SGS LTER Annual Report 2010: Activities and Findings

During this year we submitted the renewal proposal for the remaining four years of SGS-LTER VI. This proposal was declined for funding, and after considerable negotiation with NSF the project will continue with three years' funding and then be terminated.

Nonetheless, the central research objective of the SGS LTER project continues: to forecast potential impact of global climate change on the shortgrass steppe ecosystem in the western region of Great Plains of the United States. This system has exhibited remarkable persistence in a semi-arid temperate environment characterized by high inter- and intra-annual variability in precipitation. The area is characterized by low-stature C4 grasses (blue grama, buffalograss) that have experienced a long evolutionary history of grazing by large herbivores (e.g. historically by bison, now primarily as rangeland for cattle). In addition to the dominant grasses, other plants like prickly pear and scarlet globemallow well-adapted to smaller-scale disturbances caused by animals like prairie dogs. In eastern Colorado, the SGS ecosystem 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 completing measurement and data archiving from long-term experiments, we engage in scientific initiatives important to our region, and continue cross-LTER and global synthetic analyses of data.

We will continue to work to forecast responses of the SGS ecosystem to global change, defined in the broadest sense to encompass multiple factors including climate, human land use, and invasive species. Our conceptual framework incorporates 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 the relative importance of determinants of SGS ecosystem structure and function (Figure 1).

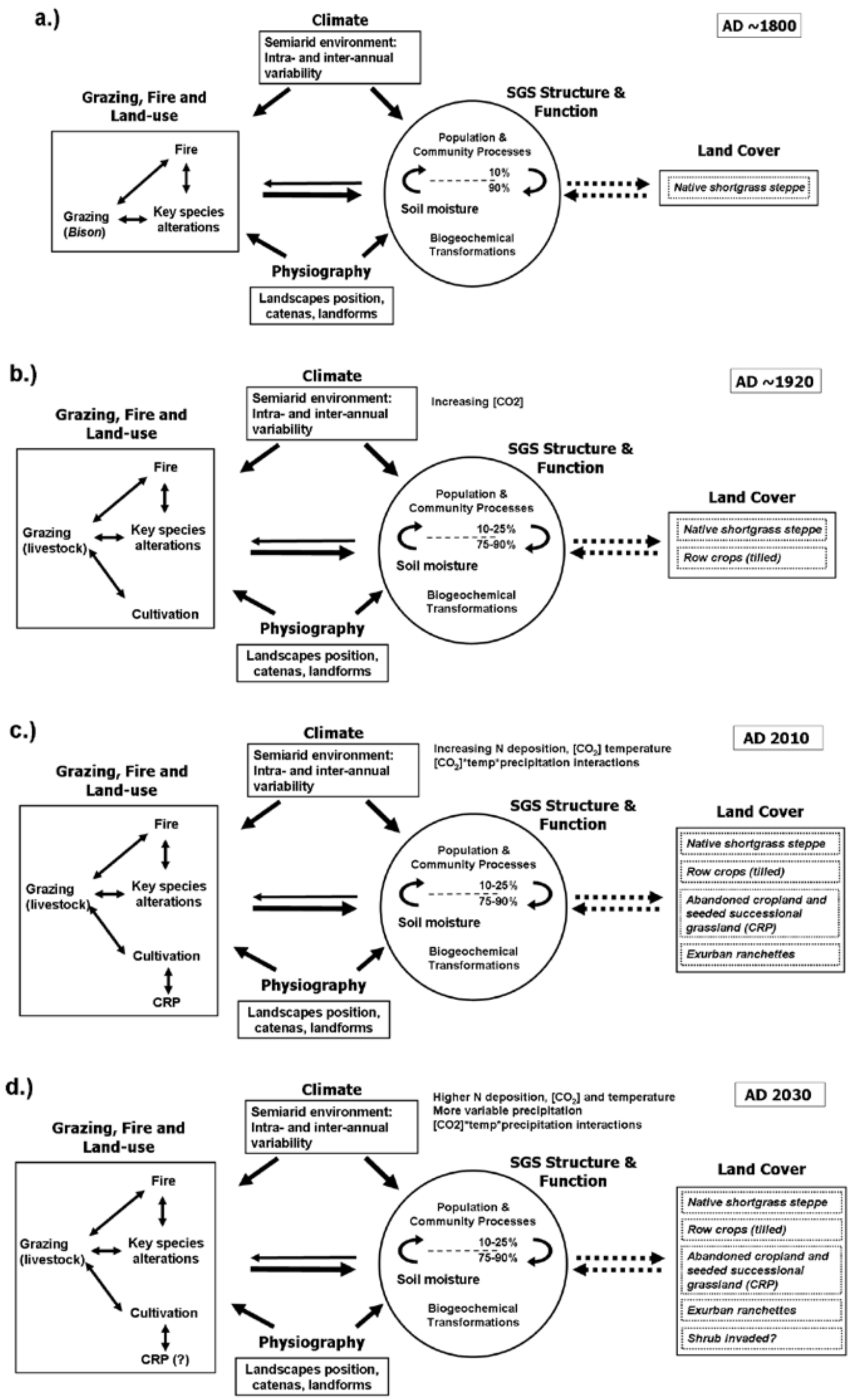
Key to this work is a long-term and ongoing collaboration with scientists with the USDA-ARS Central Plains Experimental Range (CPER), the site where most SGS LTER work has been conducted. An additional memorandum of understanding with the Pawnee National Grassland in Weld Co. extends the SGS LTER site 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 19), C) Education, Outreach and Training Activities (page 21), and D) Project Management (page 30).

A. Research Activities

During the last year, we produced 39 papers in refereed journals (published or in press), one PhD dissertations, and many abstracts from regional, national and international meetings. Most of our publications involved multiple authors, reflecting the collaborative spirit and interdisciplinary nature of the SGS-LTER research program.

Key research progress for 2008-2009 is organized to reflect the primary determinants of the SGS (Figure 1). Thus, we group research under the broad headings of 1.) Climate, 2.) Grazing, Fire and Land-use, and 3.) Physiography. Although determinants are identified separately, in most cases key interactions between 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 in previous years, in 2010 we again reassessed sampling frequency and intensity of some long-term projects.

