SGS LTER Annual Report 2009: Activities and Findings

During this year we worked to re-organize and integrate our project to focus on our renewal proposal for the remaining four years of SGS-LTER VI. Central to our project is understanding of structure and function of the SGS, an ecosystem that exhibits remarkable persistence in a semi-arid temperate environment characterized by high inter- and intra-annual variability in precipitation. Further, this ecosystem has a long evolutionary history of large herbivore grazing, and plants that are well-adapted to smaller-scale disturbances caused by animals like prairie dogs. The SGS ecosystem currently exists as a mosaic of land uses including native prairie, recovering prairie (some in the federal Conservation Reserve Program (CRP)), ranchland, tilled and irrigated farmland, and urban and exurban development. In addition to continuing our long-term experiments addressing structure and function of the SGS, we are engaged in scientific initiatives important to our region, continue cross-site and global synthetic analyses, and have initiated new experiments in response to the 2008 proposal reviews. In particular, we are working to integrate our research by expanding our inferences across multiple scales of measurement from molecular analyses of soil microbial communities to large-scale remote sensing of soil moisture.

An additional goal of the SGS LTER project is to collect data and develop models to forecast responses of the SGS ecosystem to global change, using both long-term monitoring and shorter-term experiments to discover mechanistic responses to ecosystem determinants. We define global change in the broadest sense that encompasses multiple factors including climate, human land use, and invasive species. We modified our conceptual framework to incorporate historical perspectives on how ecosystem determinants acted in the past and to illustrate that the SGS has experienced and will continue to experience change in relative strengths of determinants (Figure 1). We organize our research around these concepts (Figure 2).

Key to this work is a long-term and ongoing collaboration with scientists with the USDA-ARS Central Plains Experimental Range (CPER), the site where most SGS LTER work has been conducted. An additional memorandum of understanding with the Pawnee National Grassland in Weld Co. extends the SGS LTER site to include approximately 80,000 ha of public land under management by the USDA Forest Service. This annual report provides a summary of our A) Research Activities, B) Information Management (page 22), C) Education, Outreach and Training Activities (page 24), and D) Project Management (page 32).

A. Research Activities

During the last year, we produced 75 papers in refereed journals (61 published, 14 in press), four book chapters, two technical reports, three dissertations, two thesis and many abstracts from regional, national and international meetings. An additional eight manuscripts have been submitted for review in peer-reviewed journals, along with two manuscripts for book chapters. Most of our publications involved multiple authors, reflecting the collaborative spirit and interdisciplinary nature of the SGS-LTER research program. We are especially pleased to report publication of the SGS-LTER synthesis volume ***Ecology of the Shortgrass Steppe: A Long Term Perspective*** from Oxford University Press. This book is a comprehensive synthesis of our LTER research over the last 27 years, combining research and expertise of 23 primary authors and further exemplifies the interaction among researchers and the interdisciplinary nature of research conducted throughout the SGS-LTER program.

Key research progress for 2008-2009 is organized to reflect the primary determinants of the SGS (Figures 1 and 2). Thus, we group research under the broad headings of 1.) Climate, 2.) Disturbance and Land Use, and 3.) Physiography. Although determinants are identified separately, we are aware that important interactions occur between them, and in many cases several determinants are studied in concert. We include a fourth section on Synthesis and Modeling to describe our work on developing a larger picture through analyses of our long-term data and participation in cross-site studies. As part of our redirection toward understanding effects of global change, we have reassessed sampling frequency and intensity of some long-term projects to provide resources for new efforts. Primarily we reduced sampling frequency in several legacy experiments, for instance where experimental additions of water and N decades ago still show differences compared to native SGS. A major new effort is to study the effects of precipitation pulses on multiple responses including soil microbial and arthropod communities, plant diversity, phenology and productivity, and fluxes of C, N and trace gasses.

Figure 1. A temporal view of three primary determinants of structure and function of the SGS ecosystem: Climate, Disturbance and Land Use, and Physiography. a.) Before settlement for agriculture during the 1800s, the SGS ecosystem was dominated by herbivores (bison, prairie dogs), which acted as both primary disturbance and controlled plant species diversity by grazing of the prevalent warm season (C4) grasses blue grama and buffalo grass. The extent to which fire also created disturbance is less well known. Temporal and spatial variability of determinants formed the SGS ecosystem, a persisting drought and grazing-adapted system where 90% of biotic interaction and biogeochemical transformations occur belowground. b.) European settlers removed bison and replaced them with livestock, and began tilled agriculture. Recurring droughts, especially in the 1910s, 1930s, and 1950s led to development of irrigation systems and the change to irrigated agriculture. c.) The current state(s) of the system, with return of tilled lands to grassland, managed under the Conservation Reserve Program (CRP) initiated in part to conserve soil. The ecosystem currently exists as a mosaic of land uses. d.) With global change, temperatures have begun to rise and changes in the timing and intensity of precipitation are expected. Known interactions between rising CO_2 concentrations, temperature, and precipitation regimes may lead to several alternative states in the future.

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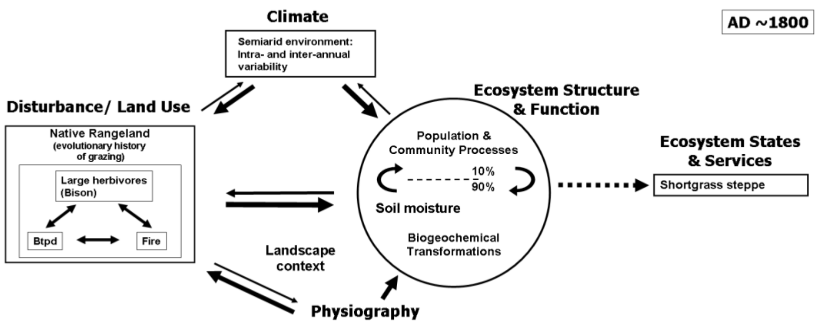

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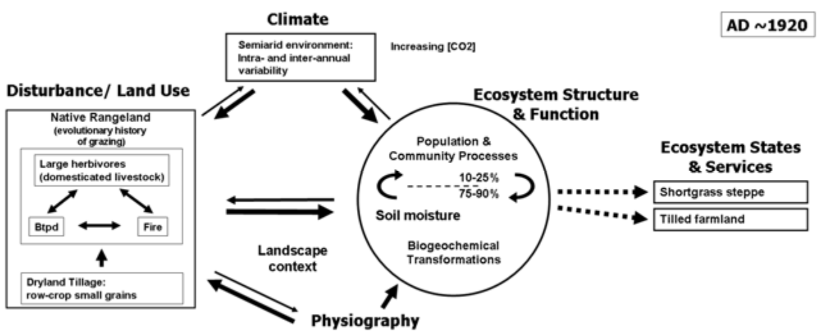

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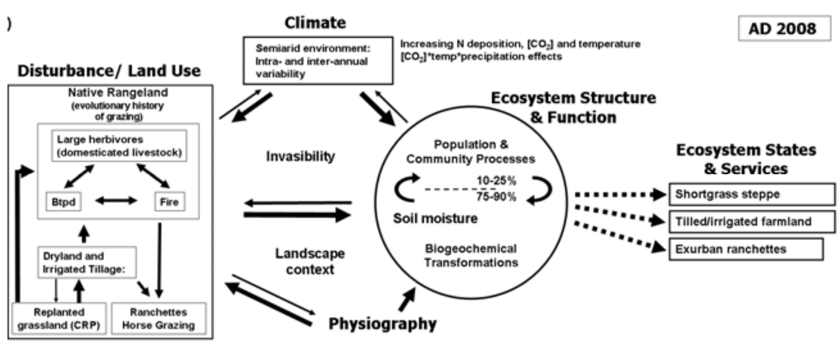

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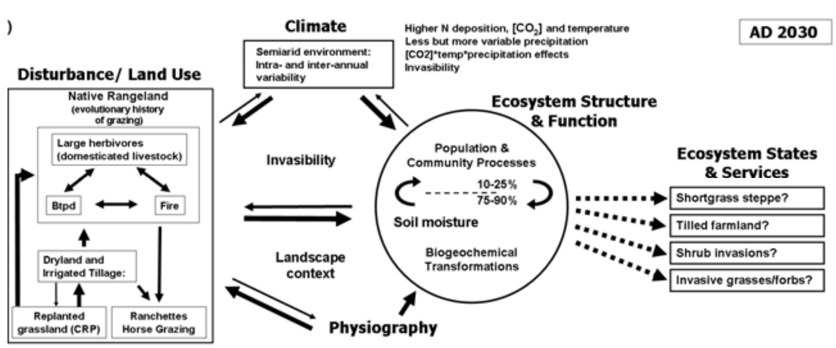
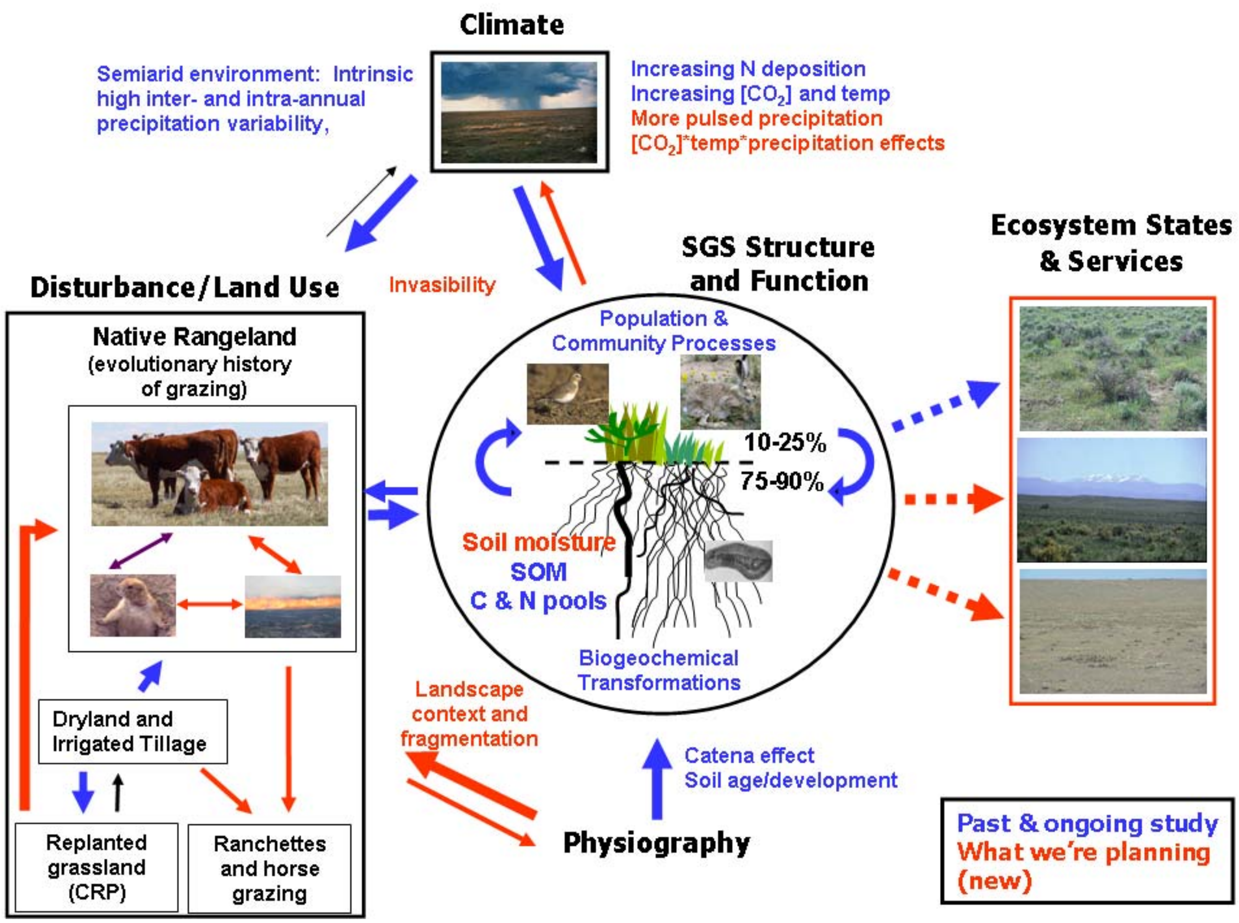


Figure 2. The SGS conceptual diagram outlining research carried out by the SGS-LTER project initiated during the last 27 years (blue) and planned for the future (red). The three ecosystem states depicted on the right represent SGS as it existed before settlement (top), the ecosystem under shrub invasions (center), and a warmer/drier regime with more bare ground. The relative thickness of arrows indicates the directionality and strength of interactions between determinants and the biotic system.



1.) Climate

We have identified climate as a major determinant of SGS structure and function, and we revisited our long term data to assess whether changes in climate have occurred. Inter-annual variation of SGS precipitation is high – since 1939 the recorded range was from 32% to 170% of the long-term annual average (95% c.i. 139 to 542 mm-yr^{-1}). Intra-annual variation underlies this pattern: amounts of rainfall in each event fall into a continuum, but events < 5 mm comprise more than 70% of the total during the growing season (Figure C1). However, events >10 mm account for most of that inter-annual variation (Figure C1; Sala et al. 1992). Moreover, because potential evapotranspiration greatly exceeds precipitation over the course of the year, water from small events has contingent ecological impacts (Sala and Lauenroth 1985), and depend on the season (e.g. physiological state of plants and microbes), soil moisture and time since the previous event, and the time of day when rains fall (e.g. an evening rainfall in summer may infiltrate) (Sala and Lauenroth 1985, Heisler et al. 2009). Intra-annual variation can be summarized by the sizes of "wetting events" (when daily precipitation > daily potential evapo-transpiration) and by duration between events. Potential for long duration between wetting events, coupled with high potential evapotranspiration, suggests that the SGS LTER experiences periods of time where biological activity is pulsed by precipitation events.

