very wet and cold soils, and aboveground litter in N-rich and arid sites. Despite these limitations, our model may still be extremely useful for global modeling efforts, because it accurately ($R^2 = 0.6804$) described general patterns of long-term global decomposition for a wide array of litter types, using relatively minimal climatic and litter quality data.
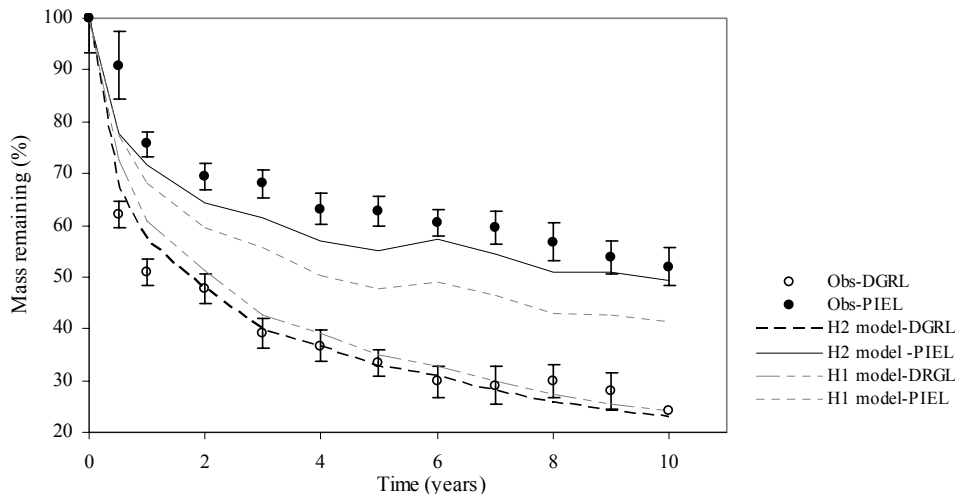

Figure 14. Litter quality affects the rate of mass loss. Leaf litter of two species with different litter quality is shown averaged across all sites: Drypetes glauca (DGRL; low L/Cell and L/N) decays more rapidly than Pinus elliottii (PIEL; high L/Cell and L/N). The predictions of two models representing different hypotheses are shown. The H1 and H2 models are both 3 pool models but litter quality modifies the decay rate of the M_2 litter pool in the H2 model. Error bars are ± 1 SE.

4) Evaluation of grassland decomposition: another LIDET synthesis: A team of graduate students at our site were interested by the fact that both of the above analyses, done on the entire LIDET dataset, suggested that grasslands behave somewhat differently. These students submitted a paper to Global Change Biology (currently under revision, Bontti et al) evaluating these grassland decomposition dynamics. In addition to resulting in interesting results below, the students were exposed to the data and metadata associated with a large cross-site study.

We used the Long Term Intersite Decomposition Team (LIDET) data set to detect the most important climatic and litter quality variables to predict above-and belowground decomposition rates in grassland ecosystems as well as assess their relative importance. We also compared above- and belowground decomposition rates of *Pinus* spp, *Drypetes glauca,* and wooden dowels, the latter to control for substrate quality. We also evaluated nitrogen dynamics by following the trends in nitrogen remaining through time in litter of high and low quality placed in xeric and mesic grasslands. Percent lignin was the best quality predictor, for above- and belowground decomposition, whereas precipitation class was the best climate predictor for belowground decomposition. This suggests that in grasslands temperature does not directly affect decomposition, but it might affect carbon pools through decreasing water availability. When percent lignin and precipitation groups were included in the same model, litter quality was more important than climate to predict decomposition. Part of the variability in decomposition remains unexplained, particularly in leaf litter decomposition, which suggests that abiotic factors such as UV light or wind might influence leaf mass loss, especially in arid and semiarid grasslands. Aboveground decomposition was faster than belowground decomposition when leaves and root of the same species were compared. The opposite resulted when above-and belowground dowels of homogeneous composition were compared, supporting the importance of other abiotic factors to accelerate aboveground decomposition of leaf. Root litter released nitrogen regardless of quality and precipitation class, whereas leaf litter of only high quality showed mineralization at mesic and xeric sites. Low quality leaf litter released nitrogen at xeric sites, and immobilized nitrogen at mesic sites, suggesting carbon limitation or UV light influence in xeric sites.
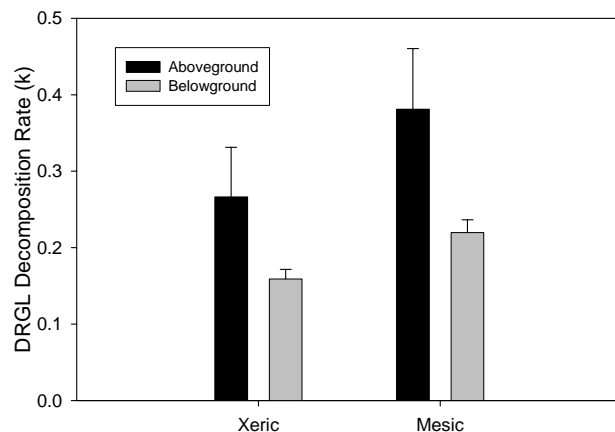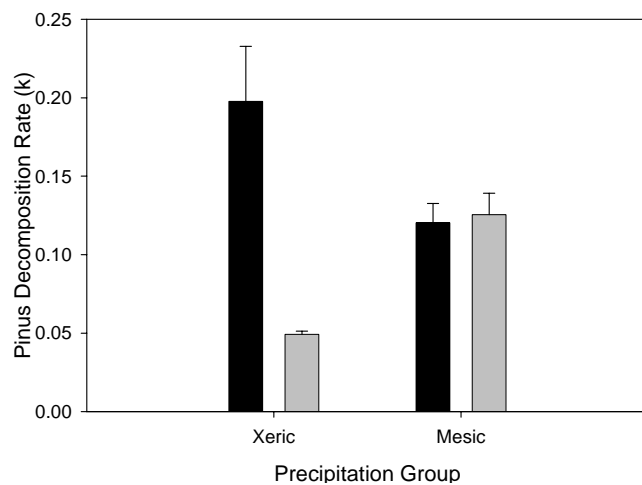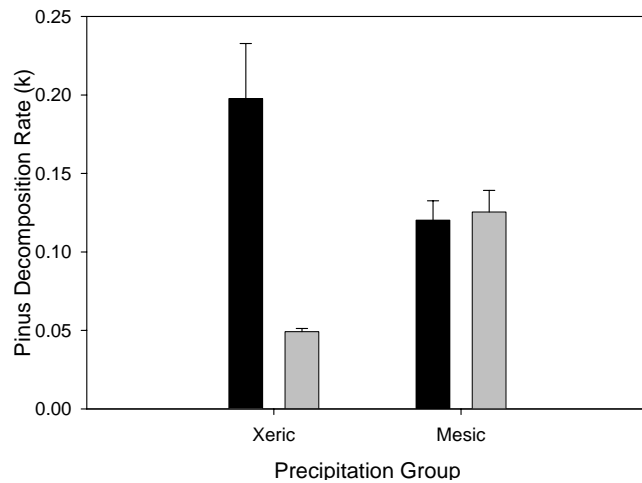
Figure 15. Aboveground and belowground Drypetes glauca and Pinus species decomposition rate (k) by precipitation group. Aboveground decomposition is significantly higher than belowground for both DRGL and Pinus species (p = 0.033 and p = 0.0069, respectively). Both aboveground and belowground decomposition rates increase with greater precipitation levels. Error bars represent ±1 SE.