Figure 1. A temporal view of three primary determinants of structure and function of the SGS ecosystem: i.) Climate, ii.) Grazing, fire and land- use, and iii.) Physiography. a.) Before settlement for agriculture during the 1800s, the SGS ecosystem was dominated by herbivores (bison, prairie dogs), acting as primary disturbances and controlling plant species diversity by grazing of prevalent C4 grasses blue grama and buffalo grass. The frequency that 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 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, 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.



1.) <u>Climate</u>

Climate is the major determinant of SGS structure and function, and examination of long term data suggests 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).

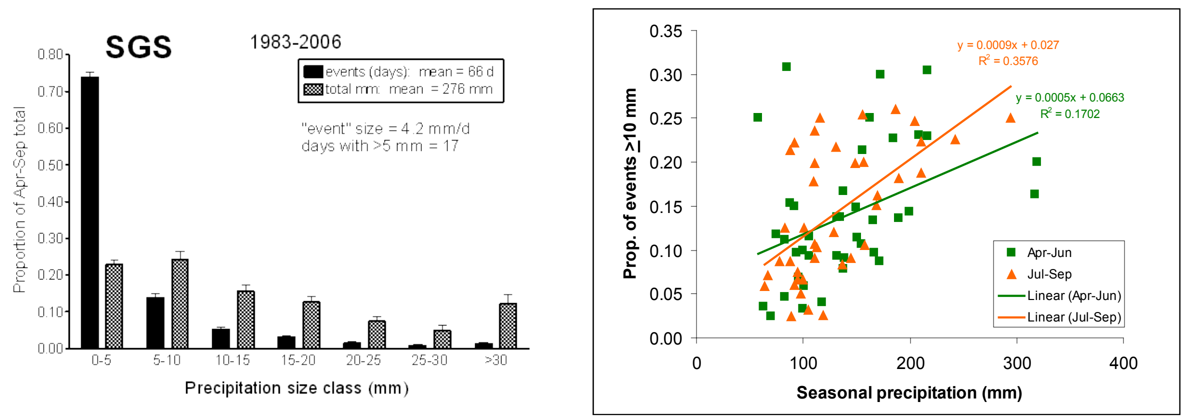


Figure C1. The distribution of rainfall events and the relationship between large (wetting) events related to annual precipitation. The SGS LTER climate is predominantly comprised of small rainfall events, but wet years have more large events.

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

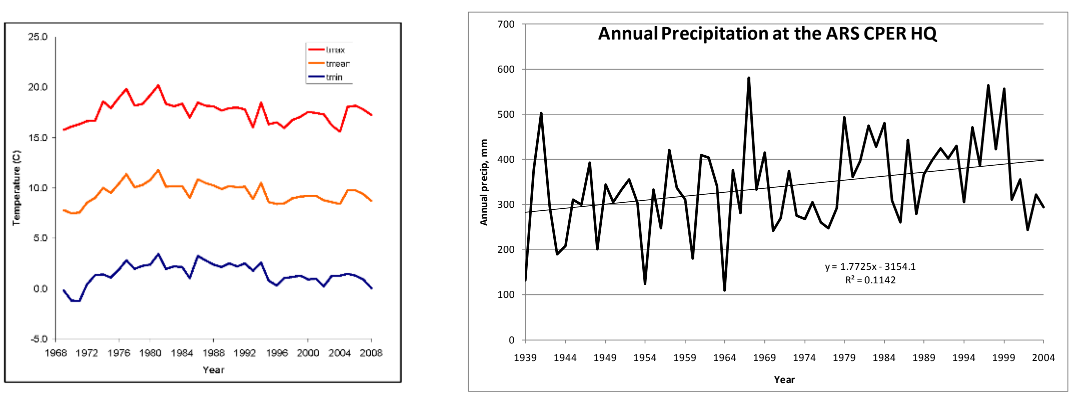


Figure C2. Annual temperature and precipitation records from the USDA ARS CPER HQ. Precipitation readings have been taken manually each day at 08:00 hr since 1939. Regression is significant (p<0.006). Wetting events are defined as >5 mm-d^{-1}. The long-term average is 340mm (+/- 115 mm SD), maximum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

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 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 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).

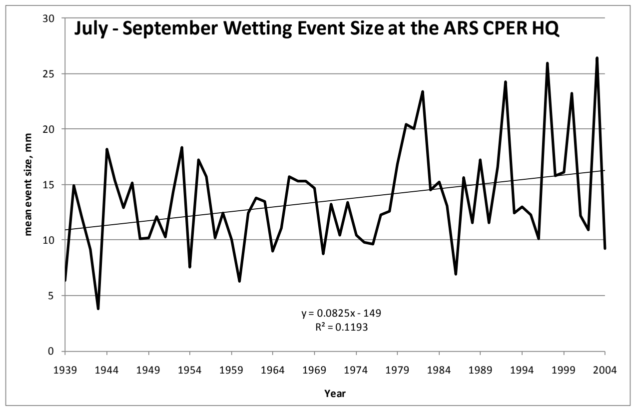


Figure C3: Size of wetting events during July, August and September has increased at the SGS LTER ($p<0.005$). The size of all events did not change over this time period ($p>0.1$), nor did the amount of water delivered by small events ($p>0.4$).

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

Our primary data set recording annual ANPP over 26 years on sites that vary in landscape position, soil texture, and species composition show that 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 sites (Swale), ANPP has ranged from 15 to 185 g-m^{-2} and

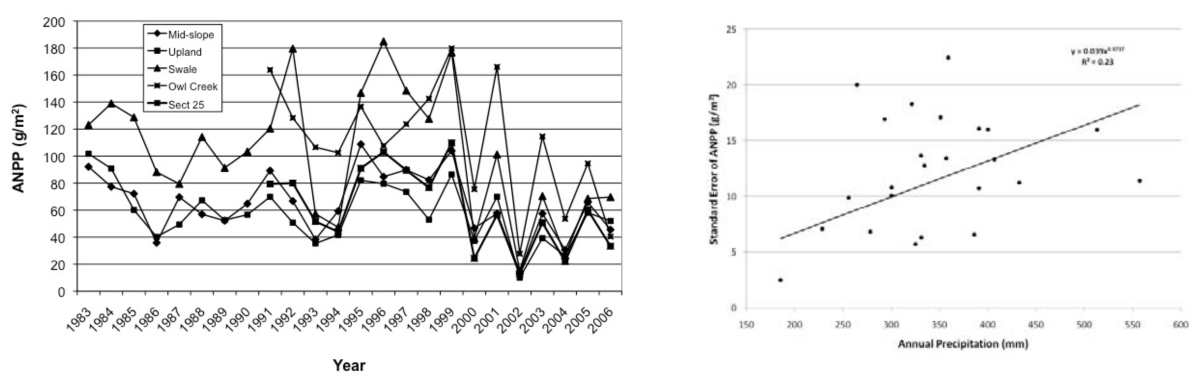


Figure C4. Annual ANPP for 5 locations over 24 years on the SGS LTER site (left), and the relationship between the variability of annual ANPP (standard error) and the annual precipitation for 5 locations.