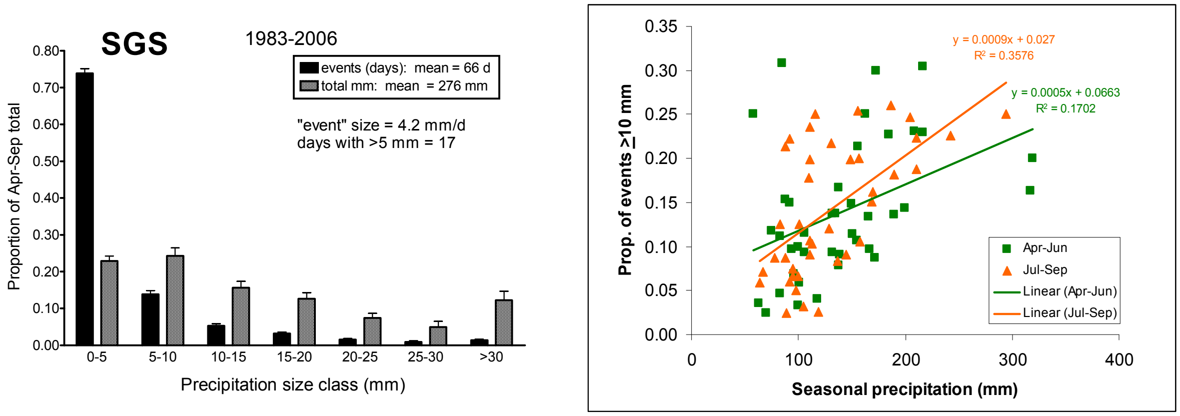


Figure C1. The distribution of rainfall events and the relationship between large (wetting) events related to annual precipitation. The SGS LTER climate is predominantly comprised of small rainfall events, but wet years have more large events.

Long-term trends in the SGS LTER climate record show little change in temperature (Figure C2) but

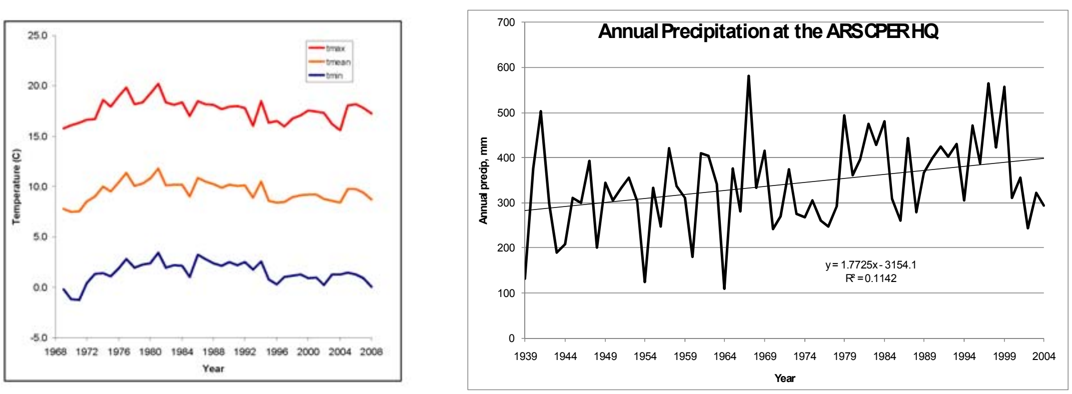


Figure C2. Annual temperature and precipitation records from the USDA ARS CPER HQ. Precipitation readings have been taken manually each day at 08:00 hr since 1939. Regression is significant (p<0.006). Wetting events are defined as >5 mm-d^{-1}. The long-term average is 340mm (+/- 115 mm SD), maximum (581mm) in 1967 and minimum (109 mm) in 1964.

alteration in precipitation. Between 1969 and 2008, the period spanning both the International Biome Project and SGS LTER projects, no discernable changes in monthly minimum or maximum temperatures were observed, except for August data that show a slight but significant cooling (both minimum and maximum temperatures, P < 0.034, r^2 > 0.11). The 1939-2004 precipitation record from the CPER HQ reveals an increase in precipitation over the past 65 years at an annual rate of 1.8 mm-yr^{-1} (Figure C2), both in summer (JAS at 0.75 mm-yr^{-1}) and winter (DJFM at 0.38 mm-yr^{-1}). During summer, average size of ALL precipitation events has not changed, but the size of wetting events has increased (Figure C3); on average, summer wetting events now deliver 5.4 mm more than

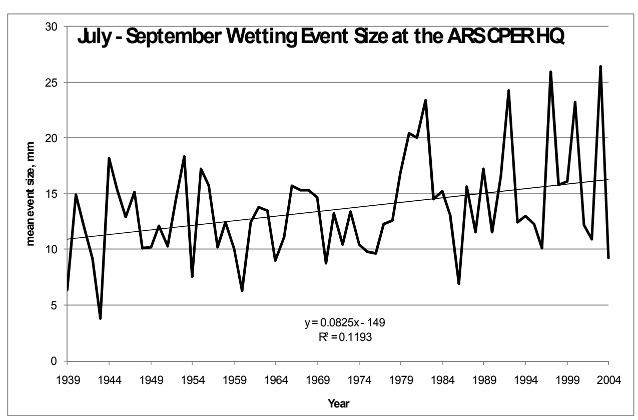


Figure C3: Size of wetting events during July, August and September has increased at the SGS LTER (p<0.005). The size of all events did not change over this time period (p>0.1), nor did the amount of water delivered by small events (p>0.4).

they did in 1939. In addition, there has been a significant decrease in the number of days between wetting events.

Our observations of increasing magnitude of precipitation events are consistent with world-wide patterns of increasing storm intensity, resulting from global climate change (IPCC 2007). Global circulation models predict that global warming will accelerate the hydrologic cycle across temperate North America, and drive both larger precipitation events and a greater number of dry days between storm events (IPCC, 2007). While model ensembles predict the SGS LTER to experience 4°C warming and 5-10% reduction in JJA precipitation (IPCC 2007), inter-model agreement on these predictions is poor. It is likely that global climate change will drive increased potential evapotranspiration on the SGS LTER, but it is unclear to what degree this increase will be offset or exacerbated by changes in the precipitation regime. Further, our own experiments indicate that effects of temperature and precipitation will be tempered by altered water use efficiency of C3 versus C4 plants with rising atmospheric CO2 concentrations (Morgan et al. 2007).

We continue to carry out experiments and monitoring to examine the effects of the climate regime on structure and function of the SGS ecosystem, and the potential for changes in structure if global change results in altered seasonal patterns of rainfall and temperature. The following highlight some of our results from this line of research.

Aboveground Net Primary Productivity (ANPP) and Climate

We have also revisited our primary data set recording ANPP over 26 years on sites that vary in landscape position, soil texture, and species composition. Annual ANPP has ranged from a low of 11 g-m^{-2} to a high of 185 g-m^{-2} (Figure C4). Within the most productive site (Swale), ANPP has ranged from 15 to 185 g-m^{-2} and from 11 to 102 g-m^{-2} within the least productive site (Upland).

Both the magnitude and variability of ANPP are related to water availability (Sala et al. 1988, Lauenroth and Sala 1992). Annual precipitation, as an index of water availability, is positively related to ANPP and to the variability of ANPP among sites (Figure C4). The largest variability was recorded in wet years and

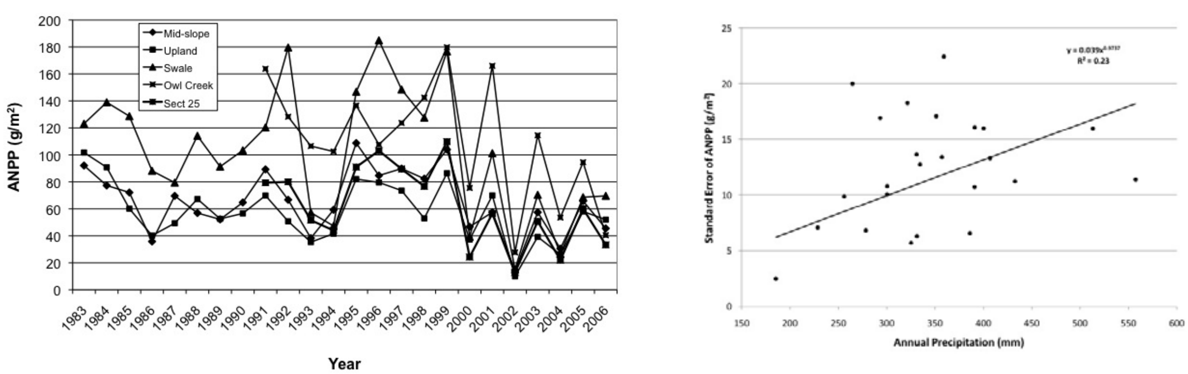


Figure C4. Annual ANPP for 5 locations over 24 years on the SGS LTER site (left), and the relationship between the variability of annual ANPP (standard error) and the annual precipitation for 5 locations.

the lowest in dry years. The large spread around the relationship is likely the effect of the seasonal distribution of precipitation during average-to-wet years.

Combining all location data into an average annual ANPP reveals a declining trend in production since the beginning of the SGS LTER project (Figure C5). Further, combining the LTER data with the long-term data collected by the CPER before the start of SGS LTER suggest a declining trend over the last half of the 20th century (Figure C5). In both cases the relationship is variable, explaining only 16 to 20% of the variability in the data, but the 68-year graph suggests that much of the definition for the decline has occurred in the past decade. What is not clear is whether this is a short-term fluctuation or the beginning of a long-term change associated with climate change. For instance, early data for 2009, which includes

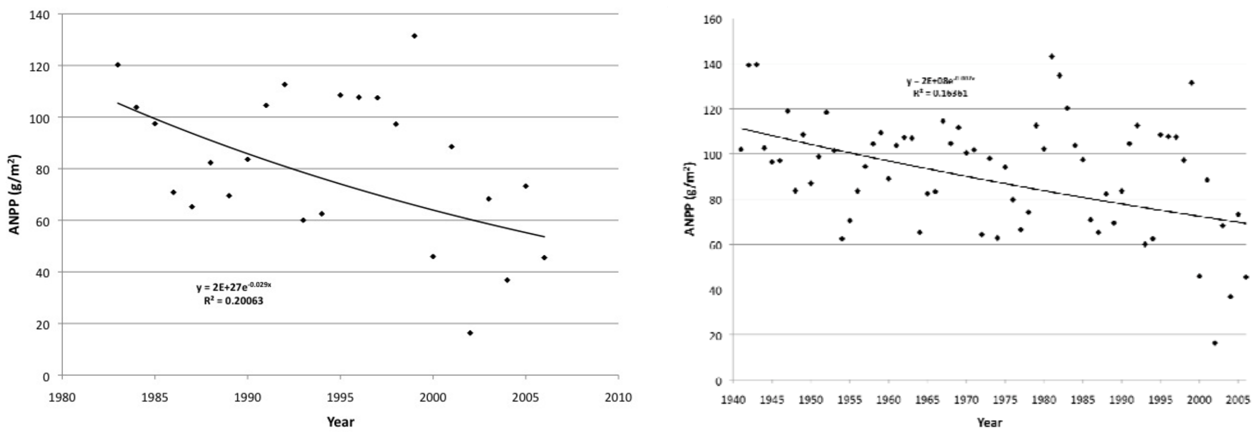


Figure C5. Declining trend in average ANPP over 24 years on the SGS LTER site (left) and over 68 years including data from the Central Plains Experimental Range (USDA-ARS) (right).

one of the wettest recorded May-June rainfall periods on record, show that this year may have close to the highest ANPP on record.

<u>Ecosystem Phenology in the SGS</u>

With changing rainfall patterns and the potential for higher temperatures in the future, we may expect alterations in plant phenology and the length of the growing season. In 2001 we began continuous monitoring of plant canopy development, where two Skye 1800 2-channel radiometers were installed in a grazing exclosure and in the adjacent grazed pasture. The radiometers are polled every minute and averaged hourly. Additionally, soil moisture is monitored using time domain reflectometry (TDR) probes at 3 soil depths, 0-10 cm, 10-20 cm, and 20-30 cm. To record site precipitation, a tipping bucket gauge was installed recording 24-hour totals. We calculate the Normalized Difference Vegetation Index (NDVI) for the noon hour reflectance average based on Fischer, (1994a, b). We can compare the beginning and end of growing seasons (SOS and EOS) by fitting double logistic curves to the NDVI data

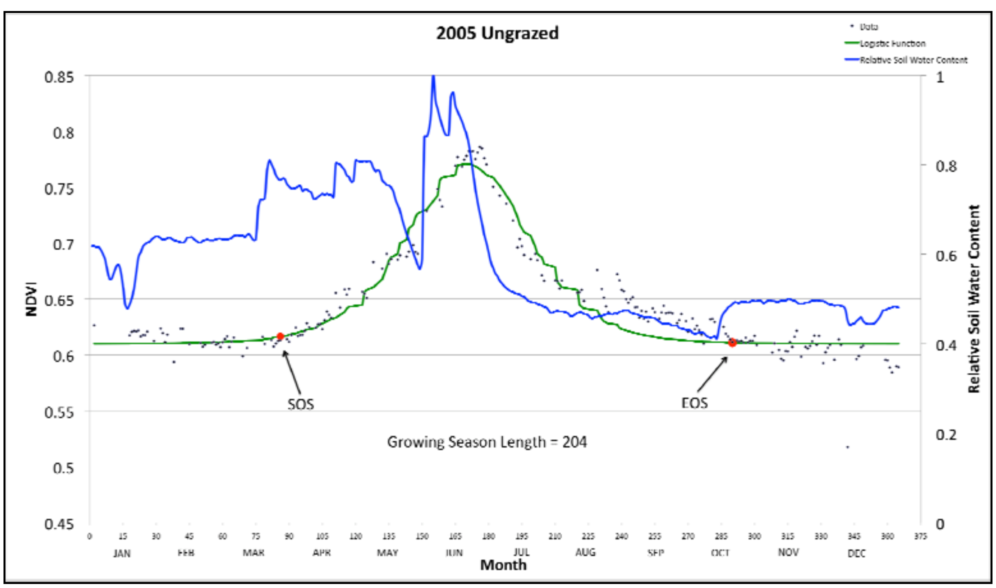


Figure C6. NDVI data, the fitted double logistic curve, and the soil water data expressed as relative water content for the ungrazed treatment in 2005. SOS and EOS denote the start and end of the growing season.