3. Land-Atmosphere Interactions

1) Soil N constraints and vegetation responses to rising atmospheric CO_2: Recent abrupt increases in atmospheric CO_2 have tremendous implications for the ecology of native grasslands like the shortgrass steppe, where NPP has been shown to be strongly enhanced by CO_2 enrichment and plant species sensitivities to CO_2 are variable. A doubling of ambient CO_2 concentration was earlier reported to lead to an average 41% increase in aboveground biomass in the shortgrass steppe over a five-year experiment (Morgan et al., 2004), but resulted in a decline in overall forage quality due to lower tissue N concentrations and species changes (Milchunas et al., 2005). In last year's annual report, we showed evidence that productivity of *Artemisia frigida*, a sub-shrub common to the site as well as to many other North American and Asian grasslands, was enhanced over 20-fold by a doubling of CO_2 (Morgan et al., in press). This is the first

evidence from a manipulative experiment supporting the notion that rising atmospheric CO_2 is contributing to the shrub encroachment in grasslands of the past two centuries. While important, these findings, cannot completely answer important questions about the long-term effects of rising CO_2 on the ecology of grasslands since time constants for many soil processes involved in soil nutrient cycling, which can modulate plant responses to CO_2, can be in the order of decades or centuries, much longer than the 5-year period of the experiment (Morgan, 2002). Understanding the long-term implications of rising CO_2 requires a fundamental understanding of its impacts on nutrient cycling. Recently, Luo et al. (2004) introduced the progressive nitrogen limitation (PNL) hypothesis, which postulates that rising atmospheric CO_2 might reduce available soil N, thereby constraining the CO_2-induced stimulation in plant growth a C sequestration. PNL is hypothesized to occur when proportionally more of the available soil N is fixed into long-lived plant biomass and soil organic matter under elevated CO_2.

2) Ecosytem Models and rising CO_2:
Two different exercises were conducted this past year to evaluate the long-term implications of rising CO_2 on N cycling. First, we parametrized the DAYCENT ecosystem model (Parton et al.., 1998) to simulate the impact of elevated CO_2 from results of the open-top chamber experiment conducted in eastern Colorado (Morgan et al., 2001), and used the results to simulate combined warming and rising atmospheric CO_2 scenarios that are the basis of a new global change experiment, the Prairie Heating and CO_2 Enrichment (PHACE) experiment. The model gave a fairly accurate prediction of plant biomass responses

Figure 16. Comparison of modeled and measured aboveground productivity (July) of chamber ambient and elevated CO_2 plots.

to CO_2 (Figure 16), and results indicated that by itself, rising CO_2 leads to increased soil water content, plant production, soil respiration and nutrient mineralization, but when combined with warmer temperatures, CO_2 has variable effects on these processes depending on yearly differences in water stress (Parton et al., 2007). DAYCENT predicted a decline in both soil organic carbon (Figure 17a) and organic nitrogen (Figure 17b) for rising CO_2, temperature, and combinations of CO_2 and temperature, but variability in these traits was affected as much by year-to-year variation in weather, making interpretations of the long-term impacts on soil C and N difficult.
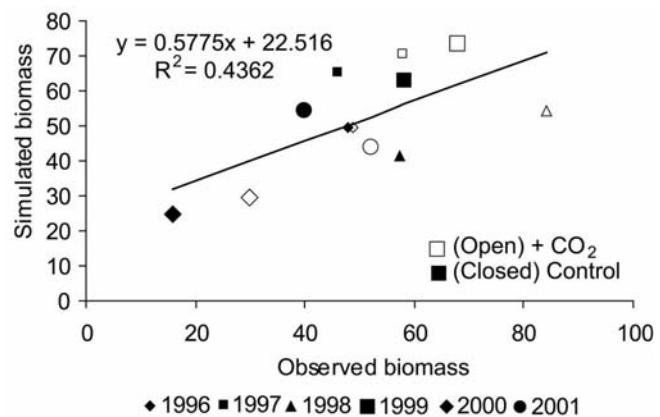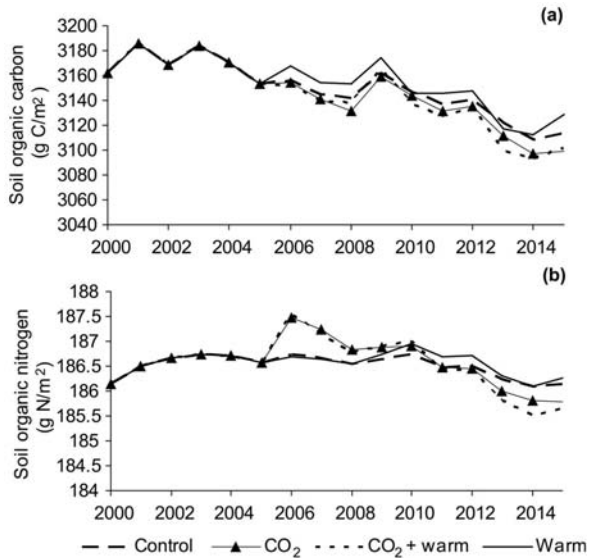
Figure 17. DAYCENT simulated soil organic C (a) and soil organic N (b) in top 20 cm of soil profile for PHACE experimental site, with treatments (control; CO₂ enrichment, warming, CO₂ + warming) starting in 2004.

In an analysis of plant and soil data form our previous open top chamber experiment, Dijkstra et al. (in review) developed a novel ^{15}N tracer method that explained how greater plant N uptake in plants exposed to double present ambient CO_2 concentrations (King et al., 2004) was due to greater soil N mineralization. We found that plant biomass ^{15}N, expressed as a fraction of total plant N from plants harvested in July and October, significantly declined over time (Figure 18). The decline in the ^{15}N fraction was larger under elevated CO_2 (significant CO_2*year interaction, $P < 0.05$). The dilution of ^{15}N in aboveground biomass occurred over time because of progressive plant uptake of non-labeled N from the soil, which Dijkstra et al. (in review) argue comes from N mineralization resulting from greater root activity and higher soil water content.