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 is positively related to ANPP and to the variability of ANPP among sites (Figure C4). The greatest variability was recorded in wet years and 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 preceding the 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%

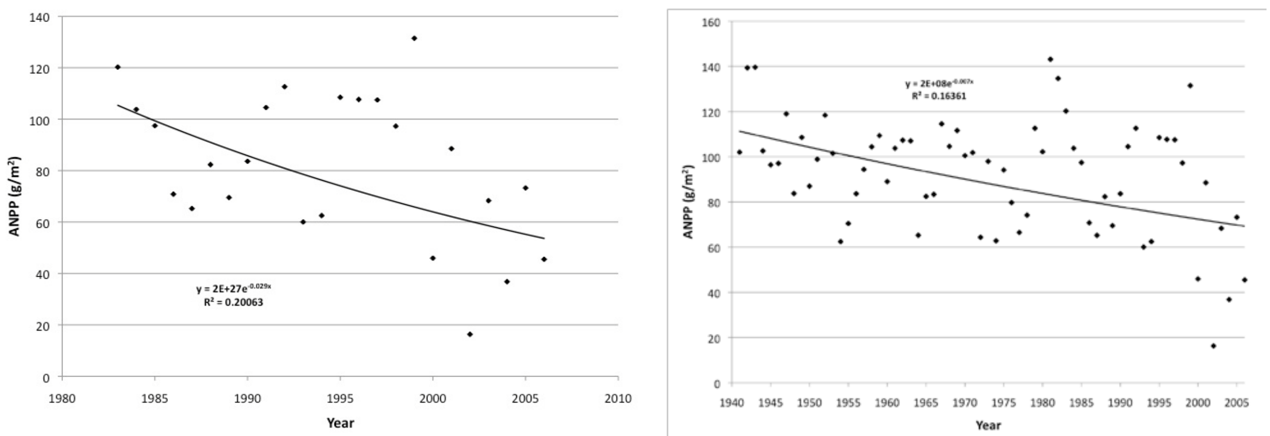


Figure C5. Declining trend in average ANPP over 24 years on the SGS LTER site (left) and over 68 years including data from the Central Plains Experimental Range (USDA-ARS) (right).

of the variability in the data. However, a 68-year graph suggests that much of 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, data for 2009, which includes one of the wettest recorded May-June rainfall periods on record, show that 2009 has close to the highest ANPP on record.

Testing Peak Biomass Measurements of ANPP

Measuring ANPP by clipping of vegetation is time-consuming, and methods based on peak biomass at a single point during the growing season may be biased. Thus we (graduate student Kerry Byrne) tested alternative methods for estimating ANPP, as supplements to the traditional method of peak biomass harvest. We assessed accuracy and precision of non-destructive techniques by harvesting biomass in 15 $0.5m^2$ plots and compared estimates from the same plots to: 1) canopy interception using a point frame; 2) green cover estimated from a digital camera; and 3) reflectance measurements using a hand-held radiometer.

For the point frame method, we used a 62 cm x 80 cm quadrat with 50 equally spaced points inside. We passed a pin perpendicular to the soil surface through each of the points and recorded the number of times the pin intercepted green vegetation. “Green hits” were separated into three functional groups: graminoids, forbs, and dwarf-shrubs. Second, we used digital images of each plot from ~1.25 m elevation taken with a First Growth digital canopy camera (Decagon Devices 2004). The instrument calculates percent green cover based on the ratio of green pixels to total pixels. Finally, we measured reflectance with a Skye Instruments SKR 1850 4-Channel Light Sensor and calculated a greenness index. Immediately after non-destructive sampling we clipped green and recent dead material from plots. We separated biomass by functional group and dried each in paper bags for ≥ 48 hours at 55 °C before being weighed.

Using the point frame method, we found that the total number of vegetation hits a statistically significant ($p<0.05$) explanatory variable that only explained 20% of the variability in biomass (Figure C6A). Including average height of first intercept and the number of hits by functional group greatly improved the model's explanatory power. No individual parameters were significant at either site, but explanatory power of the models increased to 91%. Green cover estimated by the digital canopy camera was a poor predictor (non-significant) of biomass. The model explained 10% of the variability in biomass (Figure C6B). The radiometer data explained 38% of the variability in biomass and greenness was a significant explanatory variable ($p<0.05$, Figure C6C).

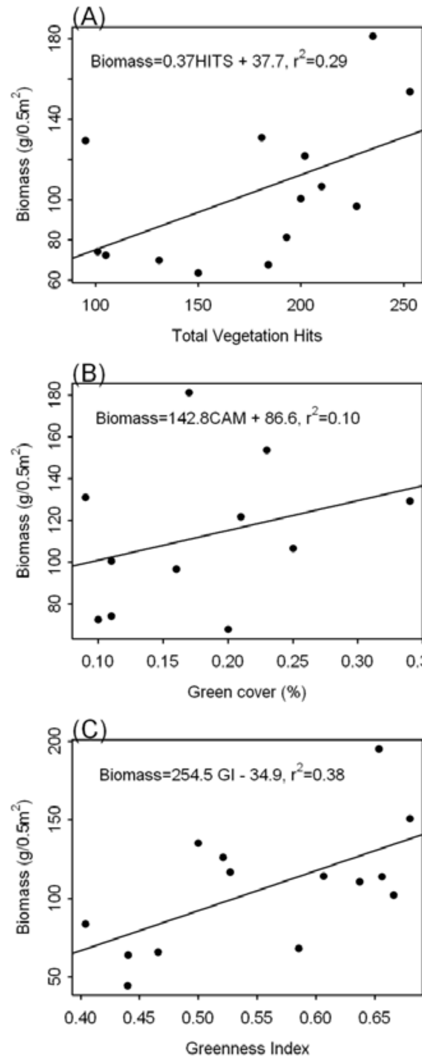


Fig. 1 (A) Relationship between total vegetation hits and biomass (r^2= 0.29, P<0.05); (B) relationship between percent green cover and biomass (r^2= 0.10, N.S.); and (C) relationship between a greenness index and biomass (r^2= 0.38, P<0.05) on the shortgrass steppe.