(Figure C6). For instance, in 2005, which had long-term average precipitation (323 mm), the ungrazed treatment had a 204 day "green" season with the peak in the middle of June. By contrast, 2002 was a very dry year with only 150 mm of precipitation, a growing season of only 142 days, a peak in July, and pulses in NDVI were associated with soil moisture pulses (data not shown).

Measurements NDVI to estimate phenology and canopy development will feature prominently in the future of the SGS LTER studies of seasonal variation, especially in relation to our long-term measurements of ANPP and rainfall manipulation experiments.

Manipulating the Rainfall Regime: Multiple Responses

Given the key role that variability in precipitation and moisture pulses play at the SGS LTER, we have an ongoing long-term precipitation experiment and have initiated short-term experiments to examine mechanistically how timing an amount of precipitation influences structure and function of the SGS. In particular, the short-term experiment is a proof-of-concept to examine the effects of precipitation pulses on ecosystem responses at multiple scales from microbes to atmospheric exchanges of moisture, CO_2 and energy.

- **Long-term drought manipulations: Effect on C and N Cycling**

Rainout shelters at the shortgrass steppe that reduce rainfall by 50% and 75% have been in place for the last 10 years. Long-term drought models show that ecosystem processes are not greatly affected by short term and less severe droughts due to tolerance of dominant species to low water availability. These hypotheses, however, have not been tested at the extremes. Measurements in the summers of 2008 and 2009 investigated how long term-drought affected carbon and nitrogen pools. Plant cover, measured yearly, was not significantly different among treatments until 4 years after the rainfall reductions began (Figure C7).

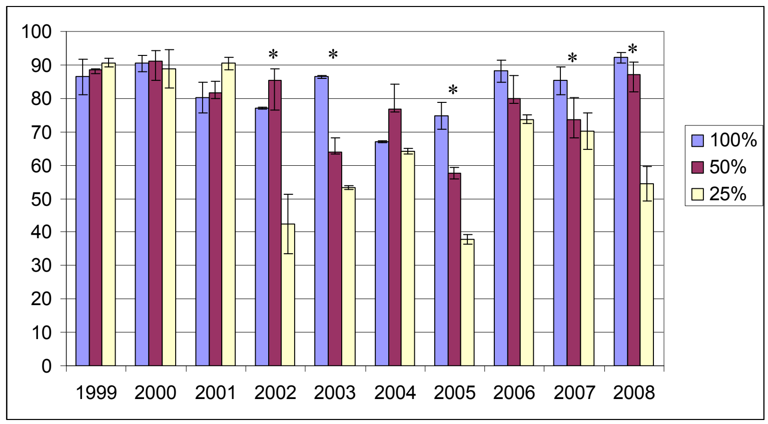


Figure C7: Percentage of ground cover for controls and two long-term water reduction experiments. Significant reductions (*) in plant cover only began after 4 years of induced drought.

In 2009, soil carbon was not significantly different among treatments, suggesting that long-term C storage was not affected by 10 years of drought in these conditions. On the other hand, soil respiration was controlled by soil moisture and availability of labile substrate: respiration was lower in drought plots. Soil organic nitrogen also was not significantly different among treatments, but extractable inorganic nitrogen showed large accumulation in the severe drought treatment, suggesting that moisture limits access to nitrogen by plants. Productivity is affected more by drought than is nitrogen mineralization. Across the summer, nitrous oxide production also did not differ between treatments. In this case, the greater substrate availability in the drought plots may interact with moisture availability to reduce nitrous oxide differences among treatments, while carbon cycling decreases with drought severity.

- **A New Short-term Pulse Experiment**

During the growing season, plants and microbes on the SGS experience periods of water stress, alleviated by periodic rainstorms that replenish soil moisture. At the ecosystem scale, rainfall events induce a short-term pulse of CO_2 release, followed later by stimulation of plant photosynthetic activity (Heisler et al. 2009, Knapp et al. 2008). The "Pulse Experiment" is a multi-investigator, synthetic experiment to characterize the magnitudes and time scales of plant and microbial responses to rainfall events of different sizes. From this experiment, we sought to develop a mechanistic understanding of the autotrophic and heterotrophic processes that contribute toward net CO_2 exchange by the SGS. Such mechanistic understanding is needed to predict the SGS response to climate change; climate change models forecast that the future hydrologic cycle may be accelerated with more rapid evaporation, more intense precipitation events, and longer intervening dry periods. For example, response of the SGS to moisture pulses will be determined by responses by plants, soil arthropods and the plant community, the rates of those responses, and the extent to which those responses depend on one another.

For this short-term experiment, we established three treatments: control, a 1cm rainfall event, and a 2cm event, with each treatment replicated five times in 2m x 2m plots. The site is on sandy-loam soils in a moderately grazed pasture. The experiment was conducted in July 2009, following one of the wettest Junes on record (95th percentile in the 69-year record). Rainout shelters protected the plots from non-experimental precipitation, and the shelters caused soil moisture levels to decline from field capacity on June 22 to very dry levels (ca. six percent volumetric water content) on July 13 when we added water. Decagon TDR probes recorded soil moisture and temperature prior to and following the experiment.

From a shared pool of soil samples collected on days 0, 1, 2, 3, 4, and 7 we measured microbial and soil faunal biomass and community composition using traditional and molecular techniques (microscopy and pyrosequencing) to characterize the bacterial and fungal community, microbial enzyme activity and extractable N pools. In separate soil samples, we assessed ammonium and nitrate dynamics on days 1 and 7 using 15N additions. We directly measured trace gas fluxes every 3 hours for the first 24 hours, and on days 2, 3, 4, and 7. Aboveground, we measured plant growth, leaf-level gas exchange, and NDVI. Results of this experiment are forthcoming, but indicate a series of staggered responses by microbial, fungal, and plant communities. Respiration from the soil began immediately and declined steadily.

Further, this experiment serves as proof-of-concept for long-term rainfall manipulation experiments planned for the future (list of participating scientists is below). Pyrosequencing for detecting soil microbial communities is being carried out at the University of Colorado under a subcontract with Dr. Noah Feier.

Precipitation Pulses and Carbon Exchange

The CPER installed Bowen ratio flux towers to monitor energy and CO_2 fluxes in three different grazing treatments (ungrazed, moderate grazing, and heavy grazing) from 2001-2003. These years span one of the severest droughts in SGS history, especially during 2002. As an example of the data, Figure C8a shows average daily net carbon exchange and daily rainfall for 2003. Almost all net carbon uptake (negative fluxes) occurred during the early growing season (April-June), with lower net carbon uptake during the late growing season (July-Sep), and net loss (positive fluxes) during the non-growing season (October-March). Net loss of carbon (C8a, c) was seen after each rainfall event, followed by a transition to net carbon uptake 2 - 5 d after rainfall. The rate and amount of carbon uptake

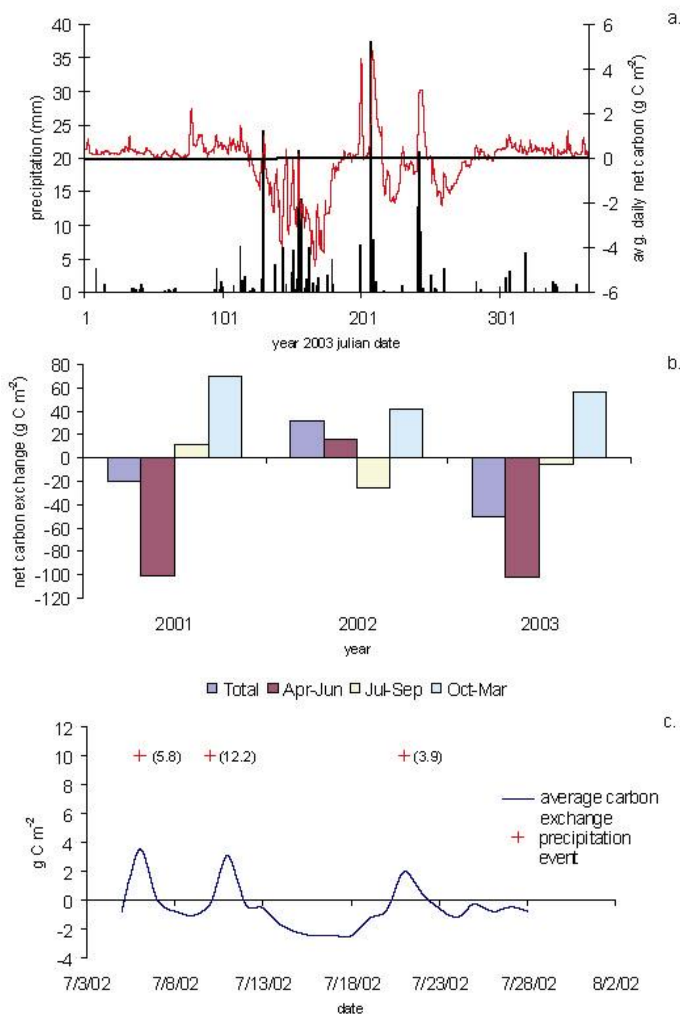


Figure C8. Net carbon fluxes (measured by the Bowen ratio method) in relation to precipitation during three years (2001 – 2003) that span two with average precipitation and ne of the driest years on record (2002).

depended on the size of rainfall events (Figure C8c).

The effect of rainfall events on carbon uptake is also contingent on seasons, and differences between early versus late growing season likely results from greater live plant biomass early in the season (live leaf biomass increases from 30 gm/m2 in mid-May to 120 gm/m2 in mid-June and then decreases to 30 gm/m2 in July for the remainder of the growing season).

Comparison of the annual and seasonal net carbon balance from 2001-2003 (Figure C8b) shows that 2001 and 2003 had similar patterns: on an annual basis we see net carbon storage, with > 95% of the net carbon uptake occurring in the early growing season. But again, some seasonal differences can be seen. Precipitation for the late growing season was higher in 2003 compared to 2001, and coupled with a higher frequency of large rainfall events (4 events > 10 mm) we see a net carbon uptake in 2003 vs. a net carbon loss in 2001. Rainfall was 50% below normal during the 2002 early growing season and near normal for late growing season. Comparison of 2002 with 2001 and 2003 shows that reduction of precipitation in the early growing season greatly reduced live plant biomass and both annual and early growing season carbon uptake. ANPP and net carbon uptake are very sensitive to changes in early growing season precipitation, and while late growing season precipitation is also positively correlated with net carbon uptake, it contributes < 5% during years with normal early season precipitation.

In conclusion, early season precipitation is the primary factor that controls ANPP and net carbon uptake at the SGS LTER site. The pattern of maximum live biomass in the early growing season and low live biomass during the late growing season is one of the main factors contributing to lower net carbon uptake during the late growing season. Small precipitation events are less effective compared to large events at stimulating net ecosystem carbon uptake and tend to enhance heterotrophic soil respiration.

2.) Disturbance and Land Use

The SGS represents a highly persistent ecosystem (Milchunas et al. 1988) in which plant communities dominated by *Bouteloua gracilis* (blue grama) have a long evolutionary history of natural disturbances operating over a wide range of spatial scales. The severity of disturbances on SGS structure and function is affected by the semi-arid climate and prior to European settlement, grazing by bison (*Bos bison*) interacting with species like black-tailed prairie dogs (*Cynomys ludovicianus*) and with fire was a primary determinant (Figure 1a). A suite of small-scale disturbances causing turnover of individual bunchgrasses and soils also played a role (Peters et al. 2008). In the mid-1800s the demise of bison herds and the introduction of livestock led to the first large-scale transition in land use, from free-range native grazers to domesticated livestock confined to small land parcels (e.g., pastures). The Homestead Act in 1862 set the stage for the second large-scale transition in land use: row crop agriculture (small grains) with and without supplemental irrigation (Hart 2008) those dramatically altered natural disturbance regimes by replacement of the diverse largely perennial native plant community with a monoculture of annual tillage and planting. This transition modified carbon and nitrogen storage and cycling, and produced a second ecosystem state (tilled farmland; Figure 1b). Removal of the native perennial plant community for tillage set the stage for the Dust Bowl during the 1930s and had legacy effects that persevered for more than six decades (Ihori et al. 1995; Coffin et al. 1996). Millions of hectares of tilled land were returned to rangeland after the 1930s, with additional land enrolled under the CRP since 1986 (Farm Service Agency, USDA). For instance, 102,000 ha (10% of total area) of Weld Co., where the SGS LTER site is located, is currently managed under the CRP, with a total of 950,000 ha in eastern CO in CRP.

Prior SGS-LTER disturbance research has focused on livestock grazing, small-scale disturbances, and abandoned cropland (Peters et al. 2008, Milchunas et al. 2008, Burke et al. 2008). Recent investigations of disturbances have included study of black-tailed prairie dogs (Guenther and Detling 2003, Stapp et al. 2004, Antolin et al. 2006, Stapp 2007, Augustine et al. 2008), and fire (Augustine and Milchunas 2009, Schientaub et al 2009). Here we describe ongoing research in this area that now includes several studies carried out at larger scales where multiple interacting determinants are measured in concert.

Interactive effects of fire and grazing in SGS

Although much of past SGS LTER research examined the influence of single disturbance factors, it has become clear that interactions between them likely important in the past and will be influential in the present. We initiated a 65 ha-scale patch burning experiment consisting of 3 unburned control pastures and 3 pastures in which 25% of the area will be burned each year. The first set of burns was implemented in November, 2007, with fuel loads that averaged 698 kg ha^{-1}. Burns were relatively homogenous and produced mean maximum temperature of 160°C (range 102 – 221°C) at 1 – 2 cm above the soil surface. Response variables measured during the 2008 growing season included soil moisture, plant production and residue, plant species composition and structure, cattle foraging distribution, cattle weight gains, and breeding bird densities.