Collectively, these findings suggest that there is still considerable uncertainty about the fate of shortgrass steppe soil N in future CO_2-enriched and warmer climates. The modeling exercise of Parton et al. (2007) showed only minor reductions of soil organic N under elevated CO_2, and Dijkstra et al. (in review) observed increasing N mineralization under elevated CO_2, contrary to the notion of PNL (Luo et al., 2004). However, CO_2-enhanced N mineralization was insufficient to meet higher N demand of more productive vege-

Figure 18. (a) Aboveground ^{15}N fractions (expressed per total amount of N) in aboveground biomass over time in July, (b) in October from grids that were not harvested that same year in July, and (c) in October from grids that were harvested that same year in July. Open circles, ambient [CO₂]; filled triangles, elevated [CO₂]. For each year CO₂ treatment effects were tested with ANOVA (ns: not significant, *: $P < 0.05$, **: $P < 0.01$, ***: $P < 0.001$).

tation, which contributed to a decline in forage quality under elevated CO_2 (Milchunas et al., 2005). Species changes which occurred in our open-top-chamber experiment under
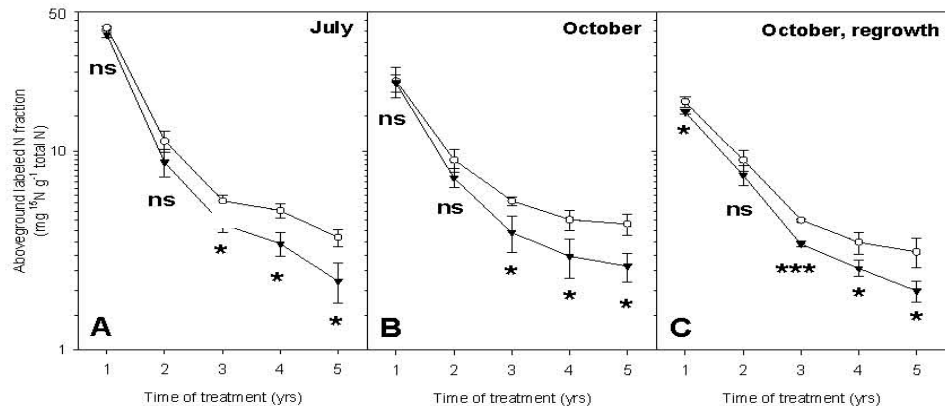
CO_2 enrichment (Morgan et al., in press) are likely affected by soil nutrient dynamics, and those dynamics may change over time depending on how global changes affect the soil biology. Our new PHACE experiment, which features an intensive soils research program, will provide additional data and insights concerning the interactive effects of combined CO_2 enrichment and warming on N cycling in semi-arid grasslands.

3) Impact of grazing on surface energy budgets: How the available energy (net radiation + soil heat flux) is partitioning between sensible and latent heat fluxes can affect the near-surface atmosphere through their impact on water vapor content and temperature. Eventually, this could influence cloud formation and precipitation processes. Variations in the characteristics of the underlying surface, like albedo, vegetation cover, leaf area index, soil wetness that occur at different time scales (i.e., 2-3 days after rainfall events, during the growing season, in dry and wet years) may also affect the energy balance and partition among fluxes. Grazing management practices can affect for instance biomass amount and albedo and consequently impact energy fluxes and near-surface climate. All these processes need to be accurately parameterized in numerical models of weather and climate to be able to use them to have a correct assessment of how different processes at the field level within SGS LTER site may affect the near-surface regional atmosphere. The goals of this analysis are to evaluate the impact of different levels of grazing and green biomass on near-surface climate and energy fluxes in the SGS region. This particular task is associated with one of the major hypotheses that drive the work in the Land Atmosphere Interactions:

> **L2d Disturbances of domestic livestock grazing and winter wheat cropping systems at the field level affect the regional atmosphere and influence local weather patterns, through their influence on energy partitioning and balance.**

We used 20-min averaged measurements of sensible, latent and soil heat fluxes using Bowen ratio flux towers located over three different grazing treatments (i.e., ungrazed, moderately and heavily grazed) plots during two growing seasons, May to October 2001 and 2002. Aboveground plant biomass was sampled monthly and separated into live (green) and standing dead (brown) biomass. Additional observations included 20-min averaged air temperature at two vertical levels, soil temperature, and water content.

There were clear interannual and seasonal variability in the energy fluxes. Mean annual precipitation average 320 mm on the western side of the LTER

Treatment means, W/m^2	Net radiation, Rn		Sensible heat flux, H		Latent heat flux, Le		Soil heat flux, Go		Bowen ratio, BR, unitless	
	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
Ungrazed (UG)	281	283	127	173	111	55	49	56	1.9	6.6
Moderate (MG)	278	273	119	179	108	51	61	66	1.8	5.8
Heavy (HG)	283	278	127	175	116	56	54	61	1.6	5.3

Table 1. Mean values of the components of energy balance and Bowen ration (H/Le) for each of the grazing treatments.

site, but characterized by a high interannual variation (Lauenroth and Burke, 1995; Lauenroth and Sala 1992). Annual precipitation during 2001 was 61% higher than in 2002, 262 mm and 163 mm respectively. The overall behavior of energy fluxes clearly reflected those differences: higher sensible heat ($0.6R_n$) than latent heat flux ($0.2R_n$) during 2002 and an increase in latent heat fluxes during the relatively wet year 2001 ($0.4R_n$) (Table 1).

We found lower sensible and higher latent heat fluxes until the middle of the growing season consistent with high precipitation and available energy (see as an example Figure 19 for latent heat fluxes). At the end of growing season the pattern reversed, associated with a decrease in available energy and precipitation.
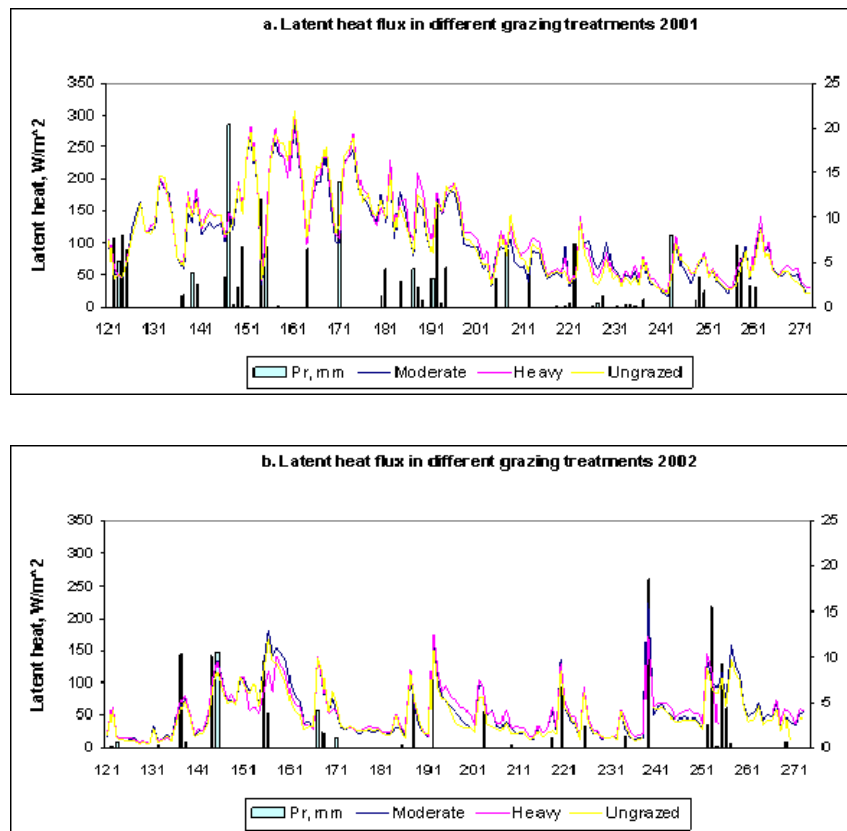

Figure 19. Seasonal variation in latent heat fluxes and precipitation (Pr) for 2001 and 2002, for each of the grazing treatments, Moderate, Heavy and Ungrazed.