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

In 2001, two Skye 1800 2-channel radiometers (red 630 nm and near-infrared 862.5 nm) were established on the SGS LTER. Reflected radiation is recorded every minute, averaged hourly and stored. Complementary to both data sources is an onsite daily record of temperature, precipitation, wind speed, and various other meteorological measurements, which will be used to develop the models. Additionally, the radiometric site has soil moisture probes at 3 soil depths. Analysis of the species specific data is focused on *Bouteloua gracilis* which contributes the majority of the leaf area and aboveground net primary production in the ecosystem (Lauenroth et al. 2008).

With changing seasonal precipitation and the potential for higher temperatures, we may expect alterations in plant phenology and the length of the growing season. In water-controlled ecosystems, the effects of temperature and photoperiod on phenology are modulated by the availability of soil water. This research directly addresses whether e question of the individual and joint effects of water availability and temperature on the onset of spring. In 1995, the SGS LTER began collection of phenological data at 2-week intervals for 10 individuals of each of 22 plant species. 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 compare the beginning and end of growing seasons (SOS and EOS) by fitting double logistic curves to the NDVI data (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 that were associated with soil moisture pulses. It was predictable that the dry year (2002) would have a shorter growing season, but surprising by the 30% shorter time than in an average year (2005). The effect of precipitation on phenology was greater than the effect of grazing, but the two effects interact. The ungrazed treatments showed a difference of 34 days between 2002 and 2005 and the grazed treatments differed by 60 days between 2002 and 2005. In years with average precipitation, growth began before the last frost in spring, whereas in dry years growth was only after the last frost. The difference between the minimum and maximum values of GI, an index of ANPP, was approximately 4 times greater in an average year than in a dry year (Figure C6). Pulses in GI were closely associated with soil water pulses in 2002 and 2005.

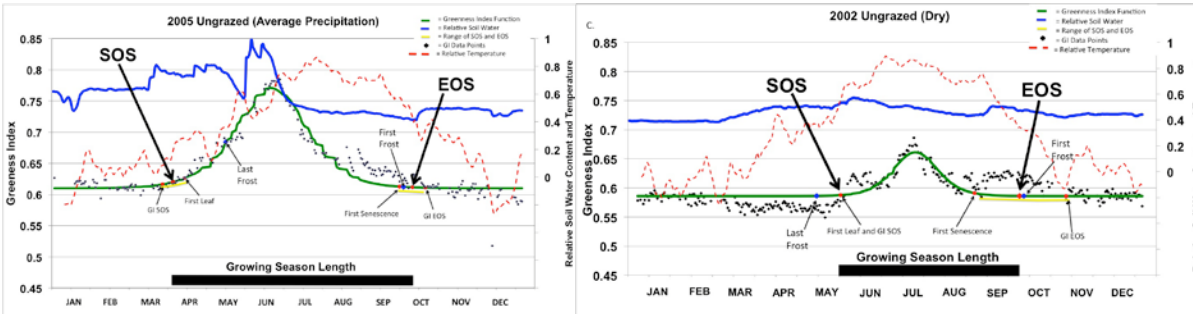


Figure C6. NDVI data for and ungrazed plot in 2005 (an average precipitation year) and 2002 (a dry year) showing the greenness index (GI) data points, double logistic curve, estimated start of season (SOS), end of season (EOS), temperature and soil water data are expressed as relative water content. First and last frost are indicated along the logistic curve. SOS=Start of season, EOS=End of season. GI=Greenness Index.

Manipulating the Rainfall Regime: Short-term Pulse Experiment

Given the key role that variability in precipitation and moisture pulses play at the SGS LTER, long-term precipitation experiments and short-term experiments demonstrate mechanistically how timing and amount of precipitation affects ecosystem processes on the SGS. We continue a long-term rainout shelter experiment that is now in its 12th season.

During the growing season, plants and microbes on the SGS experience periods of water stress, alleviated by periodic rains 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” was 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 seek to develop mechanistic understanding of processes contributing to net CO_2 exchange and better predictions of responses to climate change. Climate models predict that hydrologic cycles will accelerate, leading to more rapid evaporation, more intense precipitation events, and longer intervening dry periods.

We applied three treatments: control, a 1cm rainfall event, and a 2cm event, with each treatment replicated five times in 2m x 2m plots. The site has 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 on July 13 when we added water. 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 additions of 15N-labeled ammonium and nitrate. 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 at the plot scale.

Blue grama grass is the dominant grass on the SGS, and its response to precipitation pulses drives net primary production (Figure C8). Photosynthetic rates on the control and +1cm plots fell over time, but were elevated in +2cm plots. Leaf-level physiological measures reveal that blue grama responses depend upon stomatal controls that keep water use efficiency nearly constant. Leaf-level gas exchange measures are consistent with patterns in observed growth.

Soil fauna create a rich, interactive food web with potential to alter the standing biomass of bacteria and fungi, and therefore structure the temporal patterns of nutrient release and CO2 efflux from the soil. Illustrated here (Figure C9) are dynamics of 4 of the 19 measured groups of soil biota, many of whom showed statistically significant temporal trends. A major synthesis activity of the pulse experiment will be to couple our existing food web and biogeochemical models to better understand how food web stability alters carbon and nutrient dynamics in SGS soils.

The pulse addition induced an immediate 3x to 4x increase in ecosystem respiration that decayed to 2x baseline within 18 hours (figure C10). The size of this initial response was independent of precipitation volume, but the return to baseline between 1 and 7 days post pulse was faster for the smaller +1cm event. The response of methane uptake depended on if high soil moisture conditions slowed diffusion into the soil, or if water stress limited the activity of methane-consuming bacteria.