Initial findings show that burns removed >95% of standing dead biomass, but had no influence on plant production during the first post-burn growing season (Figure D1). Patch burning did not influence cattle weights gains (1.07 kg/steer/day on patch burn and 1.06 kg/steer/day on control pastures of the same size and same moderate stocking rate). Burned areas had less standing residue at the end of the grazing season (early October) with 523 kg/ha remaining in the burned areas compared to 585 kg/ha in the non-burned portions of the same pastures. Burns significantly reduced vertical vegetation density (visual obstruction) by ~46% (3.8±0.3 cm on unburned sites vs. 1.8±0.2 cm on burned sites). In 2008, breeding mountain plovers, which favor bare ground for nesting, were observed on each of the 3 replicate patch burns (1 - 2 adult plovers and 1 nest per burn in May; 1 adult with brood on each burn in June), while plovers were not observed in any unburned control sites.

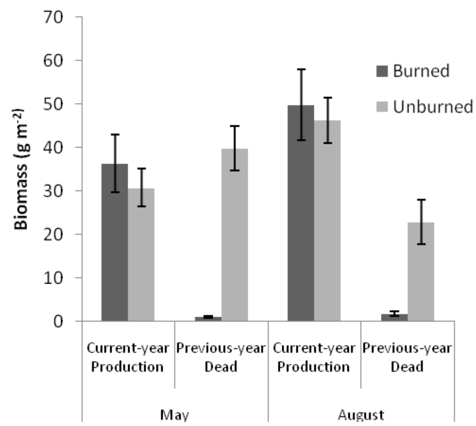


Figure D1. Comparison of burned and unburned patches on the SGS LTER/CPER. Burning reduced standing dead biomass but not ANPP in the first year.

Effects of Disturbance on SGS Consumers

We examined the effects of modifying intensity and seasonality of grazing on SGS plant and consumer communities, including species of concern like the mountain plover, which prefers to nest on open ground away from tall vegetation. Our studies not only expand upon the range of grazing intensities (light, moderate, heavy) to include long-term cattle exclosure and grazed prairie dog colonies, but also increase the plot sizes to encompass areas where both functional (behavioral) and numerical (population-level) response can be manipulated. An example of how grazing regime influences livestock is in Figure D2. Sampling of bird nests ended in 2008 but we re-sampled small mammal populations and vegetation characteristics in summer 2009. A manuscript, led by former postdoctoral scientist Scott Newbold, describing results from the first stages of this project (2003-2006) is in review at *Oecologia*.

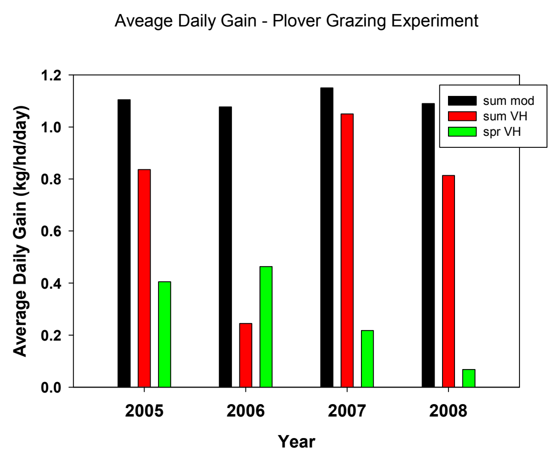


Figure D2: Comparisons of daily weight gain in cattle on two heavy-grazed pastures in comparison to levels known to be sustainable over the long term

Long-term Monitoring of Small Mammals and Carnivores

In 2008-2009, we continued our long-term population studies of small mammals and carnivores. In September 2008, we worked closely with scientists and staff with the NEON project to develop and test sampling protocols for the Fundamental Sentinel Unit aspect of the NEON project. In addition to developing cost and manpower estimates for arthropod and small mammal sampling, we tested the efficacy of three sampling designs for sampling small mammal populations, based on our existing SGS

LTER trapping webs. The comparison of these designs was included in a white paper submitted to NEON in spring 2009 and is expected to be the basis of a manuscript to be submitted within the next 6 months.

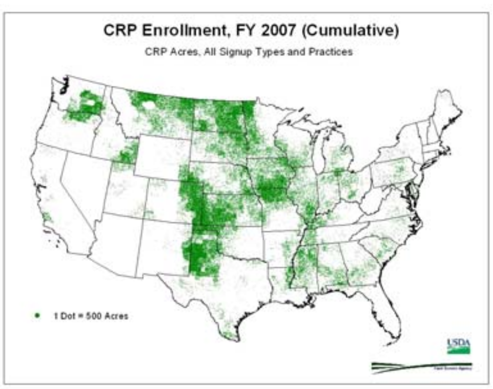
In 2009 we revised our sampling protocols to eliminate carnivore scat sampling in winters, when the effects of freezing, snow and unpredictable access to roads has complicated efforts to get a consistently reliable sample. We also modified our grasshopper sampling design to better integrate with sampling efforts, led by David Branson (USDA-ARS), for rangeland grasshoppers elsewhere in the Great Plains.

Plague and Disturbance of Prairie Dog Towns

Plague, as an exotic pathogen in Colorado since the 1940s, has altered population dynamics of black-tailed prairie dogs to that of a metapopulation where local disease outbreaks cause extinctions of towns that are subsequently re-colonized within 1-4 years (Stapp et al. 2004, Antolin et al. 2006, Augustine et al. 2008). Prairie dogs are a foundation species that creates habitat (and disturbance) by burrowing, is preyed upon by numerous species, and directly influences plant community composition by grazing of dominant grasses and clipping of other vegetation on their towns. Thus, plague outbreaks play an ecosystem-level role by controlling prairie dog populations, including the spatial distribution of their disturbances on the landscape and recovery from prairie dog disturbances to plant communities (Hartley et al. 2009). Further, because of detailed knowledge of mechanisms of pathogenesis in the plague bacterium *Yesinia pestis*, this pathogen serves as a model for translational research of infectious diseases from genomics to population-level analyses and beyond (Antolin 2008, Stapp et al. 2008). This project has been partly funded in part by a separate NSF-EID grant to study the mechanisms of persistence of this highly virulent pathogen (PIs Antolin, Stapp, ending in August 2009). Work has included a large number of graduate students, and we list recent highlights here: 1.) molecular genetic analyses to identify the source of host blood meals in fleas to determine the host range of fleas and potential interspecific routes of infection (also see Stapp et al. 2009); 2.) movement of grasshopper mice (*Onychomys leucogaster*) a known alternative host; 3.) the role of increased flea abundance on prairie dogs during plague outbreaks (Tripp et al. 2009); 4.) transmission efficiency of the two main prairie dog fleas, *Oropsylla hirsuta* and *O. cynomurus tuberculata* (Wilder et al. 2008a,b); 4.) development of robust methods for population estimation based on visual counts of prairie dogs (McClintock et al. 2009); 5.) radio-tracking swift fox (*Vulpes velox*) and leg-banding of burrowing owls (*Athene cunicularia*) to determine home range shifts in relation to die-offs of prairie dogs, 6.) time necessary for recovery of plant communities after plague epizootics devastate local prairie dog towns (Hartley et al. 2009).

Grazing of Lands enrolled in the Conservation Reserve Program (CRP)

This year will be the third season of grazing on a study that evaluates limited grazing on succession and stability of CRP. CRP in the SGS region is a large component of the landscape (Fig. D3). The tall-grass



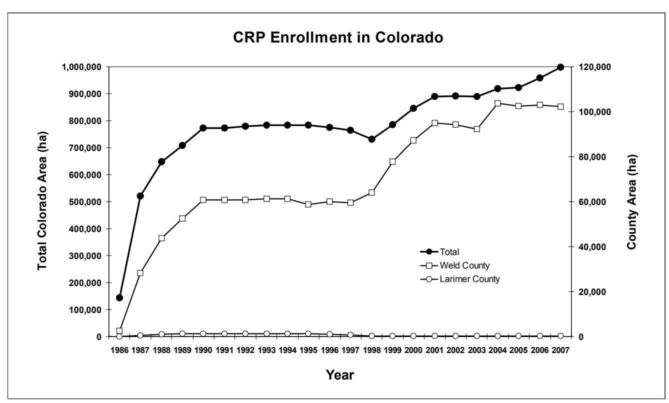


Figure D3. A large portion of the short grass ecosystem in Colorado, Kansas, Oklahoma and Texas is currently enrolled in the CRP program administered by the Farm Service Agency of the USDA. Since its inception in 1986, CRP enrollment has grown to cover about 10% of eastern Colorado, including Weld Co. in northern CO where the SGS LTER site is located.

structure of the C3 grasses planted in CRP (as opposed to the native dominant short C4 grasses like blue grama) are a source of fragmentation for native plant and wildlife populations and may allocate a larger portion of C to aboveground production than do native grasslands (Milchunas et al. 2005). In this context, grazing should reduce opportunistic "weedy" species (as it does in native communities), speed succession, and stabilize the systems through selecting for species with greater belowground allocation and potential to sequester carbon in soil. Plant community composition and productivity are sampled annually, and root biomass every fourth year.

Three years of light grazing has had no effect on ANPP, but ANPP is much greater on new CRP relative to either old CRP or native grazed shortgrass. Light grazing reduces exotic species cover in both new and old CRP. A new heavy grazing treatment was added to the design this year, after the rancher accidentally allowed extremely heavy grazing to part of the CRP fields in 2008. Soil erosion from the heavily grazed CRP treatments was excessive, and soil loss measurements were made this spring. Vegetation recovery on these new treatments will be made this August, along with those of previous treatments. Observations in June suggested remarkable recovery. This very heavy grazing represents what is often applied to CRP under drought emergency grazing due to lack of regulation enforcement by management agencies.

Given the large areas of Weld Co enrolled in CRP (102,000 ha, larger than the current SGS LTER site including the Pawnee National Grassland), its potential importance in fragmentation of habitat, and role in altering large scale C and N storage and fluxes, the SGS LTER project will increase its focus on the ecosystem-level effects of land use practices with these studies.

Legacy Effects of C and N on SGS Biogeochemistry

One of our longest term experiments examines legacy effects of C, N, and water additions to the SGS. In recent years, we assessed the influence of five carbon (C) treatments on the labile C and nitrogen (N) pools of historically N enriched plots on the SGS LTER site. We applied sawdust, sugar, lignin, sawdust + sugar, and industrial lignin +sugar to plots that had received N and water additions in the early 1970's. Previous work showed that these water and N additions altered plant species composition and enhanced rates of nutrient cycling, still apparent 25 years after cessation of treatments (Lauenroth et al. 2008). We hypothesized that 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.

Of the five current carbon treatments, sugar, sawdust and sawdust plus sugar suppressed N availability. We ceased carbon treatments after 8 years, but continued to measure N availability.

Our results suggest that highly labile forms of carbon generate strong short-term N sinks that disappear just one year following treatment. More recalcitrant forms did not maintain a strong impact on reduced N availability three years after treatment. Notwithstanding the lack of long term effect on N availability, sawdust plus sugar was the most effective combination to decrease exotic canopy cover and increase native density in the long term (Figure D4). Labile carbon had neither short- nor long-term effect on exotic species. Even though the carbon sources and concentrations applied did not help recover the dominant native species, *B. gracilis*, they were effective in increasing a native sedge species, *Carex eleocharis*. These results indicate that C addition may be a useful tool for restoring some native species in the SGS.

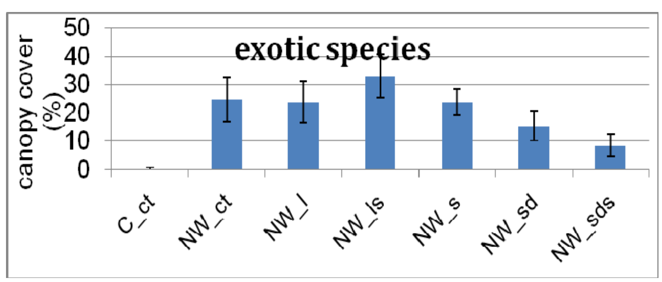


Figure D4 Comparison of plant cover of exotic species in control plots (C_ct) on native shortgrass steppe, NW_ct = nitrogen + water treatments from the 1970's, the NW_l had lignin applied, NW_ls lignin plus sugar, NW_s had sugar applied, NW_sd sawdust, and NW_sds sawdust plus sugar. Note that the carbon additions only occurred during a 5 year period, the data show effects four years after that time.

3.) Physiography

Pedology and Ecohydrological Dynamics in the Short grass Steppe

In order to identify soil hydrological processes that operate consistently, or at least predictability, across the SGS, we initiated studies across a chronosequence to evaluate pedological controls on water storage and distribution. At this scale, we can ask about the long-term distribution of water across the SGS landscape units, the range in key soil chemical properties that *reflect* the biogeochemistry and long term ecohydrological controls on water distribution, and how long term soil water dynamics along landscapes influence the ANPP, plant community composition and "hydrological limits" of the SGS.

In water limited systems such as the SGS, three broad phases of soil development are linked to the ages of the landscapes. *Phase I*, the *Aggrading or Building* with soil development from new substrates deposited by erosion or wind or as exposed sedimentary rocks. The soils are weakly developed, with some mineral transformations but little differentiation between surface and subsurface materials. *Phase II,* the *Intermediate or Equilibrium* with dominance of clay and $CaCO_3$ in the soil profiles, pedological and hydrological differentiation between surface and subsurface horizons, and retention of mobile ions like Ca, Mg, and K by ion exchange. *Phase III*, the *Degrading or Declining* where weather able primary minerals have been transformed into secondary forms. In this stage of development soils experience losses of clay and removal of $CaCO_3$. Pedological and hydrological differentiation is at a maximum and the systems capacity to store water is likely diminished. Combined, these three soil phases cover >90% of the SGS and their distributions are mapped. Understanding the role that this soil (and geo-hydrologic) template will play in constraining or amplifying ecological responses to future climate changes is a key challenge for the SGS LTER research program.