Overall, grazing treatments showed little impact on seasonal energy fluxes (Table 1 and Figure 19) and evapotranspiration rates. Heavy grazing tended to have the lowest live and total (green + standing brown) biomass as expected, but the impact of grazing level on green biomass was relatively small (results not shown). This could have influenced the overall response of energy and water (evapotranspiration) fluxes to grazing.

Rainfall events have an impact over water losses at the shortgrass steppe (Parton et al. 1981): water loss is equal to potential evapotranspiration rate immediately after

precipitation events, and then decreases rapidly after three to four days. We selected two to three days after each rain event and analyzed the possible impact of green biomass on energy fluxes and air and soil temperature. Significant effects of green biomass were found on fluxes and soil temperature: high evapotranspiration rates are expected to be found with high green biomass values during wet periods (Figure 20). No clear impacts of grazing treatments were found in the energy fluxes vs. green biomass relationship, but results suggest a significant potential impact of grazing on energy budgets if grazing treatments had a significant effect on live biomass.

During the wet periods after a rainfall event high green biomass were related to cooler soil temperatures (Figure 21). No effect was found for air temperatures at 2 m and 1m. This indicates that high
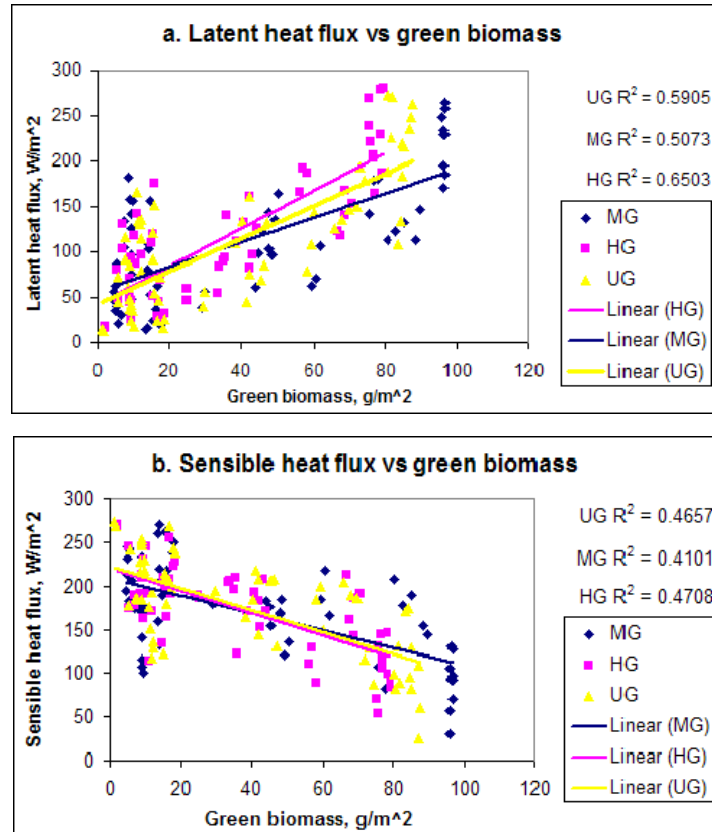

Figure 20. Latent (a) and sensible (b) heat flux versus green biomass during the wet periods in 2001 and 2002, for each of the grazing treatments: HG: heavy grazing; MG: moderate grazing; UG: ungrazed.

green biomass tends to reduce the soil-air temperature differences after a rain event: the available energy is used in evaporation and transpiration, reducing soil temperatures and air-soil-air temperature differences.
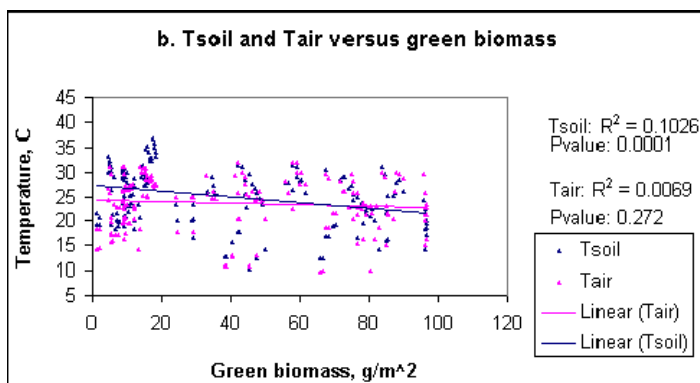
Figure 21. Mean soil and air temperatures versus green biomass during the wet periods in 2001 and 2002.

In summary, we did not find a clear effect of grazing on the surface energy fluxes and temperature when all the growing season information was considered. This could be significant in the days following a rainfall event, through the impact of green biomass on latent and sensible heat flux partitioning: our analysis showed a significant potential impact of grazing on energy budgets if the live biomass is very different in each of the grazing treatments.

Further analysis is needed to clarify some of the results. We recommend the following:

- Albedo measurements collected at each grazing treatment plot would help assess albedo impact on net radiation. Remote sensing technology could also be used to assess reflective differences of the surface.
- Estimation of evaporation and transpiration separately would allow addressing differential effects of soil and vegetation characteristics on latent heat fluxes.
- Remote sensing technology could be used to obtained high resolution vegetation greenness maps through vegetation indices like Normalized Difference Vegetation Index (NDVI). The indices could help in addressing spatial differences in surface energy budgets within the SGS LTER domain.
- Species composition, vegetation cover, and soil characteristics could be more thoroughly studied to clarify grazing treatment effects on energy fluxes in the SGS LTER domain.

4) Modeling of photosynthesis and energy fluxes: We also continued the refinement of the GEMRAMS and GEMLEAF modeling systems being used together with observations of water, energy, and CO_2 fluxes to investigate land-atmosphere interactions at the Shortgrass Steppe LTER. The photosynthesis parameterization in GEMLEAF was evaluated using leaf gas exchange measurements conducted over three growing seasons (1997 to 1999) collected using large open-top chambers that received ambient air (approx 360 mol mol-1 CO_2). For a detailed description of the chambers and the complete set of experiments see Morgan et al. (2001) and LeCain et al. (2003).

Previous evaluation of the photosynthesis submodel for the dominant C_3 and C_4 species in the SGS LTER, *Pascopyrum smithii* (PASM) (C_3) and for *Bouteloua gracilis* (C_4) (Chen et al. 1996) were performed with leaf gas exchange experiments data obtained from plants in growth chambers. Although this data represents controlled conditions of light, temperature, soil water conditions, and CO_2, rarely are those conditions present in the field, especially in terms of water stress. The parameters $V_{c,max}$ (maximum rate of carboxylation by Rubisco), J_{max} (saturated rate of electron transport and quantum efficiency (α) required for the estimation of leaf photosynthesis were taken from LeCain et al (2003). We used data provided by D. LeCain and J. Morgan to evaluate the response of photosynthesis to intercellular CO_2.