The pulse induced a burst of mineralization (leading to high ammonium on day 1), followed by a nitrification pulse (leading to high nitrate on day 2).

The activities of enzymes that degrade C-rich substrates increased following the pulse, peaking after two days, then declined below non-pulsed control plots (Figure C11). In contrast, peptidase activities peaked after day four. Our results challenge the paradigm that enzyme activities in soils are relatively stable, but rather indicate that a large non-stabilized pool of enzymes is subject to rapid turnover and is responsive to moisture pulses. These data also suggest that microbial production of enzymes degrading different substrates are decoupled through time, perhaps in response to changing stoichiometric needs and nutrient availability through time.

We anticipate several additional data sets from this experiment:

• 15N isotope pool dilution for dynamics and fates of labeled ammonium and nitrate.

• Pyrosequencing for deep phylogenetic analysis of changes in microbial community composition. Preliminary results from Dr. Noah Fieier indicate the use of a newly-developed pyrosequencing technique to characterize soil bacterial communities from a relatively large number of samples in unprecedented detail. Analyses averaged 1006 sequences per sample for 132 samples analyzed. Results from a 'cross-SGS' surveys revealed large variation in the structure of soil bacterial communities across the landscape, with

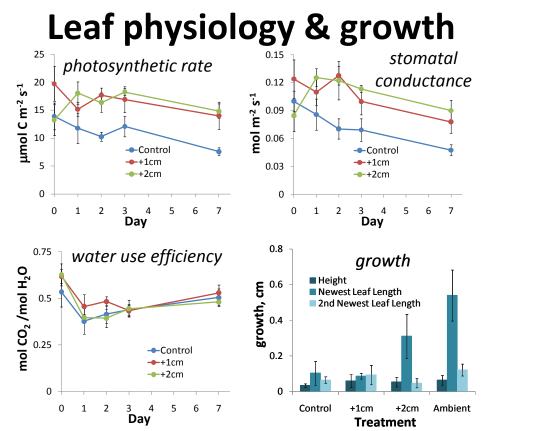


Figure C8. Water use efficiency of the dominant grass blue grama remains constant over a range of experimentally-induce water levels

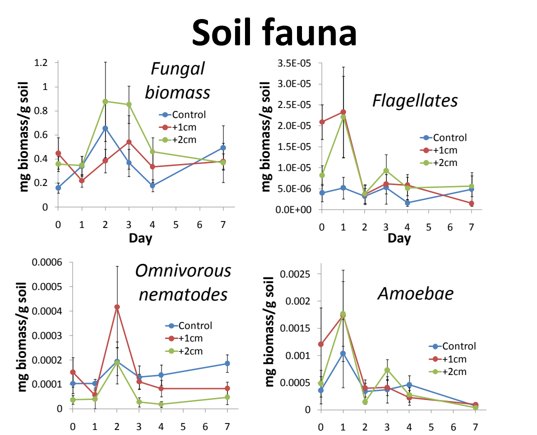


Figure C9. Water pulses increased led to brief but linked changes in soil microfauna.

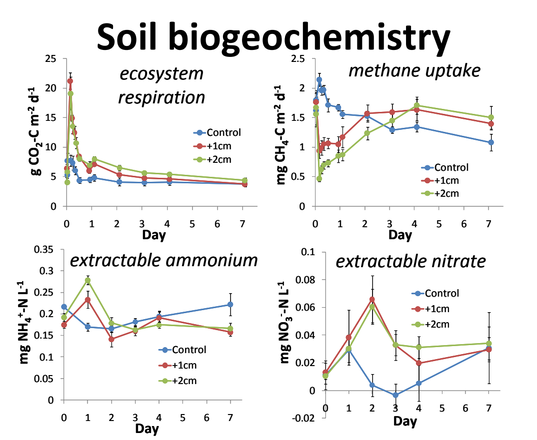


Figure C10. Ecosystem-level responses to water pulses were short-lived.

much of this variability predictable from changes in soil pH. Shifts in bacterial community composition related to soil depths consistently across the profiles examined. For reasons that are not yet clear, soils in or near prairie dog colonies harbored very distinct bacterial communities. Results from the pulse experiment revealed no short-term (1-2 days) or longer-term (>1 week) effects of rainfall events of varying intensity on either soil bacterial community composition or diversity. These results suggest that soil bacterial communities are remarkably resistant to perturbations caused by rainfall events.

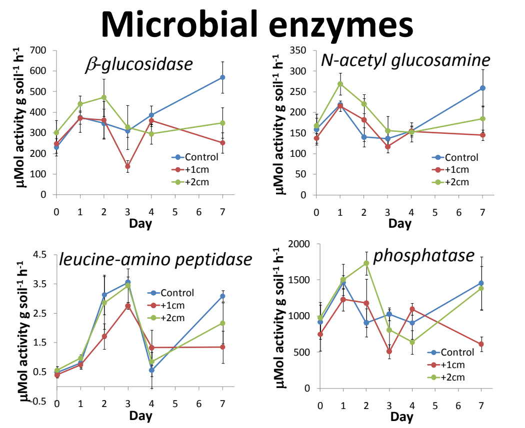


Figure C1. Induction of microbial enzymes varied relative to addition of water pulses

• Plot-scale measures of NDVI, for finer temporal observation of green-up and senescence.

• Concomitant eddy covariance tower measures of season-long ecosystem C fluxes, and responses to natural precipitation events .

2.) Grazing, Fire 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.

SGS-LTER research on plant community disturbance 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, Hartly et al. 2009), 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. Dr. David Augustine and David Augustine 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. 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 include 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).

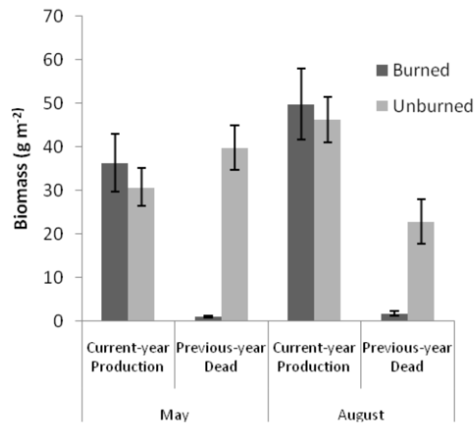


Figure D1. Comparison of burned and unburned patches on the SGS LTER/CPER. Burning reduced standing dead biomass but not ANPP in the first year.