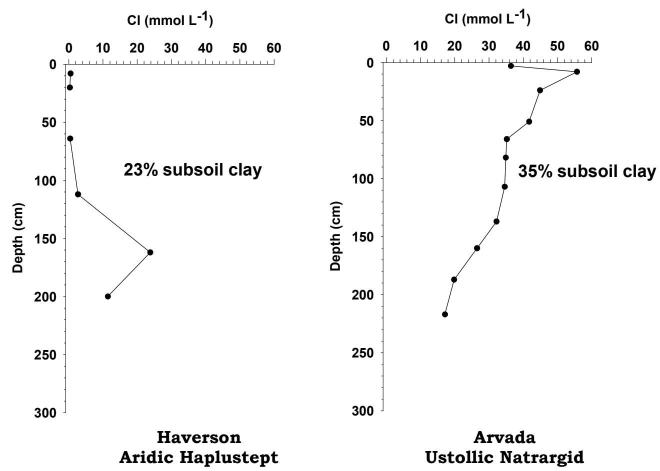


Figure P1. Chloride Mass Balance data for two Holocene soils on contrasting textures.

We sampled 15 pedons this summer across the three generalized landscapes (e.g. *Phases I, II, II*) and are conducting Chloride Mass Balance (CMB) analyses on the samples. Figure P1 shows preliminary data from 2008 demonstrating the variability within soils of similar age as a function of clay distribution in the soil profile.

Pedology and Biogeochemistry

In part supported by additional funding from NSF (PI Kelly), we are conducting studies of primary controls of biogenic silica (BSi) in soils of grass-dominated ecosystems: The overall goal of the research is to address three questions. (1) how variable are BSi soil pools, (2) do climatic controls of BSi in North American grasslands operate similarly in South African grasslands, despite differences in parent material and degree of soil development, (3) how do ecological determinants (fire and grazing) influence the size of BSi pools? This year we tested the hypothesis that parent material type (Granite vs. Basalt) will have a strong impact on the storage of above and belowground BSi in subtropical savanna grasslands.

The elemental losses and gains from soils are the result of multiple processes and compositional difference among parent materials. These processes regulate the intensity of transformations, transfers and net loss of Si from soils. Shingwedzi and Skukuza basaltic soils accumulated Si relative to the parent materials while granitic soils at both locations presented net losses relative to parent material amounts (Figure P2).

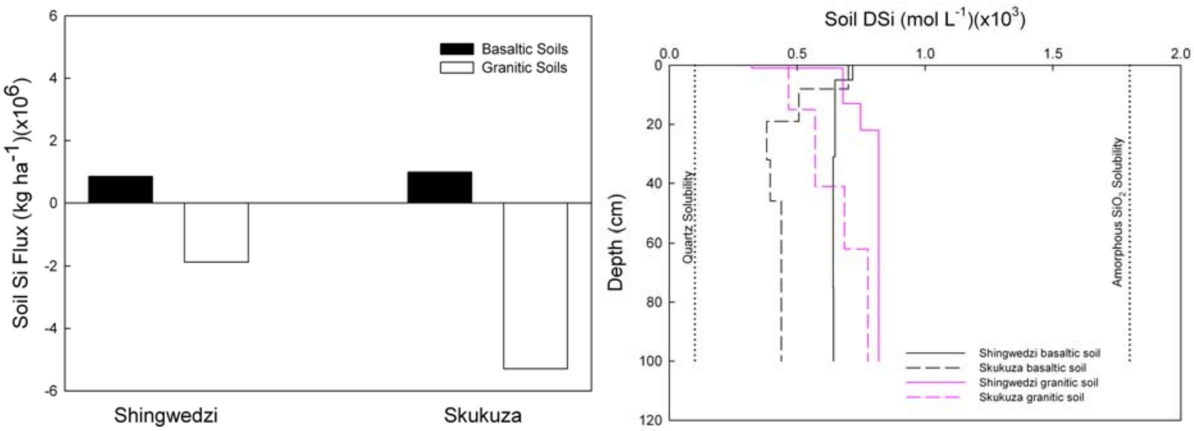


Figure P2. Soil Si flux (kg ha^{-1})(x10^{6}) for basaltic and granitic soils at Shingwedzi and Skukuza sites. Calculations were based on soil depths of 100 cm. (left). Dissolved SiO_2 (mol L^{-1}) as a function of depth to 100 cm for basaltic and granitic soils at Shingwedzi and Skukuza sites.

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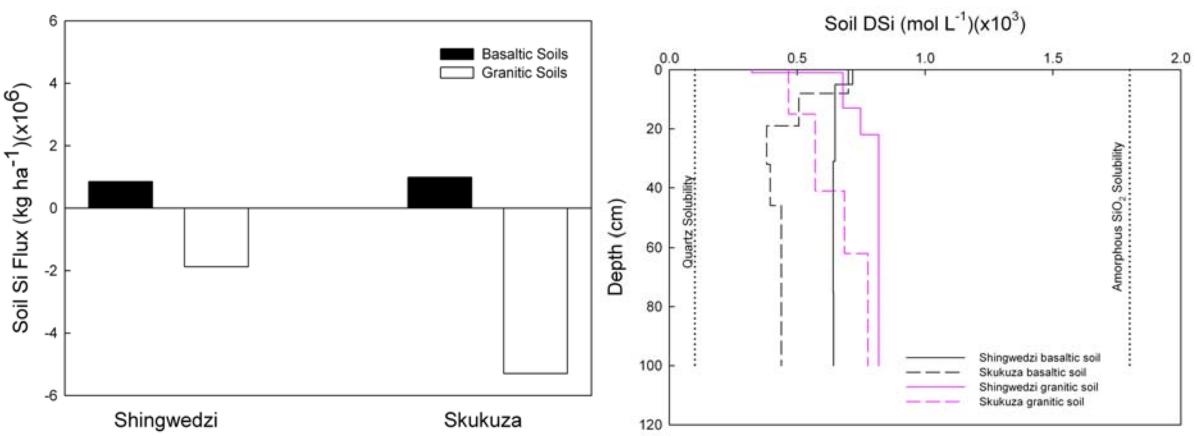

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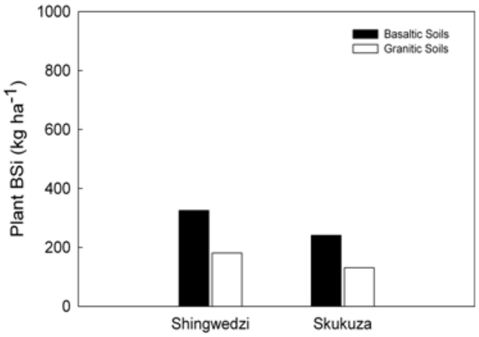
In general, BSi values in plants ranged from ~ 4 to 7% by weight (131-325 kg/ha) and are generally higher than those of North American grasslands (Sangster & Hodson 1986; Epstein 1999; Blecker et al. 2006). Although plant species differences can account for some of the BSi variability, precipitation and soil Si availability seem to predominate (Blecker et al. 2006). Regardless of site, plants overlying basaltic soils had greater BSi than plants overlying granitic soils (Figure P4).



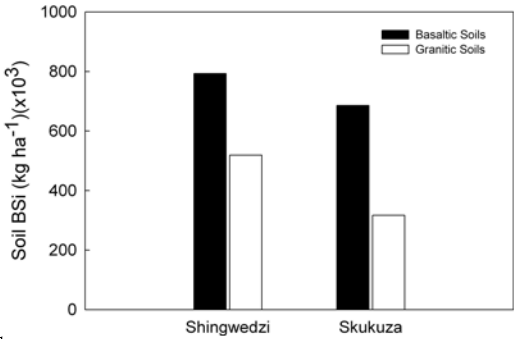


Figure P4. Plant biogenic silica (BSi) (kg ha^{-1}) for the dominant grass species on basaltic and granitic soils at Shingwedzi and Skukuza sites(left) reflect Bsi) (kg ha^{-1}, x10^3 calculations were based on soil depths of 100 cm.).

Remote Sensing of Soil Moisture

On the SGS LTER, plant spatial and temporal variability in soil moisture levels are likely to be powerful predictors of primary production. Measurement of soil moisture on the small scale is possible from soil sampling or from the deployment of TDR probes, but extrapolation to the landscape scale is difficult due to differences in soil properties (e.g., texture, topography) and because summer convective rainstorms create ephemeral “streaks” of moisture across the SGS landscape. Synthetic Aperture Radar (SAR) is a remote sensing tool that offers the capacity to visualize spatial and temporal patterns in the SGS LTER soil moisture at the landscape scale. Pixel sizes are on the order of 100m, and a single scene covers >30% of our site’s 84,000 ha. As part of our effort to extend scientific investigation to the landscape scale, we have initiated a collaboration through a subcontract with Dr. Nancy French at the Michigan Tech Research Institute. French and her colleague Laura Chavez have begun analysis of existing SAR scenes, which reveal distinct soil moisture features including those resulting from land use, soil properties, and convective rain events. The subcontract will support further analysis of these and additional scenes to provide data on soil moisture at the landscape scale. Our long-term goal is to apply the existing DayCent model at the landscape scale, and to use the SAR-based soil moisture data, coupled with soil maps, digital elevation maps, and NDVI data to generate dynamic understanding of the SGS landscape.

4.) Modeling, Synthesis and Cross-site Analyses

Modeling and Analysis

Development of broadly useful analytical and simulation model is one of the recognized strengths of the SGS LTER project, e.g. worldwide use of the DayCent ecosystem models and analyses of food web stability. Work also continues on landscape-level models to examine habitat suitability (e.g. for prairie dogs) and classical metapopulation models for prairie dogs that include local extinctions (due to plague) and recolonization. In all cases, we use data from SGS LTER measurements to parameterize and/or validate the models.

- **DayCent and Land Use on the Great Plains**

Using additional funding from an NIH grant we have begun to quantify historical changes in agricultural land use for Colorado and the Great Plains. The these studies show that the dramatic expansion of irrigated agriculture and animal feedlots from 1960 to 1980, increased gross green house gas emissions and soil N_2O emissions (>50%) due to increases in N fertilizer application, and overall reduction in soil carbon storage. The effects of recent land use changes can also be seen, particularly in the effects of lands returned to grassland from tilled agriculture or enrolled into the CRP program (Figure M1). Similar analyses have been carried out for comparison to the entire Great Plains. In particular, grasslands (pasture, CRP, return) have lower productivity, but also reduced emissions and greater C and N storage. Summed over the total area of the Great Plains, the global effects of land use are potentially large.

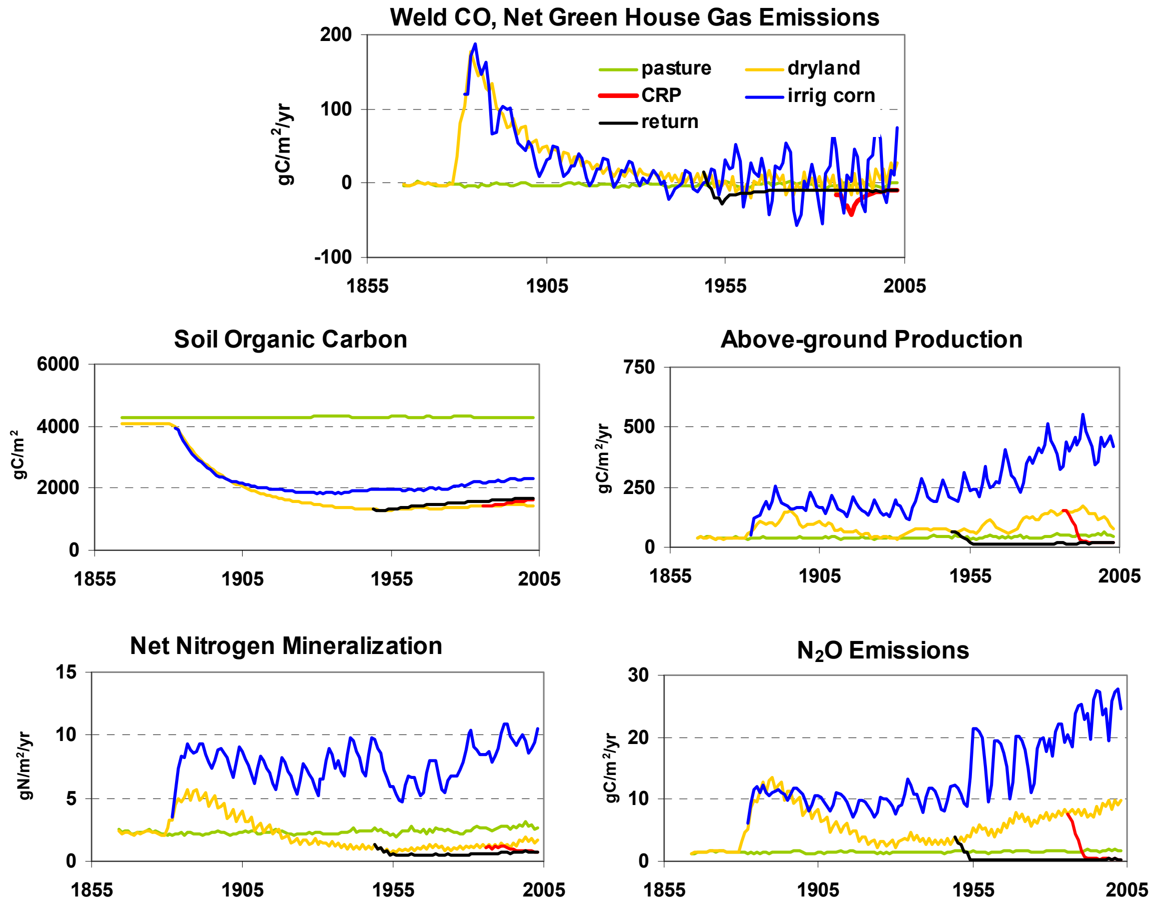


Figure M1. Results from long term DayCent runs for Weld Co., CO, showing the dramatic effects of land use changes on large-scale green house gas emissions and C and N storage.