Preliminary results are shown in Figure 22 for PASM observed and simulated photosynthesis. Data showed the typical asymptotical response to increases in intercellular CO_2 (C_i). LeCain et al (2003) in their Table 1 present three different values of $V_{c,max}$, J_{max} and α for each part of the early, mid, and late growing seasons. The best values that fit the observations were the average value of $V_{c,max}$= 57 µmol CO_2 m-2 s-1; photosynthesis was controlled by $V_{c,max}$ for all ranges of C_i values.

For a better visualization, the data was divided according to temperature (Figure 22). For temperatures around 25°C, simulated photosynthesis was underestimated for high C_i values. For higher temperatures (30.7°C), the agreement was slightly better with the

observed data for high Ci. During the mid-season (days of the year around 188 and 190) the typical seasonal water stress developed, with leaf water potential of approximately -3 MPa. Water stress effect on assimilation rates is incorporated using zero-to-one factor functions parameterized using plant water potential. Using plant water potential values of -2 MPa and -3 MPa greatly improved the response of assimilation rates to water stress.

In summary, the current photosynthesis submodel in GEMLEAF for PASM using the information from leaf gas exchange field experiments in the SGS LTER accurately simulated the response of photosynthesis to intercellular CO_2. We expect also that the C_4 photosynthesis submodel will satisfactorily reproduce the observed photosynthesis data for *Bouteloua gracilis* and will adequately reproduce the effect of doubled CO_2 concentration on photosynthesis for both C3 and C4.

The next step is to evaluate the C4 photosynthesis submodel and

Figure 22. Top: Leaf photosynthesis versus intercellular CO_2 concentration for PASM measured during the 1997 to 1999 growing seasons. Data was grouped according to mean temperature Modeled data is shown with lines, and with open triangles for temperatures higher than 30°C Bottom: Modeled vs. observed photosynthesis.

doubled CO_2 effects in photosynthesis rates and soil and plant water relations. In a second step, all the updated values and/or parameterizations will be incorporated into the land-surface model GEMLEAF and the 3-D spatial model GEMRAMS. Several model experiments will be conducted to address the effects of landscape heterogeneity (i.e., increasing the area covered by cropping systems), C3/C4 grasslands dominance and CO_2 enrichment over the near-surface atmosphere. CO_2 fluxes collected using Bowen ratio flux towers for a mixed C3/C4 shortgrass site, winter wheat and corn will also be used to assess if GEMLEAF is able to capture the differences among those systems.
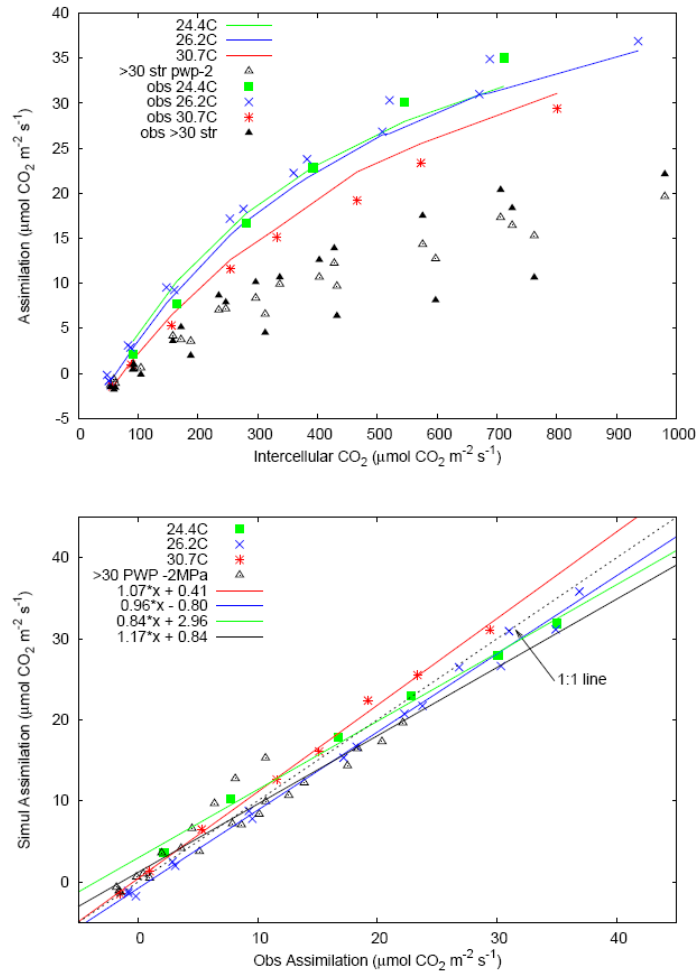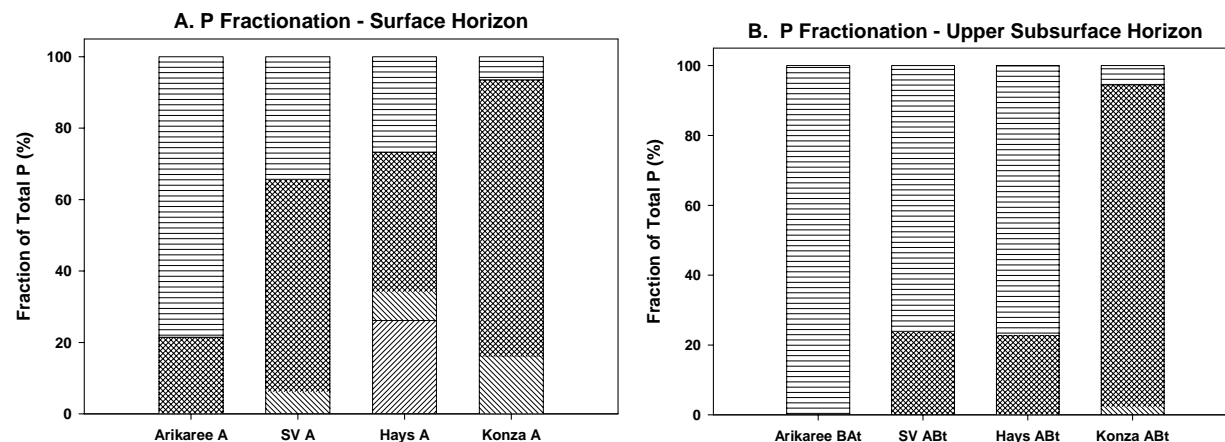
4. Integrated, Synthetic and Cross Site Research

1) Phosphorus Transformations as a function of weathering in semi-arid Ecosystems: Ecosystem P is mainly supplied through weathering of parent material. As soils weather, P can be partitioned into secondary mineral precipitates, incorporated into biomass, or lost via leaching and erosion. As little is known about P cycling under semi-arid conditions, studying P biogeochemistry within may provide insight into the importance of abiotic and biotic P controls within such ecosystems. We further assessed P fractionation patterns and processes in three grassland communities spanning a 400-mm precipitation gradient across the central Great Plains. Total element to Ti ratios indicated basic cations weathered rapidly, P moderately, and Fe and Al slowly from the shortgrass steppe to the tall grass prairie. Soil surface horizon P accumulation was likely related to plant uptake and decomposition, though eolian input cannot be discounted. Patterns across the climosequence follow previous observations of decreasing Ca-bound P and increasing occluded P with increasing weathering intensity (Figure 23). Upper soil horizons showed evidence of Ca-bound P, yet inorganic C content was low. Ca-bound P trends within these horizons do not appear to follow that of organic C, supporting the contention that secondary Ca-P mineral precipitation has broad implications for the retention of P across semi-arid ecosystems. Subsurface Ca-bound P compared well with inorganic C content, demonstrating the importance of carbonate P controls in semi-arid ecosystems.