Additional prescribed patch burns were implemented on the three replicate pastures in October, 2009. The effects of the burns on cattle grazing continued in the 2010 field season (May and June), with measurements of cattle grazing distribution via GPS collars, plant species composition and structure, and densities of grasshoppers and grassland bird species.

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. Mountain plover is a species of concern in Colorado and has recently been proposed for listing under the Endangered Species. The patch burn experiment continues to document strong selection for burned sites by nesting mountain plovers. In addition, Dr. David Augustine ((USDA-ARA) monitors nesting plover responses to wildfires, prescribed fires, prairie dog colonies, and grassland sites throughout the Pawnee National Grassland and Central Plains Experimental Range. Detailed measures of vegetation structure are made at nest sites and at randomly-selected grassland sites with varying levels of cattle grazing to identify key features of mountain plover nesting habitat.

In a study examining the direct effects of prescribed fire on ecosystem processes, Drs. Derner, Augustine von Fischer and Blumenthal continued measurements of soil moisture, temperature and inorganic N dynamics, ANPP, and plant N content in relation to precipitation pulses in burned and unburned sites. Microbial community composition of soils from this study is currently under analysis, and will be linked to burn effects on soil moisture, temperature and N cycling. Part of this study is led by Dr. Joe von Fischer's graduate student, Paul Brewer.

Long-term Monitoring of Small Mammals and Carnivores

In 2009-10, we continued our long-term monitoring studies of mammals, their resources and habitat. These datasets were updated, checked and revised and are available on the SGSLTER website. USFS staff also continued to monitor changes in the status of prairie dog colonies on the PNG, which is also done on CPER. Following a peak in rabbit numbers in 2006-07, populations of black-tailed jackrabbits and cottontails have fallen. However, kangaroo rats have continued to be the most abundant rodents since the 2000-02 drought. The total area of active colonies continued to increase following the widespread plague outbreak in 2005-06, but colonies on the CPER have not recovered and are still very small.

In 2009, we modified our protocols for estimating density of grasshoppers, following methods used by ARS scientists. This included changing to smaller sampling hoops, increasing the number of hoops per site, and adding sampling to estimate community composition. We continue to estimate grasshopper densities on plots associated with the ARS patch-burn study. Graduate student Sean Hauser (Cal-State

Fullerton) is using these methods to examine the effects of prairie-dog and livestock grazing on diet and abundance of grasshoppers.

We continued to sample vegetation structure, plant species composition and small mammal abundance as part of a long-term study of the effects of native (prairie dog) and non-native grazing on rodent populations. Sampling of small mammals now is conducted every third year (2006, 2009), with the next sampling to be conducted in 2012.

We examined responses of vegetation and small mammals to chemical removal of prickly pear cactus, a project that began in 2008. Herbicide was sprayed in June 2009 and we estimated densities of kangaroo rats pre- and post-spray, with kangaroo rats slightly more abundant on controls. We also sampled vegetation and habitat characteristics on treated and control sites. REU student Leslie Herington is continuing sampling on this project in summer 2010.

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).

Long-term studies of prairie dog effects on the CPER examine the effects of a plague epizootic that removed prairie dogs from most colonies during 2006-2007. In July, 2009, Drs. Augustine and Derner completed measures of vegetation cover and composition at >1000 permanently marked plots on plague-affected colonies. During July – August, 2009, we also measured cattle distribution (GPS collars) in relation to these prairie dog colonies, and during the 2009 growing season we measured cattle weight gains in pastures with and without the plague-affected colonies.

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. D2). The tall-grass 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 wildlifepopulations 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.

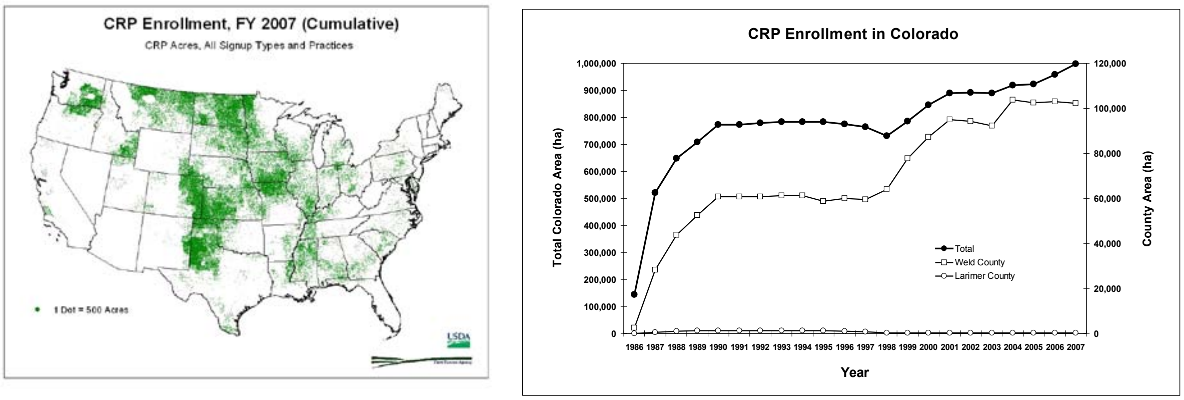


Figure D2. A large portion of the short grass ecosystem in Colorado, Kansas, Oklahoma and Texas is currently enrolled in the CRP program administered by the Farm Service Agency of the USDA. Since its inception in 1986, CRP enrollment has grown to cover about 10% of eastern Colorado, including Weld Co. in northern CO where the SGS LTER site is located.

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.

Progress in 2009-2010 includes installation of root-ingrowth donuts for estimating belowground net primary production (BNPP) (Milchunas 2009) on the CRP study site in all treatments. This has two important implications for testing our conceptual framework. First, we directly test that grazing of early seral stage revegetated grassland will speed succession by selecting for grazing-tolerant perennial short grasses that allocate relatively more belowground than aboveground. We hypothesize this will lead to greater stability system in the face of fluctuating annual climate cycles and drought, and sequester greater amounts of soil carbon compared to annual and invasive forbes. The belowground (root) production data will be used with currently collected aboveground primary production data, and community species composition data to test the hypotheses. Second, unbiased estimates of BNPP based on soil coring that measure response to grazing are extremely rare in the global literature, and represent a gap in our understanding of the SGS. This adds a new dimension to our ongoing collection of

Figure D3 A view along the boundary line of former sorghum (left) and wheat (right) crop strips that simultaneously occupied the field a year prior to seeding to a native grass mix under the CRP. The tall light colored grass on the sorghum side is western wheatgrass, and darker colored kochia (exotic annual weed) dominates the wheat side.

aboveground plant community structure and production data in response to grazing by large and small herbivores and the persistence of SGS to interactions between a fluctuating environment and shifts in grazing pressures.