- **Food Webs**

The Food Web model parameterized with data from the SGS and elsewhere (Hunt et al. 1987, de Ruiter et al. 1993), has been used to study basics properties of ecosystem structure, function and dynamics, as a template for cross-site comparisons, and as a means to develop simpler abstract models for theoretical studies. We elaborated on the importance of compartmentalized structure to the stability of the food webs (Rooney et al. 2008). In subsequent analyses we found that disturbances common to the SGS altered how pathways within food webs were compartmentalized (aka separated) spatially and temporally (Moore et al. 2008). These concepts align well with the current SGS LTER themes of resilience, change, and pulse dynamics. They have also led to an emerging concept of apparent complexity (Moore 2009).

- **Modeling Habitat Suitability**

Black-tailed prairie dogs may be considered a foundation species within short- and mixed-grass prairie ecosystems, but the historical extent of their habitat occupancy is not known because their populations have been reduced to a fraction of historical abundance. Understanding the habitat requirements of black-tailed prairie dogs within the SGS is critical for identifying and conserving the areas for prairie dog persistence. The objectives were to identify landscape features associated with current prairie dog occupancy and build a spatially explicit model that predicts suitable prairie dog habitat on the SGS. Long-term surveys of prairie dog towns on SGS LTER site since 1981 show that less than 1% is presently occupied by prairie dogs, with up to 3% of the area occupied at some point in time. Analyses revealed that prairie dog towns were on drier, flatter areas in close proximity to low lying drainages with relatively deeper soils and east-facing exposure. Evaluation of a logistic regression model's ability to predict habitat shows that 23% of publicly-owned land on the SGS LTER site is suitable (although not necessarily preferred habitat). This same approach will be developed for additional animal species on the SGS, especially species of conservation concern like swift fox and burrowing owls.

- **Metapopulation modeling**

When virulent pathogens invade new host populations they may alter host spatial structure to facilitate their own long-term persistence. Plague, caused by the bacterium *Y. pestis*, recently spread into the range of black-tailed prairie dogs and changed the spatial distribution of prairie dog towns from large, contiguous populations to small, isolated towns in metapopulations. We developed a stochastic patch occupancy model to compare competing hypotheses of plague transmission at the landscape level including unstructured plague spread and structured spread from recently plague-killed towns. The model was parameterized and validated using twenty years of empirical data from the SGS LTER site. The model demonstrates that metapopulation dynamics can allow prairie dog and plague persistence without the involvement of additional reservoir hosts (i.e., other resistant rodent species), and implies that pathogens can manipulate host population spatial structure to their own benefit. This analysis also suggests that prairie dogs are unlikely to disperse *Y. pestis* among towns, but alternative pathways like flea-carrying carnivores may play an important role in landscape-level plague transmission.

Cross-continental Comparison: Effect of precipitation and land use on soil carbon dynamics

We forged collaboration with scientists at the Chinese Academy of Sciences Institute of Botany, partly funded by an East Asia and Pacific Summer Institute grant. The team sampled grasslands in northeastern China (Inner Mongolia) along a precipitation gradient at sites with different land use types, and sampled soils for C and N content. We found that more labile C pools, (coarse and fine particulate organic matter) were more influenced by temperature and land use, while resistant pools (mineral associated carbon) were explained by soil texture and land use. Interestingly, land use was not a significant explanatory factor in total carbon, but rather 75% of variance could be explained by precipitation and soil texture alone.

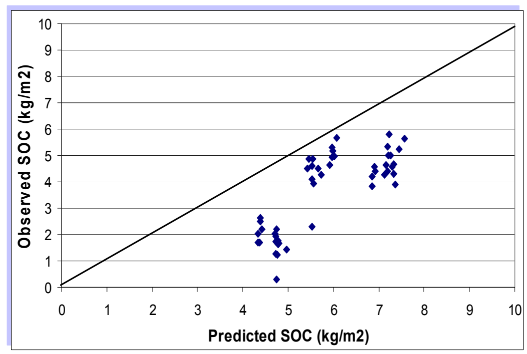


Figure M2: Soil organic carbon across a precipitation gradient in Inner Mongolia, China, compared to predicted SOC from a model based on of North American grasslands.

We compared observed total C values with those predicted by a model relating C, climate and land use for the US Great Plains (Burke et al. 1989). We found that the data had a strong and consistent bias toward lower C values than those predicted (Figure M2). Because current land use did not significantly explain total carbon variation, our data suggest that the lower values observed may result from soil carbon reductions due to long-term land use, and this long-term degradation may affect our ability to predict soil carbon dynamics in this region.

LTER cross-site N availability

Previously we reported on differential effects of large versus small herbivores on plant diversity across seven grasslands sites in North America and Europe (Bakker et al. 2006), and a recent synthesis extended this analysis to test how plant N concentrations and herbivory impact N availability in soils (Bakker et al. 2009). Herbivore effect on soil N availability was significantly related to both plant N concentration (negatively) (Fig. M3) and total soil N (positively), whereas relationships with rainfall (negative) and with grazing intensity (no effect) were not strong. We hypothesize that as plant and litter N increase herbivores may more strongly reduce N inputs from litter decomposition than they replace by recycling wastes. Our study confirms the importance of plant N concentrations as predictors of herbivore effect on N availability across grasslands, but the relationship that we found is opposite of what current theoretical models predict.

Nutrient Network (NutNet) at the SGS

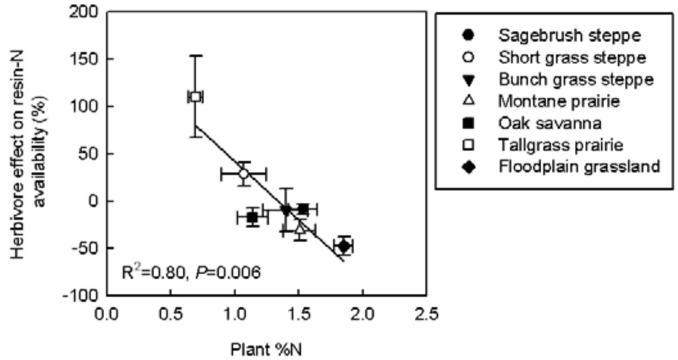


Fig. M3. The relationship between plant tissue N concentration and herbivore impact on resin-available N. The relationship is tested with linear regression analysis, with n=7 sites. Values of plant tissue N concentration are from the ungrazed plots. Data are means ± se.

NutNet examines interactive roles of bottom-up and top-down controls on structure and function of grassland systems around the world through a coordinated network of more than 50 grassland sites in 11 countries. Individual sites apply a multiple nutrient addition experiment crossed with large and small vertebrate herbivore exclosures. NutNet at the SGS allows us to examine multiple resource limitations and consumers on plant production and diversity at multiple scales: within the SGS, along a three site Great Plains precipitation gradient (SGS, mixed grass prairie, and tallgrass prairie at KNZ LTER), and across grassland systems globally. Overarching research objectives include: A.) effects of single or multiple nutrients; B.) control of herbivory, nutrients and interactions; C.) extent of spatial variation among sites.

NutNet was established at the SGS LTER during the summer of 2007, when we collected baseline data on plant and soil characteristics. In May 2008, we initiated the nutrient addition treatments and installed large herbivore exclosures. In May of this year, we added small mammal exclosures to the large herbivore treatments, so that all vertebrate herbivores are excluded from some plots. The first year of this experiment already show that nutrient additions decreased total aboveground biomass at the SGS site but increased total aboveground biomass at the tallgrass prairie (Figure M4). Moreover, significant interactions between nutrient additions and herbivore exclusion occurred at the SGS site (the dry end of the gradient), but not at the other sites. The trend in species richness in response to one year of nutrient additions was negative at the tallgrass and mixed grass prairie sites, but positive at the SGS site. Moreover, interactions between nutrient additions and herbivore exclusion were seen present at the mesic tallgrass prairie site, but not at the mixed grass or SGS sites.

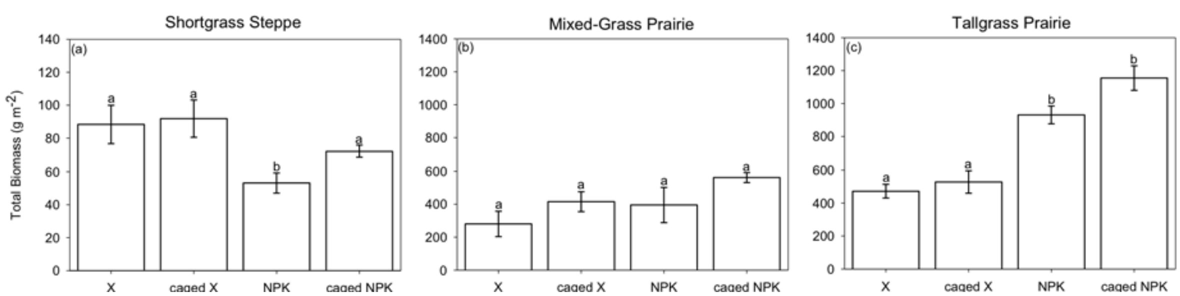


Figure M4. Total aboveground plant biomass after one year of fertilization and herbivore exclusion across a Great Plains precipitation gradient.

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B.) Information Management 2009 -Nicole Kaplan, Information Manager and Bob Flynn, GIS and IT Manager

The SGS-LTER Information Management Team (IM Team) has been focusing on improving access to information and data online. The new SGS-LTER website (http://sgslter.colostate.edu), launched January 2009, is supported by an underlying information architecture that contains more relationships between information and EML level 5 compliant metadata. The SGS-LTER website enables users to access information and data from several related sections so discovery requires fewer clicks. A new map section was implemented to serve maps that provide general site features and historical grazing treatment information, as well as customizable maps using an interactive mapping application called ArcGIS Server. We also are continuing to work closely with SGS and other LTER site researchers and graduate students on data integration and synthesis, spatial analysis, as well as implementing technology to facilitate successful collaborations.

The design and behavior of the SGS-LTER website is the result of a collaborative effort between LTER staff, researchers, and web development professionals at the Colorado State University (CSU) Creative Services. Results from ease of use studies and recommendations developed by the LTER Information Management committee were taken into consideration during the development process. Staff and researchers contribute content regularly to new sections of the website, which were designed to share current events and accomplishments and provide access to data and metadata with few mouse clicks. The new menu allows users to navigate throughout the rich content of the website and provides access to datasets and publications from various sections of the website.

The new maps section of the website contains various maps in PDF format that show physical features of all the research areas of the SGS-LTER. New PDF maps of historical grazing treatments of the Central Plains Experimental Range from 1991 to the present are available as well. The maps section also includes a new interactive mapping tool that allows users to view and print maps that they customize by making different layers visible. It uses a standard map server tool called ArcGIS Server which simplifies map development and maintenance.

We implemented tools locally to collect and analyze information about end-users downloading specific datasets as well as activated Google Analytics to report a broader overview of people and machines visiting the website. Thirty-eight individuals registered themselves on the local system, allowing SGS-LTER to track data downloads for different purposes including making an inquiry into how our online data access system works, conducting college coursework and scientific research, and applying data to GK-12 education or conservation efforts. Since April 2009, fourteen of those individuals have downloaded thirty-eight datasets, including data from long-term monitoring of primary production, meteorology and physiography at the shortgrass steppe research site.

The Google Analytics provides us with different information about our visitors, including from where and how they are visiting the site. Most of our visitors are from Colorado, but we have visitors from every state in the United States, as well as from seventy-five other countries or territories. We also can see people are visiting from over six hundred networks, including our home institution, CSU, other institutions such as the US Forest Service, National Park Service and National Science Foundation, as well as internet providers, such as Qwest and Comcast. Google Analytical tools give us a broad overview of users as well as the ability to drill down to report on more specific characteristics and behaviors of visitors.

Finally, our new system supports the documentation, generation, and harvest of metadata in the Ecological Metadata Language level 5. We currently have approximately half of our LTER datasets in the new system and 56 EML metadata packages were successfully generated and harvested to the LTER Metacat, a metadata catalog accessible by the broader ecological community to facilitate data discovery and access. Next steps for the database and website include creating more links between related information in the system and more automated methods for documenting and generating EML as today it is done manually mostly.

We are integrating long-term datasets from the SGS-LTER and other sites across the Network to support analysis of long-term records of plant production, species composition, and meteorological measurements in disturbed, grazed and burned areas to describe dynamics occurring at larger temporal and spatial scales. We also have extended existing GIS programs for analysis of SGS-LTER data, for example to study the movement of swift fox, visualize precipitation patterns across the greater region of the shortgrass steppe, model soil properties using satellite imagery, and summarize growth patterns of individual plants within a square meter over ten years.

We also implemented new technologies to support collaborations between SGS-LTER scientists, staff and students, and with our partners at other agencies and colleagues across the network. We are able to support video teleconferencing with up to four units locally and engage in large virtual meetings with the support of staff at the LTER Network office. In addition, researchers are planning and discussing progress of new experiments in a blog that we implemented with controlled access using WordPress.

After five years, we continue to participate on the design team for the Grasslands Data Integration Project (GDI). The GDI database is innovative in that it contains over one hundred thousand ANPP data from seven sites that are integrated at the level of the species and sampling unit, which facilitates fine temporal and spatial scale analysis of patterns of ANPP and species diversity. We recently proposed an ASM working group to prepare the GDI dataset for submission to Ecological Archives and to discuss opportunities for including the GDI within the cyberinfrastructure of the LTER network, such as EcoTrends. Nicole Kaplan continues to participate in Network level leadership activities, is finishing her three-year term as co-chair of the IM Committee and is participating in a governance working group for the IM committee.

C.) **Education, Outreach, and Training Activities (2008-2009)**

Research Experience for Undergraduates (REU): During the summer of 2008, two REU students worked on the SGS LTER project.

Lindsey Seastone (junior, Colorado State University) worked with Dr. Alan Knapp and graduate student Karie Cherwin on the recovery of shortgrass ecosystems from prolonged drought. She assisted in an on-going project which addressed the impacts of global climate change on the productivity and invasibility of shortgrass prairies. She successfully completed a separate project to create a plant-available soil nitrogen gradient by the addition of N-enriching and N-reducing soil amendments throughout the summer. Soil cores were collected at the end of the season for analysis. Five significantly different concentrations of plant-available nitrogen (as NH4 and NO3) were observed. These results were used to compliment the larger investigation of productivity and invasiblity of shortgrass steppe.