Across all US Great Plains grassland sites elemental weathering losses were variable when compared to soil Ti concentration. The shortgrass steppe to tall grass prairie weathering scheme of Ca > Mg > P > Fe >= Al was similar to that found by others. In addition to intermediate P weathering, some redistribution to the soil surface occurred at all sites suggesting biological cycling or eolian input. Soluble P played a minor role within all soil profiles most likely due to this phase being quickly utilized by plants, microorganisms, or precipitated as secondary mineral phases. The greatest percentage of inorganic P was bound to Ca phases in the shortgrass steppe (Arik) and mixed grass prairie (SV and Hays) sites. As observed in other weathering sequences, the total amount of P associated with Ca phases decreased with a concomitant increase in occluded P, following increased weathering intensity along the precipitation and ANPP gradient.
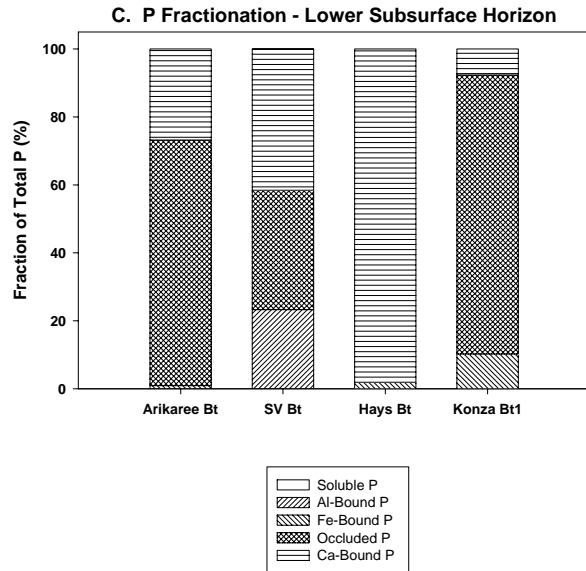
C. P Fractionation - Lower Subsurface Horizon

Legend:
- Soluble P
- Al-Bound P
- Fe-Bound P
- Occluded P
- Ca-Bound P

Figure 23. Phosphorus fractions of A) A horizon, B) upper subsurface, and C) lower subsurface horizons across sites.

2) <u>Primary controls on soil BSi pools in grass dominated ecosystems</u>: The overall goal of the research is to address three questions. (1) How variable are biogenic silica soil pools in grass-dominated ecosystems, (2) Do climatic controls of BSi identified in North American grasslands operate similarly in South African grasslands, despite differences in parent material, soil age (degree of development), and evolutionary history? And (3) How do key ecological drivers (fire and grazing) of grassland structure and function influence the size of these biogenic pools. We were testing the hypothesis that precipitation amount will have a strong, inverse impact on the storage of above and belowground Biogenic Silica in subtropical savanna grasslands and this pattern will be similar to that observed in North America (Fig. 24).

We have now preliminarily sampled experimental plots in three LTER sites in North America (KZ, SEV, SGS) and in South Africa to begin to assess differences in BSi content in plants and soils as a function of ANPP (Melzer and Kelly, unpublished data) and the results are intriguing.

With increasing ANPP, biogenic silica stored in aboveground vegetation increases (Fig 24). However, biogenic silica storage in the soils was inversely related to aboveground production suggesting that greater losses of this biogenic material occurred in higher ANPP grasslands - this is consistent with other North American studies (Blecker et a, 2006). Further assessment of lower ANPP sites (lower MAP) on different parent materials will allow us to more rigorously test this hypothesis.
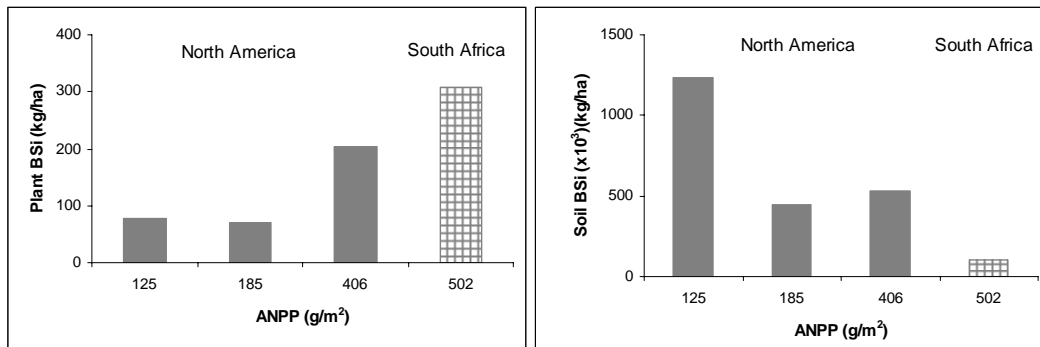
Figure 24. Preliminary data of BSi content of Plants and Soils (A horizons) as a function of ANPP for North America and South Africa study sites.

<u>Frequent fire will increase BSi amounts in vegetation, but have a negative impact on Si storage in the soils of savanna grasslands.</u> We base this prediction on our central Great Plains studies that suggest that in tallgrass prairie where fire is most important, BSi in above ground materials was greatest. This could be due to a fire-induced increase in transpiration and ANPP, a shift to greater graminoid dominance or due to an increase in water stress in the post-fire environment (Knapp et al. 1998, Collins et al. 1998). Further, soil mass balance calculations indicate that leaching of Si could not account for the low quantities of BSi found in soils (Blecker, 2005), suggesting that frequent fire could be an important vector of silica loss through wind and water erosion of ash. In sites with complete fire exclusion, soil BSi will be increased since no post-fire loss occurs.
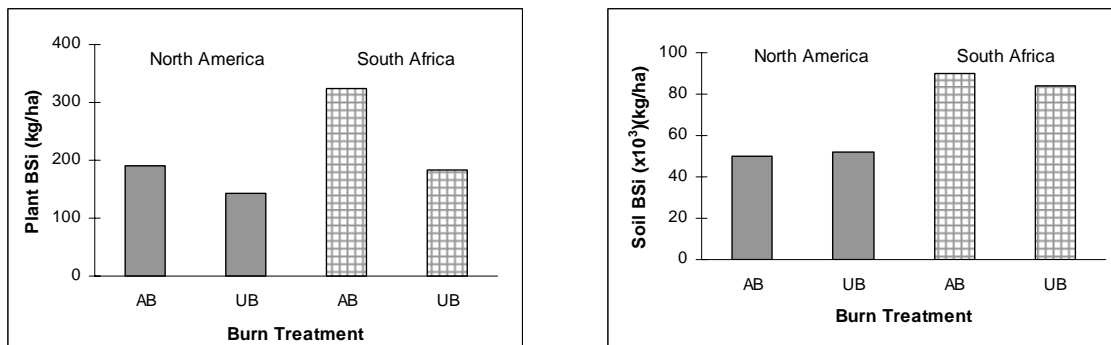
Figure 25. Preliminary data of BSi content of plants and soils (A horizons) as a function of fire frequency for North America and South Africa study sites. AB = annually burned, UB = unburned.