Finally, this CRP study has already resulted in a potential breakthrough in restoration of native grasses in this drought-prone environment, where re-seeding failures are common. An allelopathic cover-crop (sorghum) in contrast to replanting wheat crops prior to grass seeding had dramatic effects on successful weed control and establishment of native grasses (Figure D3). Collection of plant community structure and productivity, and soil erosion and carbon data continues on this and adjacent old CRP and native SGS fields.

3.) Physiography

Pedology and Ecohydrological Dynamics in the Short grass Steppe

Based on extensive studies of soil development we understand the following about the Pedology of the SGS. In water limited systems areas such as the SGS, there are three broad phases of soil development that are linked to the landscape ages identified above (Kelly et al In Prep). *Phase I*, the *Aggrading or Building Stages* in which soil development begins with a new substrate deposited by Alluvial and Aeolian processes or exposed sedimentary rocks. The soils are generally weakly developed and although mineral transformations have occurred the soil is genetically simple (little horizon differentiation with surface and subsurface materials being pedogenically and hydrologically similar. *Phase II,* the *Intermediate or Equilibrium Stage* during which the formation and clay and $CaCO_3$ become dominate features in the soil profiles and there is significant pedological and hydrological differentiation between surface and subsurface horizons. Clay particles that form as secondary minerals within the soil also retain relatively mobile ions like Ca, Mg, and K by ion exchange. *Phase III*, the *Degrading or Declining Stage* in which the most weatherable primary minerals have been transformed into secondary forms. In this stage of development soils experience losses of clay (relative to soils in the intermediate stages of development) and complete removal of $CaCO_3$ is apparent. Pedological and hydrological differentiation is at a maximum and the systems capacity to store water is likely diminished.

Work Completed: This year we completed our pedon sampling across a chronosequence (Jenny, 1940, 1980) to evaluate pedological and landscape scale controls on water storage and distribution. With the help (and support) of the USDA-NRCS we sampled and additional 12 pedons this summer across the three generalized landscapes (e.g. *Phases I, II, II*) and have hired a student supported by non-LTER funds (Martin and Kelly are co-advising Mr Shawn Salley) to complete the Chloride Mass Balance (CMB) analyses on the samples collected in 2009 and 2010.

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.

Impact of Precipitation Seasonality and Pulses on NEE for the Short Grass Steppe

Daily net ecosystem carbon dioxide (CO_2) exchange (NEE) was measured on SGS vegetation at the USDA Central Plains Experimental Range in northeastern Colorado from 2001-2003. Over 95% of the growing season (April-October) carbon uptake occurred during the April-June time period for the normal precipitation years 2001 and 2003 (Figure M1a), while carbon uptake during the same April-June time period was low in the dry year 2002 with more carbon uptake occurring during July-October. July-October daytime NEE (NEE_d) was negative for all three years, with the highest net carbon uptake occurring in 2003. Nighttime growing season net carbon loss (Figure M1b) was lowest during the non-growing season and similar for the May-June and July-October time periods.

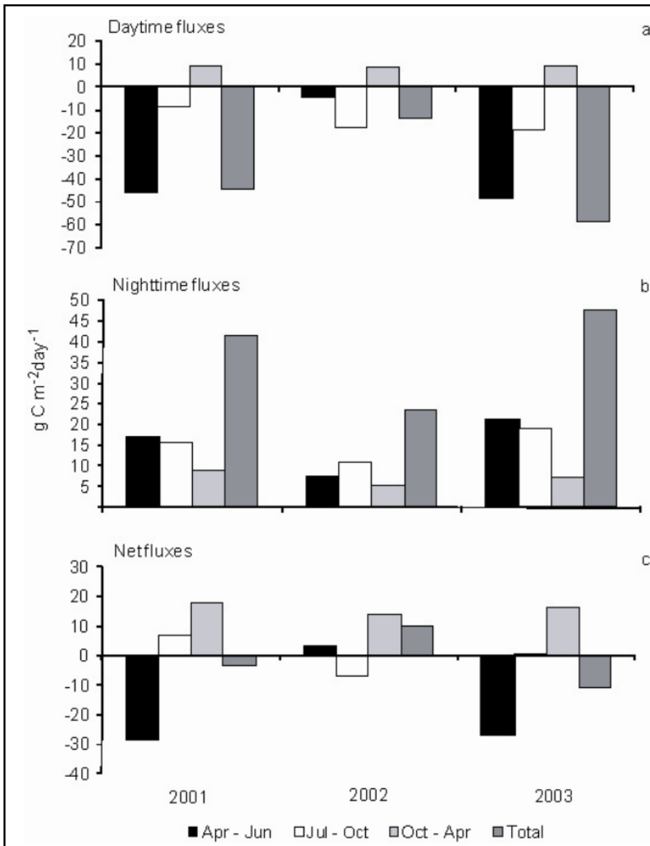


Figure M1. Annual April-June, July-September, and October-April NEE for daytime fluxes (a), nighttime fluxes (b), and net fluxes (c), for 2001, 2002, and 2003. The convention for fluxes is that negative values indicate C uptake, positive values indicate C efflux.

Large precipitation events (> 10.0 mm day^{-1}) promoted carbon uptake, while small precipitation events (< 5.0 mm day^{-1}) enhanced heterotrophic respiration and resulted in a net loss of carbon from the system. Large precipitation events enhanced carbon uptake because they increased soil water content which promotes plant photosynthesis. Live aboveground plant biomass and soil water content were the major variables that controled daytime net CO_2 uptake (NEE_d) and nighttime respiration losses (NEE_n). NEE_d and NEE_n were positively correlated to the live plant biomass. These results suggest that the major factor controlling growing season nighttime respiration flux is the amount of carbon fixed via photosynthesis during the day. Heterotrophic soil respiration is greatly enhanced for one to two days following rainfall events. A regression model was developed to simulate daytime and nighttime net carbon exchange as a function of soil water and temperature and live plant biomass ($r^2 = 0.76$).