Lydia Yeung (sophomore, College of Wooster, Ohio) worked under the direction of Dr. Joe Von Fischer and graduate student Craig Judd conducting lab measurements that helped understand the importance of methane production across the SGS LTER landscape. On the SGS, most soils are a sink for atmospheric methane. Within these soils, methane oxidizing ("methanotrophic") bacteria consume the methane that diffuses in from the atmosphere. Although the primary energy source for SGS methanotrophs is this supply of methane from the atmosphere, there is growing evidence that methane production may occur within anoxic microzones of otherwise oxic soils, and this in situ source of methane may supplement the energy supply for SGS methanotrophs. To better understand the variation in methane production across the SGS, Ms. Yeung conducted lab assays of potential methane production on soils from sandy and clay areas and from a playa (dry at the time of sampling). Her results showed that while the playa soils had the highest rates of methane production, the sand and clay soils also produced significant amounts of methane. Thus, methane production in oxic soils likely does "fertilize" SGS methanotrophs, and increase their biomass.

During the summer of 2009 we again are supporting two REU students, partially from our prior REU supplement and partially from our research funds. Christine Byrne (junior, University of California, Berkeley) is working on a project to calibrate destructive and non-destructive sampling measurements for ANPP under the direction of Dr. William Lauenroth and graduate student Kerry Byrne. Kristina Tosic (senior, Colorado State University) is investigating the impacts of drought on productivity and invisibility of shortgrass steppe under the direction of Dr. Alan Knapp and graduate student Karie Cherwin.

Teacher Professional Development 2008-2009: The SGS-LTER has developed strong partnerships with K-12 schools in eastern plains and Front Range of northern Colorado. Our NSF funded GK-12 program Human Impacts along the Front Range of Colorado is central to these efforts. The GK-12 program by design focuses on the professional development of graduate students, but includes professional development activities of K-12 teachers. During 2007-2008 we continued the efforts reported in our 2007 annual report and we expanded our work to include efforts that are more teacher-centric in terms of professional development. The following five initiatives were under-taken in the past year:

- NSF Funded Math and Science Partnership that focuses on environmental literacy, learning progressions and culturally relevant ecology (DUE 0833755: Targeted Partnership: Culturally relevant ecology, learning progressions and environmental literacy, $12,499,000). The MSP project is a multi-LTER site (BES-LTER, KBS-LTER, SBC-LTER, SGS-LTER) and LTER Network Office initiative that evolved from the discussions that generated the LTER Decadal Plan. The project ties together the professional development conducted at the sites and conducts research on learning progressions under the themes of *Carbon*, *Water*, *Biodiversity*, and *Citizenship.* The aims of the project are to improve our understanding how students come to understand the science content within each theme, and how this information can inform teacher professional development and curriculum development.

- 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 we biogeochemistry). The project co-hosted a series of eight professional development workshops (see below – CDE MSP) and is developing a Soil Formation module and an Entomology module, both in English and Spanish.

- CSU Funded Teacher Professional Development focusing on the transfer of field experiences to the K-12 classroom (CSU WCNR $9,900). 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. For 2008-2009 the project contributed to development of the professional development workshops (see below – CDE MSP)

- 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 recruited 16 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 white students. Eight graduate students were placed in K-12 classrooms to assist teachers in instruction and project development. The teachers attended the following workshops: 1) Monitoring Invasive Species; 2) Water quality and watersheds; 3) Soil Ecology; 4) Life at the Poles; 5) Data Management; 6) Statistical Analysis; 7) GIS concepts; and 8) GoogleEarth for data display.

- Bohemian Foundation funded grant award to establish a network of K-12 schools to use GPS and handheld devises to monitor and ID invasive plant species. (Pharos Fund $22,000). Teachers were trained in the uses of the GPS units to collect data and GIS to represent and analyze results. Implementation in the classroom occurred in the Fall of 2008.

Research Assistance for Minority High School Students (RAMHSS) 2008-2009: - Funds for 2008-2009 were used to support **one** student from schools across Colorado on guided inquiry research projects at Colorado State University (CSU) and the University of Northern Colorado (UNC). Our student was recruited through the partnership we have with the Poudre School District.

Schoolyard LTER 2008-2009: The SGS Schoolyard LTER initiative is based on a partnership between the SGS-LTER, Colorado State University, The University of Northern Colorado, Greeley School District 6, and the Poudre School District. The partnership is supported by the SGS-LTER and coordinates several other grant initiatives (listed above). The projects listed below were designed by the teachers at our partner schools and the graduate students placed in the schools supported through the SGS-LTER and our GK-12 program. The teachers and students developed proposals for the work over the summer of 2008. In September 2008 we convened a panel of fellows and teachers to review and comment on the proposals. We patterned the process after the NSF peer-review system with proposals circulated prior to the panel meeting for comment, a presentation of the proposal to the panel, followed by a discussion of the proposal and reviews. Funds from the Schoolyard supplement were used to support the efforts. The reports we present below were prepared by teachers and graduate students from each school. The reports were included the annual report for the GK-12 project as well as in this report.

Rocky Mountain High School
Teachers: Carol Seemuller, Marion Annis, Dave Schwartz
Graduate Students: Miriam Galeas
For the academic year beginning August 2008, we have been maintaining existing field and lab experiments, have created new research opportunities in a research plot, and have also created new units and labs for use in the classroom. We have continued the field ecology project at Hazaleaus Natural Area, where we collect data on arthropod number and diversity, plant cover, and soil nitrogen compounds. We took this trip twice in the fall, once to set the experiment up, and once to collect data, with approximately sixty students being involved. For this project we develop new curricular materials such as 'phage-hunting' protocol, as well as a field observation presentation and exercise. We plan to disseminate our findings by have three students present at the Front Range Ecology Symposium. Another existing project that was continued was a trip to Loch Vale and a project which had the students analyze long-term climatic and deposition data in the Rocky Mountains. We are also in the process of a new project, where the goal is to create a school-yard plot where we can do research on a reconstituted grassland habitat. The goal is to be able to perform manipulations related to climate change. Curricular development so far has included a research permit exercise as well as climate change presentations and lab exercises. We hope to establish an on-line herbarium for students as well as on-line storage of long-term data. In addition to on-going and new work, a few units and labs have been created for the classroom. We have created a Biodiversity unit which includes a presentation as well as a lab on modes of speciation. A climate change presentation with a lab on climate change proxy data, and a research design presentation with a research permit and peer review activity have also been developed. We are in the beginning stages of creating a lab for an environmental science class on limiting factors and toxicity using Petri dishes and fast plants.

Greeley West High School
Teachers: Kelly Longacre
Graduate Students: David Reavill
Kelly Longacre and David Reavill have begun the study of Greeley West Park with the Animal and Plant Science Class here at Greeley West. The class first began with a unit in ecology. The following lessons included: natural resource management, consumer pollution, watersheds, wetland marsh, plant identification, soil and water quality, soil and water testing, and invasive species. The class has used goggle to map the park and divided the park into four separate ecosystems to study. They have used the GPS to identify each eco systems boundaries. The eco systems include the pond, wetland marsh, dry land grass, and irrigated grass. The group has identified the different plant species found in each ecosystem, different invasive species and has collected the first round of water and soil samples for each ecosystem.

Fossil Ridge High School
Teachers: Dana Jensen
Graduate Students: Karen Galles
During the Fall of 2008 my fellow and I worked on getting permission to develop a restoration area on the property of Fossil Ridge High School. We received permission in November and spent some time developing introductory lesson plans for a restoration project for my Environmental Science and Biology classes. This Spring I have been developing a unit that centers around the book Animal, Vegetable, Miracle by Barbara Kingsolver. This book addresses the issues proposed by the Doubly Green Revolution, sustainable agricultural solutions that minimize impact on the environment. I am planning one field trip to a local Organic farm and plan to have various speakers come to FRHS to address several questions, one being "will we still be able to consume meat in the future?" I hope to begin the restoration project in March of 2009 and have spoken to a soil scientist who is willing to help us with endeavor.

Preston Junior High School
Teachers: Mary Klass, Mary Laszlo-Hunter, Erin Panozzo, Brian Riedel
Graduate Students: Brian Heinold, Miriam Galeas

Our seventh grade student project centered around water quality comparison and macro-invertebrate identification above and below the water outlet from the wastewater treatment plant near the Environmental Learning Center in east Fort Collins. The students were trained in the classroom to perform water quality tests for the presence of ammonia, phosphate, nitrate, pH, temperature and chlorine. They also learned about the physical characteristics and pollution tolerance of macro-invertebrates likely to be found in the area. They were then taken on a field trip to the ELC where they tested the water and collected and identified the bugs. Each group of students also took a GPS reading of the location of their group. Back in the classroom, the students compared the water quality and macro-invertebrate populations above and below the water treatment plant. Our eighth grade students (270) are involved with a project on Plant Diversity, Invasive species, and Climate Change. Part I of the project was completed in October 2008, when a site assessment of the Environmental Learning Center in east Fort Collins was obtained. Student groups were assigned 1 of 4 research plots, 5 by 5 meters in measure, from which they did a percent cover of plant material, soil sampling, plant sample collection from a randomly selected 1 by 1 meter section of their plot. In addition water content measurements were obtained. Follow-up lab work included, pressing plant material, analysis of soil texture and color, and determining the pH of the soil. Additional field work will take place in April 2009.

Heath Middle School & Chappelow
Teachers: Alex Melendez, Marguax Braun, Laura Grissom
Graduate Students: Vince Rose, David Reavil
The focus of past months has been on the recycling component of the project. A field trip was taken to Centennial Middle School in Boulder to learn about an established recycling program (along with Laura Grissom of Chappelow). A recycling pre-survey was conducted to collect baseline data for later comparison. All recycling boxes have been made (lid, label, box, etc.) and distributed. Contacts have been made with the recycling company and Shriners (donating recycling service) and for the home energy audit component of the project (Xcel Energy, Vestas, etc.). Plans for future lessons with Vince have continued, the "Friends of the Earth Club" was started in December, and the field trip to the PLC in April has been planned and reserved. The following months will begin with recycling box pick-up weekly (boxes will be weighed for data collection), daily announcements on recycling statistics, hanging of posters to support the recycling program, and growth of the "Friends of the Earth Club". Contacts and plans for the home energy audit component of the project will be made.

Brentwood Middle School
Teachers: Steve Swenson, Mike Chandler, Mark Bruemmer, Libby LeFebre, Laura Weisenreder
Graduate Students: Mike Urban, Ann Wheeler
Brentwood Middle School, in Greeley, Colorado is a five person, interdisciplinary team consisting of an 6th grade earth science and social studies, 7th grade math, 6-8 grade tech arts and 8th grade physical science teacher team. Our on-going project list from last includes creating outdoor classroom/teaching sites that include: Stream table 40 feet long, rock gardens, rock patio and eating area and a 20 by 40 foot scale map of Colorado—mountains placed first. We added an archeological dig with soil horizons and soil types with ancient civilization artifacts that the student will excavate as archeologists and soil scientists in the spring, continuation of well testing on site and at another school (water depth and temperature for 6th grade and nitrates and pH for 8th grade).Construction of 3 composters and expand recycling at the school, plant test plots-germination rate vs. soil content. Our goal is teach major topic ideas from an interdisciplinary approach and have students work on the projects and use the sites over a three year term. The projects are designed to promote real world job skills and show students what a variety of careers might entail (scientist, geologist, soil scientist, hydrologist, archeologist, construction worker, chemist, environmental scientist). The projects incorporate student work whenever possible (they did not help with the big rocks-due to safety concerns).

Blevins Junior High
Teachers: Mike Viney, Christine Carpenter
Graduate Students: Ch'aska Huayhuaca, Nathan Snow, Colin Quinn

GK-12 began its presence at Blevins JH in the fall of 2008. Our primary goal for the first year of collaboration are general strengthening of the biology curriculum. As the fall semester progressed , a few unforeseen projects arose, discussed below. The semester began with Cristi Carpenter's annual butterfly project. In recent years she has found it increasingly difficult (and more expensive) to procure Monarch eggs for this project (in which 9th grade students raise the butterflies while learning about their life cycle and eventually release the insects with stickers for tracking them on their migration route back to Mexico). GK-12 funds were used to purchase the butterfly eggs and the project was successful, though the survival rate was not as high as we had hoped. Also funded by GK-12 was a field trip for 9th grade biology students to Ross Natural Area, where students met with City of Fort Collins Utilities education coordinator Marcee Camenson and others. Over the course of two days, all of the 9th graders were able to participate in two workstations, one that explored wetlands and one that focused on macroinvertebrate identification and their use as stream quality indicators. One of the unforeseen projects that has emerged is a collaboration with the Office of the President at CSU. Graduate student Zach Freeman has chosen Blevins as a pilot location for a project using a breeding colony of leopard geckos to illustrate various concepts in biology, from genetics to behavior and adaptation. This endeavor is entirely funded through the Office of the President and is essentially their project, but it involves the GK-12 fellow as an intermediary who creates modules from information provided by Zach Freeman to be presented in the classroom by Cristi Carpenter to the pre-AP biology students. Roles may shift throughout the spring semester, but it is believed that this will be an exciting and beneficial collaboration between Blevins and two units within CSU. Another role for the GK-12 fellow that has emerged is that of Science Olympiad coach for the Environmental Chemistry team. This involves a weekly hour and a half session covering topics in soil chemistry with students in the 7th and 8th grades. Science teacher Heidi Lovaas is the principle coordinator for this program. For the spring semester we are looking forward to working with Marcee Camenson in assisting in her development of an online key to macroinvertebrates. We also plan to use GK-12 funds to support "Brain Awareness Day", when Cynthia Smeranski will introduce students to neurology and brain functioning. And finally, we are still considering the best use of our funding to follow up on our goal of integrating technology into the classroom.