Preliminary sampling from Konza and Kruger National Park (Fig. 25) indicates that, in general, the uptake of Si by plants increases with frequent fire, but this response is not evident in the soil, perhaps due to BSi loss in ash. It's also interesting to note the higher content of BSi in plants and soils found in the South Africa site relative to North America sites. This could be due to the longer history of grazing in South Africa.

B. Information Management

The SGS-LTER Information Management System archives extensive amounts of data, metadata, and other information. This year we have made significant revisions to our relational database management system to more efficiently organize, relate and deliver information, data and metadata. Our new schema also contains metadata content to generate level 5 EML, which defines each attribute within each dataset and the associated measurement units or code definitions. We are beginning to implement EML level 5 with long term studies consisting of 30 datasets, (15% of our entire database) which support both legacy and current studies. Perl scripts have been developed to generate EML from our database and store it on our web server for harvest by the LTER Network metacat catalog. This level of metadata and our participation in the communitywide metacat will facilitate data discovery, data integration and synthetic research.

We have contracted with a web development team at our home institution, Colorado State University, to implement our newly designed website that queries, joins, and publishes information from the revised database. The benefits of using the database to drive the website content include delivery of information that is more dynamic, connections between different types of information within the relational database management system, and increased ease of use for our end users with the latest web features. An example of related information that can be delivered within just a few clicks of the mouse includes a publication citation with the supporting data and the authors' e-mails. The SGS-LTER website is large in scope, presenting an impressive amount of information that requires unique tools compared to other projects on the CSU campus. The tools we will build can be maintained and expanded by SGS-LTER Staff and may be passed along to other LTER sites. Implementation is planned for Fall of 2007.

We also provided data, metadata and expertise to integrate datasets with other LTER sites working directly with researchers from the SGS, SEV, and JRN, as well as the leaders of the TRENDS project. The Grasslands Data Integration Project (GDI) brings together ecologists, computer scientists, and information managers to address the challenges of integrating diverse datasets and produce analyses from the integration product. Unfortunately, integrating NPP data over time and over regions is not a straightforward problem. Issues of ecological synthesis and data integration arise from questions of methodology (e.g., sampling, plot sizes, etc.), data semantics (e.g., changing taxonomic information), and straightforward but messy data transformations. These datasets represent a core area of research within the LTER community, and an integrated databank would create a powerful resource for ecologists from several sites to perform cross-site analyses.

Our IM staff continues to provide support for SGS-LTER researchers and students in various aspects of GIS including gathering data with GPS equipment and imagery, assisting with GIS model development for their particular research, and providing GIS data and maps for field work and modeling. We have also extended existing GIS programs for analysis of SGS-LTER data.

We continue to participate in planning future activities for the LTER IM committee. Kaplan serves as co-chair of the IM Committee, which establishes priorities and strategies to facilitate network-level and synthetic research that requires greater integration of information and interoperability of systems.

C. Educational, Outreach, and Training Activities

1. Research Experience for Undergraduates (REU): During the summer of 2006, two undergraduate students worked on the SGS-LTER project as part of our REU program. For the first time our REU students participated in the Student Ecology Research Program (SERP) at CSU as well as conducting their own research. SERP provided a cohort of similar summer research interns and fellows with whom our REU students could discuss their research activities. Seminars on a variety of topics were provided to help undergraduate students integrate into the larger research community. Feedback from our students indicated that this was a worthwhile program for them and complimented their research experience.

Ian Hough, Middlebury College student, 2006
Mr. Hough worked with Dr. Alan Knapp and PhD student Ms. Jana Heisler investigating the effects of varied frequency and amount of rainfall on species composition and plant growth on the shortgrass steppe. In past experiments, ANPP values were greatest for plots receiving fewer and larger rainfall amounts than other plots. Mr. Hough's work was aimed at helping to sort out the processes that might be responsible for the varied ANPP measurements. He compared plant growth in plots receiving manual watering at 10, 20 and 30 day intervals and a control receiving only natural rainfall. All the treated plots received 191 mm of 'rain' during the normal 120 day growing season, in aliquots appropriate for the frequency regime. He measured plant size as stem diameter and blade/leaf length, % of ground covered by vegetation and the species composition of the vegetation. He observed no significant differences in plant size on his plots although there were some suggestions that longer-term experiments might lead to enough data to validate the trends seen in his work. He did observe a trend toward increased plant cover by B. gracilis in the plots receiving the least frequent and largest event treatments.

Kathryn Turner, Austin College student, 2006
Ms. Turner worked with Dr. Bill Lauenroth and PhD student Mr. Seth Munson investigating carbon and nitrogen input from plant species on lands in the Conservation Reserve Program. Leaf, root and litter samples were collected from plots that have been in the CRP program for 2, 7 and 18 years, and from control plots on the shortgrass steppe. CRP fields had been seeded with native and non-native seed mixes. CHN analysis of the samples showed that there are differences in the quality of litter and above-ground tissue between field types, but not in the tissue quality of roots. In native-seeded fields, N content in litter generally increased with the length of time the field had been in the CRP program. Quality of litter and above-ground plant tissue was high (low C:N ratios) in native shortgrass steppe, followed by plants in 18 year-old CRP fields

seeded with native species and then by plants in 18 year-old CRP fields seeded with non-native seed mixes. There were also differences in tissue quality both between and within species. Perennials had significantly lower quality than annuals, and grasses had lower quality than forbs. Tissue quality varied within the same species in different fields. Ms. Turner presented her results in a poster at the 2007 Shortgrass Steppe Symposium in Fort Collins this January.

We currently have two REU students involved in summer projects at the SGS-LTER. Tyler Benton, from the Colorado School of Mines, is working on Conservation Reserve Program lands with Dr. Bill Lauenroth and PhD student Mr. Seth Munson. Tyler was a participant in our Schoolyard LTER programs during his early high school years and we are delighted to have him working with us again this summer. Helen Lepper is a student at CSU, working on plague transmission on the Shortgrass Steppe with Dr. Michael Antolin and PhD student Ms. Liz Harp.

2. Teacher Professional Development 2006-2007: The SGS-LTER has served as the nexus for the NSF funded GK-12 program *Human Impacts Along the Front Range of Colorado*. The GK-12 program by design focuses on the professional development of graduate students, but includes professional development activities of K-12 teachers. During 2006-2007 we expanded our effort to include efforts that are more teacher-centric in terms of professional development. The following three initiatives were under-taken in the past year:

1. NSF Funded Teacher Professional Continuum project that focuses on Ecological Complexity (DRL 0554379: Teaching Ecosystem Complexity through Field Science Inquiry, $1,187,740). The TPC project is a multi-LTER site (AND-LTER, CAP-LTER, JRN-LTER, LUQ-LTER, and SGS-LTER) initiative operated through Portland State University designed to develop modules with field and laboratory protocols that focus on ecological complexity (e.g., species diversity, food webs, biogeochemistry) for use by K-12 teachers in the classroom. To date the project held a two-week workshop (June 18 – June 29, 2007) attended by nine K-12 teachers (6 from northern Colorado schools districts, 3 from Montana school districts) that included presentations by SGS-LTER scientists on the basic theme and on methods and approaches to address them.