Union Colony School
Teachers: Cathy Hoyt, Ron Lamb, Jennifer Parrish, Todd Dolesholl
Graduat Students: Ann Wheeler, Madan Guatam
There are two focal areas for our GK 12 project; human impact and invasive species. Our goals are to 1) align curriculum with Colorado Model Content Standards in science, mathematics, reading, and writing, 2) broaden the understanding of the impact that people have on the environment, and 3) develop collaboration between middle and high school students. Students in math and science classes will learn about composting and recycling and then implement a school wide recycling program to educate staff and students about how to successfully maintain recycling within a school. Students will also take field trips to the Poudre Learning Center to identify invasive species and collect data to be analyzed in math classes. Last fall ninth grade students paired up with 6th graders to teach invasive species protocols during a field trip to the Poudre Learning Center. Students also completed river investigations and investigated ecosystems. The GK 12 fellows have designed and taught lessons, completed research, assisted with school field trips and science fair, and assisted teachers in their classrooms. Our plans for this spring are to take students to the Poudre Learning Center for an integrated science/math field trip, to collaborate with teachers from Christa McAuliffe elementary school in Greeley to write an article for science activities, to build compost bins, and start phase one of the recycling program.

Riffenburgh Elementary and Mountain View Elementary
Teachers: Merin Lewis, Mikaela Perea
Graduate Students: Casey Brown
The primary goals for this project was to educate students on what harms our earth, what the impacts are, and what we can do to help. This fall, we focused on energy consumption and waste issues that are important to our communities. Our classes typically included two parts. During the first part of each class, we gave information and answered questions from the students. For example, during Mrs. Perea's Energy

Saver's class, we started the class by discussing the differences are between renewable and nonrenewable resources and where our electricity comes from. The second part of each class included hands- on activities directly related to the information from part one. During Mrs. Bruinsma's Reduce, Reuse, Recycle class the students looked at what items were most commonly thrown away in the classroom and how Riffenburgh's waste compares to the national average. While teaching these subjects we were also able to provide students with education on eco-friendly products and how they may lessen our impacts on the earth. Out of the classroom, Riffenburgh's fifth grade participated in three days of Ecoweek at Pingree Park. We focused on a certain topic for 2 months, studying each topic in depth, but also doing projects and activities for each topic.

Riffenburgh Elementary
Teachers: Bob Faris
Graduate Students: Casey Brown, Brian Heinold
The goal for this project was to provide a format for students to participate in forming hypotheses, experiment design, data collection, analysis, and conclusion reporting. This fall, we visited three sites along the Poudre River to introduce students to different data collection methods. We specifically looked at soil, water, and animal relationships along the Poudre River. These field trips took place at three different life zones along the Poudre so we could compare data between sites. We provided the students with directed questions and activities at each site, however, the field trips also gave an excellent opportunity for students to formulate their own questions and hypotheses. The second half of the semester focused on analysis and conclusion reporting. We worked on entering our data into Microsoft excel spreadsheets. We also spent several weeks looking at scientific writing methods and how they differ from five paragraph essays. We will begin examining experimental design in January, and hope to see the culmination of our teachings at work when the students participate in the school science fair this spring.

Irish Elementary
Teachers: Marion Wells
Graduate Students: Ch'aska Huayhuaca, Nathan Snow
This year at Irish we continued to make good progress toward our goals of curriculum development in the realms of natural science, ecosystems and the environment, the scientific method and mathematics. We are also continuing our endeavor to strengthen sustainable links between the school and CSU, as well as other resources within the community. An example of a field trip attending to the latter endeavor and funded by GK-12 was "CSU Day," which took place in March and was geared toward encouraging the students to start thinking about the possibility of going to college. In a day coordinated by the GK-12 fellow, 6th grade students visited the CSU Engines Laboratory, weather station, Little Shop of Physics, and El Centro. Another trip made possible by GK-12 was a visit to the Denver Museum of Nature and Science in June for the entire 6th grade; GK-12 also funded a visit to the school by nature photographer Perry Conway. Field trips in which the fellow(s) was involved but travel funding came from other sources were: Lee Martinez Park, Bobcat Ridge Natural Area, EcoWeek and Pingree Park, Viestenz-Smith Mountain Park and Lions Park. An important collaboration between the teacher and fellows at Irish this fall semester (to be continued in the spring) is the Advanced Math and Science Program. This class meets twice a week and provides an opportunity for more advanced students to challenge themselves. Topics in the first semester focused largely on ecosystems and the environment and water use, as well as the scientific method and science fair. Activities included a field trip to Lions Park to meet with CSU ecologist Dan Auerbach, a walking tour of a local riparian ecosystem, in class experiments, and descriptive study of the nature area located behind the school (involving invasive species, tree and insect identification). Students were evaluated based on a test, work completed in field notebooks and their science fair project (not yet evaluated). Another GK-12 initiative new this fall was an after-school math help program called "Math Wizards." This program consisted of two 1.5 hour sessions/ week in which students reviewed material covered in class (multiplication and division, percents, averages, conversion, factoring, etc). The pedagogy for this class adapted to the needs of the students, so rather than lecturing, we focused on math games and outdoor activities (e.g. creating a map of the nature center and converting its dimensions from feet to meters; and a game in which students converted years to millimeters and

measured out distances analogous to geological events), as well as homework help. Evaluation for this group of students will involve a comparison of pre- and post-MAPS math test grades (to be taken in January). It is currently unclear whether Math Wizards will continue; we are brainstorming ideas for a different afterschool program to replace it. Our goals for the spring include continuing our work with the Advanced Math/Science group, this time with a focus on energy use. As the 6th grade class, with whom we have worked extensively over the past year and a half, will be moved to the junior high next school year, we plan to work to incorporate the 4th grade in GK-12 related activities. We have established a dialogue with the 4th grade teacher and one fellow accompanied them on a life zones field trip up the Big Thompson Canyon. In the coming semester we plan to purchase bilingual science books for them and hope to fund a field trip to the Denver Museum of Nature and Science at the end of the spring, much like we did for the 6th graders last year.

Dos Rios Elementary
Teachers: Lynn Perrich, Rachel Landon, Veronica Simpkins
Graduate Students: Yeni Garcia
As a team we have met regularly since summer to plan for EXTREME SCIENCE, our afterschool science program. We targeted students who normally don’t receive science and taught them how to set up a science notebook, modeled the 5E’s and developed students’ abilities to do and understand scientific inquiry. These concepts are truly works in progress meant to build upon their foundation so they can formulate good questions before they conduct a scientific investigation. Landforms were the first modules introduced to students. We noticed students comparing, classifying, organizing and making relationships between models and the landforms around them. On our trip to Bellview Fish Hatcheries, students experienced the river, observed landforms around them, measured water velocity, and made connections from the classroom to the real world. Besides field trips we held EXTREME SCIENCE after school three times a week, which consisted of 15 to 25 students per session. This program allowed students who had not been exposed to the inquiry process to investigate some of the conditions such as the ones that affect erosion and deposition. Students formed claims and then looked for evidence to support their findings. We further supported our science by taking a field trip in the Fall to the Poudre Learning Center in Greeley. We conducted various water experiments, explored pond life, and learned about the impact of humans in the area. Our students continue to use skills formulated in the class to relate to the outside world. The goal is to continue the work started on generating good questions, writing claims and enhancing the scientific process and skills.

Poudre Learning Center
Teachers: Ray Tschillard
Graduate Students: Yeni Garcia
Our main goal at the Poudre Learning Center (PLC) is establish long-term research plots at the site to assess ecological change in vegetation. The overarching research question centers on how to set up long term research opportunities for teachers and K-12 students to develop protocols, methodologies, and skills and processes to scaffold to those used at a post doc level. Since the site selection and marking has taken place, we will now move forward in the baseline data collection. Additional work at the PLC included adding specimens to the PLC herbarium, site maintenance (pulling weeds), grant writing, field trips, workshops, and curriculum development. For the herbarium, plant specimens were collected, dried, identified and labeled and added to the collection. The PLC team wrote grants to help cover the construction of a bridge on the site to link two areas and for a barn to support educational programs. We wrote a grant entitled the SciGirls en Español grant to have a summer program for Latina girls to expose them to research opportunities similar to the summer institute for teachers that was offered to the GK-12 teachers last summer. For curriculum and field trips, our main goal was for the activities at the PLC to be an integral part of the curriculum that is already in place for the school districts we service.

Cross-LTER Site Education Initiatives: The SGS-LTER site has maintained the cross-site initiatives reported last year and expanded its cross-site initiatives to include other LTER sites and share its models with them. The SGS-LTER has initiated the following partnerships, some of which have been discussed above:

- NSF GK-12 2000-present: *Human Impact Along the Front Range of Colorado* and NSF and ANS 2004-2008: *Collaborative Research: Aboveground and Belowground Community Responses to Climate Changes in Arctic Tundra*. For the summers of 2007 and 2008 we supported 3 K-12 teachers that have worked at the SGS-LTER to work at the ARC-LTER site at Toolik Lake, AK.

- 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 by K-12 teachers in the classroom. Conducted a two-week professional development workshop in June 2009.

- NSF MSP 2008-present: *Culturally relevant ecology, environmental literacy, and learning progressions.* (BES-LTER, KBS-LTER, LNO-LTER, SBC-LTER, SGS-LTER). Designed to study the learning progression that students from different backgrounds undergo to understand of ecological concepts (see description presented above).

- USDA AFRI SPE 2009-present: Summer Soil Institute: Addressing Environmental Challenges with Current and Emerging Techniques from Microbial to Global Scales (SGS-LTER, MCD-LTER). Designed to develop modules with field and laboratory protocols that focus on soil chemistry, soil physics, and soil biology for undergraduate and graduate instruction and for K-12 teachers in K-12 classrooms. The project will conduct a two-week professional development institute in June 2010.

D. Project Management

Project management at SGS LTER has changed since the beginning of the last round of proposal review and funding in 2008, with a goal to develop a structure designed to open lines of communication and integration for the SGS LTER while we emerge from probation with NSF. This management structure was developed in consultation with Dr. Terry Chapin from the Univ. of Alaska and Bonanza Creek LTER (BNZ), who visited Fort Collins Oct 6-8 2008 to directly discuss organization of an LTER project and steps taken at BNZ when that site as on probation with NSF.

Central management of the project is by an Executive Committee (SGS-EC), currently with Dr. Michael Antolin (MFA) as lead PI and Drs. Justin Derner, Eugene Kelly, and John Moore, that works with the PI both to manage project logistics and to map out the general scientific directions of the project. Justin Derner is a scientist with the USDA ARS Rangeland Resource Research Unit (ARS-RRU) stationed in Cheyenne WY, and represents our partners with the Central Plains Experimental Range where the majority of SGS LTER research has been conducted. Because our members have been dispersed across several institutions, we implemented video-conferencing. During the last year, membership of the SGS-EC changed, with the stepping aside of Drs. Ingrid Burke, William Lauenroth and Jack Morgan (also ARS-RRU). Drs. Burke and Lauenroth, who have moved to the University of Wyoming, continue to work as with the SGS LTER under a subcontract with the SGS LTER. Dr. Justin Derner replaced Dr. Jack Morgan on the SGS-EC, and Dr. Morgan continues as a scientist working with the project.

We also formed a Science Steering Group, comprised of active scientists on the project, who provide specific guidance about the scientific enterprise (e.g. design and implementation of research projects, data analyses, interpretation of results). Members of the Steering Committee are expected to attend monthly Science Meetings (second Wednesday of each month), with additional ad hoc meetings for more specific topics (also on Wednesdays, since this time is on the calendar for members). All of the SGS LTER community is invited to meetings, meeting provide videoconferencing for all remotely-based members, and meeting notes are made available to the community on our web page.

This structure specifically moves us away from LTER V (2002-2008), where we had formed individual research sub-groups with a single co-PI leading each of the groups. Although in theory this structure would have created hierarchical management that would have tightened coordination of research, the actual result was loss of communication and integration across the entre project.

Currently the Science Steering Group includes: David Augustine (USDA-ARS), Indy Burke (UWyo), Rich Conant (CSU), Justin Derner (USDA-ARS), Niall Hanan (CSU), Gene Kelly (CSU), Julia Klein (CSU), Alan Knapp (CSU), Bill Lauenroth (UWyo), Daniel Milchunas (CSU), John Moore (CSU), Jack Morgan (USDA-ARS), Paul Stapp (Cal State Fullerton), Joe von Fischer (CSU), Matt Wallenstein (CSU).

We also continue to recruit new scientists to the project from within the CSU community, especially for those who can coordinate new research ideas and measurements with existing long-term projects. In particular, we are aware of the low gender diversity of the SGS LTER group, and have been encouraging several female plant ecologists and a social scientist to join the project. Scientists who are not currently on the Science Steering Group but who are active researchers include Amy Angert (CSU), Cynthia Brown (CSU), Heidi Steltzer (now Fort Lewis College in Durango, CO), Dana Blumenthal (USDA-ARS), Catherine Keske (CSU, Agricultural Economics)

To coordinate the logistical aspects of the SGS LTER project (e.g. timing of field work, long-term climate monitoring, inputting metadata to the Information management system) also schedules monthly “Nut’N’Bolts” meetings. Again, members of the SGS LTER project are invited to attend the meetings, but all staff are expected to attend Nuts'N'Bolts meetings, we provide videoconferencing for all remotely-based members, and meeting notes are made available to the community on our web page.

To integrate our science and maintain project cohesiveness, we also organize a semi-annual SGS All Scientists Symposium, which was held this year on January 15, 2009 at the new SGS Research and Interpretation Center at the filed site 8 miles north of Nunn, CO. A report of that meeting can be viewed on our new web site at http://www.sgslter.colostate.edu/reports.aspx.

The SGS LTER currently has three subcontracts for research activities with collaborators at other universities:

1.) University of Wyoming (Dr. Indy Burke and William Lauenroth): continued work on long term ANPP and plant phenology, long-term biogeochemistry and climate manipulation experiments.

2.) University of Colorado, Boulder (Dr. Noah Feier): pyrosequencing of soil microbial communities from sites know to differ on the SGS, and for measuring responses to experimental precipitation pulses.

3.) Michigan Tech University (Dr. Nancy French): using ground penetrating radar from satellites to measure large-scale differences in soil moisture across the SGS.