2. CSU Funded Teacher Professional Development focusing on the transfer of field experiences to the K-12 classroom. The CSU project was funded through the Warner College of Natural Resources to promote K-12 teacher professional development on issues related to natural resources. The SGS-LTER is participating partner in this initiative.

3. Colorado Department of Education funded Mathematics and Science Partnership focusing on teacher professional development through field and laboratory inquiry (CDE MSP; $404,000). The project will recruit middle school and high school teachers from schools with low performance on the state standardized tests, and/or with wide gaps in the achievement between minority students and white students, and pair them with SGS-LTER scientists and graduate students to

conduct research, develop modules aligned with state science content standards, and to place SGS-LTER graduate students into local K-12 classrooms as resource (modification of the GK-12 model).

3. <u>EdEn 2005-present: "An Assessment of Ecological Literacy and LTER Education and Outreach.</u>": There were two goals for the project: 1) conduct a project and program wide evaluation of the effectiveness of different models used in the schoolyard ecology program in terms of participation, teacher classroom practice, and student learning, and 2) assess the role of culture in the implementation and effectiveness of the different models used in the schoolyard ecology program in terms of promoting environmental literacy and participation of groups traditionally under-represented in the study and practice of ecology and the environmental sciences. The surveys were conducted and the results are in the process of being summarized and analyzed.

4. <u>RAMHSS 2006-2007:</u> Students from groups under-represented in STEM were selected from the UNC Upward Bound Math (2006-2007), UNC Science and Frontiers of Science Institute (2006-2007), and the CSU Upward Bound (2007) summer resident programs. For the UNC programs, four students worked in the laboratories of scientists, developed independent projects, prepared and delivered poster and oral presentations. Our program expanded its RAMHSS outreach to include students from the CSU Upward Bound resident program in 2007. The model we adopted is similar to the one developed for the programs at UNC, but was adapted to fit the scheduling and curriculum of the CSU program. Four minority students (rising HS seniors) were selected from regional high schools. The students have been placed in research labs working under the supervision of SGS-LTER scientists.

5. <u>RET 2007</u>: The SGS-LTER supported Ms. Cathy Hoyt, a high school teacher at Union Colony Preparatory School in Greeley Colorado. Ms Hoyt has been a long-time member of the SGS-LTER Schoolyard Ecology effort and the GK-12 program. Ms. Hoyt has set up in-class experimental terrariums since they do not have open land at their school currently. Ms. Hoyt is also working with the new building construction to allow for an experimental plot on their new school site. The onsite experimental plot will allow Ms. Hoyt to teacher her student's data collections methods that can then be transferred to the SGS-LTER.

6. <u>Schoolyard 2006-2007</u>: Recent SGS-LTER schoolyard efforts have continued to focus on the Poudre Learning Center (PLC). Since this center is used by many regional school districts we have been able to impact a large amount of students over the year. With the support of the SGS-LTER, the PLC is continuing to survey plants and animals, restore the prairie and riparian areas, as well as develop their on-site reference collection. The schoolyard efforts have also supported field trips for schools. SGS-LTER schoolyard was able to pay for buses for students to come out to the SGS-LTER site. While the students were there they received a GPS lesson, viewed animal collection, learned about cattle processing and uses, and did some plant identification. The age of the students ranged from 6th grade to 12th grade.

<u>7. Cross-LTER Site Education Initiatives</u>: The SGS-LTER site was given high praise for its education initiatives during the 2005 mid-program site review by NSF. The review team recommended that the SGS-LTER expand its initiatives to include other LTER sites and share its models with them. In response to this recommendation, the SGS-LTER has initiated the following partnerships, some of which have been discussed above:

1. NSF EdEn 2005-present: *An Assessment of Ecological Literacy and LTER Education and Outreach.* (BES-LTER, KBS-LTER, SBC-LTER, and SGS-LTER). Conducted a survey of LTER wide education activities.

2. NSF GK-12 2000-present: *Human Impact Along the Front Range of Colorado* and NSF and ANS 2004-present: *Collaborative Research: Aboveground and Belowground Community Responses to Climate Changes in Arctic Tundra.* (ARC-LTER and SGS-LTER). Supported 2 K-12 teachers that have worked at the SGS-LTER to work at the ARC-LTER site at Toolik Lake, AK.

3. NSF TPC 2006-present: *Teaching Ecosystem Complexity through Field Science Inquiry.* (AND-LTER, CAP-LTER, JRN-LTER, LUQ-LTER, and SGS-LTER). Designed to develop modules with field and laboratory protocols that focus on ecological complexity (e.g., species diversity, food webs, biogeochemistry) for use by K-12 teachers in the classroom. Conducted a two-week professional development workshop in June 2007.

D. Project Management

We continue to refine our management process as needed to facilitate efficient support of our research, outreach and reporting efforts. The executive committee has met this past year to discuss primarily science and research topics and to spearhead the organization around our new submission next year. The meetings were very positive with regard to initiating new experiments and as we continue to expand the geographic sphere of our research. We have secured large scale grazing exclosures (approximately 320 acres) so that we may better address grazing landscape interactions. We have also initiated experiments to address the impact of fire on the SGS ecosystem and expanded into international collaborative research projects.

Dr. Eugene Kelly (EFK) is serving as lead PI. Dr. Michael Antolin (MFA) has assumed his position as lead co-PI replacing Dr. Indy Burke (ICB). The small management group remains the same as it did last year (EFK, MFA, ICB and the leads of our other three research areas, Dr. Jack A. Morgan (JAM) for Land-Atmosphere Interactions, Dr. William K. Lauenroth (WKL) for Plant Dynamics, and Dr. John C. Moore for our Education and Outreach programs. We are in the process of recruiting new scientists to participate in the leadership of the four research areas. We are hoping to establish a similar rotation of leadership within each of the groups as we have done with lead the PI of the project.

We remain active in attracting new scientists to the project. Dr. Julia Klein is a new hire with experience and interests in plant community ecology and will begin to organize our participation in NutNet. Drs. Joe Von Fisher (Biogeochemistry) and Alan Knapp (Plant Ecology and Land Atmosphere) have formally joined our research team and each participates in several of the scientific groups and attended ASM under our sponsorship.

Our brown bag seminar series continues to be a venue for inviting new researchers to meet our investigators, and talk about collaborations. We are meeting twice monthly during the academic year and have heard presentations from visiting scholars at CSU, graduate students, senior researchers from ARS and USGS, and our own researchers. Within our own research community the feedback provided from those in one area has often given those in another area new ideas about interpreting data or setting up their next round of experiments.

We hosted our biennial meeting in January to discuss research and other issues of interest to the broader shortgrass steppe community. This year the symposium was structured around the theme "A Town Hall Meeting: Where is the Prairie Growing?" Presentations, discussions, and posters focused on changing land use on the grasslands and the impacts of shifting urban/rural boundaries.