Nutrient Network (NutNet) at the SGS

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 is exploring the fundamental role of top down versus bottom up controls on grassland structure and function. The goal is to examine relative strength of these controls and their interactive effects at a range of scales. In terms of global change the experiment aims to mimic anthropogenic alterations of nutrient inputs to ecosystems along with the type and intensity of consumers. The collaborative NutNet Great Plains gradient allows examination of top down versus bottom up responses on different North American grassland systems and whether responses are generalizable at the regional scale. We are also addressing important questions lie the potential for shrub encroachment under nutrient enhancement across a precipitation gradient. The greatest strengths of NutNet are both the number and the geographic breadth of sites that are conducting this common experiment. Findings from NutNet will be applicable to grassland systems as they undergo the stresses imposed by global changes, including altered nutrients, consumers and climatic conditions.

NutNet was established at the SGS LTER during the summer of 2007, when we collected baseline data on plant and soil characteristics, with nutrient additions beginning in 2008. the yearly cycle of fieldwork includes erecting grazing exclosures in May and removing them in September (since they can act as snow fences); adding nitrogen, phosphorus and potassium, in all factoral combinations, to the plots in May; and monitoring species composition, aboveground biomass and light availability.

We collaborate with Dr. Melinda Smith, from Yale University and the Konza Prairie LTER site, and her PhD student, Kimberly LaPierre, who is a NSF Graduate Research Fellow. LaPierre is examining nutrient and grazing effects on grasslands across the tallgrass prairie in Konza, the mixed grass prairie in western Kansas, and the shortgrass site in Colorado. In addition to the measurements at the SGS, LaPierre is examing soil nutrients, plant traits, plant and invertebrate tissue chemistry, and invertebrate diversity and density. In spring 2010, La Pierre and Laura Dev, a PhD student from Colorado State University, conducted a shrub encroachment study across the Great Plains gradient by transplanting shrub seeds and seedlings into a subset of the NutNet sites. In early summer 2010, we joined a litter decomposition experiment, led by Dr. Sarah Hobbie from the University of Minnesota. Graduate student Dev has been exploring PhD work that would examine how precipitation seasonality (growing season versus non growing season precipitation regimes) alters the effect of nutrients and grazing on community structure. In August 2009, SGS scientist Cynthia Brown participated in network-level synthesis activities and manuscript preparation at the first NutNet meeting at Oregon State University.

Literature Cited

Antolin, M.F., L.T. Savage, and R.J. Eisen. 2006. Landscape features influence genetic structure of black-tailed prairie dogs (*Cynomys ludovicianus*). *Lands. Ecol.* 21: 867–875

Augustine, D.J. M.R. Matchett, T.P. Toombs, J.F. Cully Jr., T.L. Johnson, J.G. Sidle. 2008. Spatiotemporal dynamics of black-tailed prairie dog colonies affected by plague. *Lands. Ecol.* 23:255–267.

Augustine, D. J., and D. G. Milchunas. 2009. Effects of prescribed burning on grazed shortgrass steppe. Rangeland Ecology and Management 62:89-97.

Bakker, E. S., M. E. Ritchie, H. Olff, D. G. Milchunas, and J. M. H. Knops. 2006. Herbivore impact on grassland plant diversity depends on habitat productivity and herbivore size. Ecology Letters 9:780-788.

Bakker, E. S., J. M. H. Knops, D. G. Milchunas, M. E. Ritchie, and H. Olff. 2009. Grazer impact on nitrogen cycling along a grassland productivity gradient. Oikos (accepted).

Blecker, S.W., R.L. McCulley, O.A. Chadwick, and E.F. Kelly. 2006. Silica biogeochemistry in grassland ecosystems of the Great Plains. *Global Biogeochemical Cycles*. 20: GB3023

Burke IC, Yonker CM, Parton WJ, Cole CV, Flach K, Schimel DS. 1989. Texture, climate, and cultivation effects on soil organic-matter content in US grassland soils. *Soil Science Society of America Journal* 53: 800-805.

Burke, I.C., A.R. Mosier, P.B. Hook, D.G. Milchunas, J.E. Barrett, M.A. Vinton, R.L. McCulley, J.P. Kaye, R.A. Gill, H.E. Epstein, R.H. Kelly, W.J. Parton, C.M. Yonker, P. Low, and W.K. Lauenroth. 2008. Soil Organic Matter and Nutrient Dynamics of Shortgrass Steppe Ecosystems. Pages 306-341 *in* W.K. Lauenroth and I.C Burke, eds. Ecology of the Shortgrass Steppe: A Long Term Perspective. Oxford Univ. Press, N.Y.

Burke IC, Yonker CM, Parton WJ, Cole CV, Flach K, Schimel DS. 1989. Texture, climate, and cultivation effects on soil organic-matter content in US grassland soils. *Soil Science Society of America Journal* 53: 800-805.

Coffin, D.P., W.K. Lauenroth, and I.C. Burke. 1996. Recovery of vegetation in a semiarid grassland 53 years after disturbance. *Ecological Applications*. **6**:2 538 - 555

De Ruiter, P.C., J.A. van Veen, J.C. Moore, L. Brussared, and H.W. Hunt. 1993. Calculation of nitrogen mineralization in soil foodwebs. *Plant and Soil*. **157**: 263 - 273

Epstein, H.E., I.C. Burke, and W.K. Lauenroth. 1999. Response of the shortgrass steppe to changes in rainfall seasonality. *Ecosystems*. **2**: 139 - 150

Fischer A. l994a. A simple model for the temporal variations of NDVI at regional scale over agricultural countries. Validation with ground radiometric measurements. *Int. J. Remote Sensing,* 15, 1421-1446.

Fischer A. l994a. A simple model for the temporal variations of NDVI at regional scale over agricultural countries. Validation with ground radiometric measurements. *Int. J. Remote Sensing,* 15, 1421-1446.

FischerA. (1994b) A model for the seasonal variations of vegetation indices in coarse resolution data and its inversion to extract crop parameters. *Remote Sensing Environ.* 48, 220--230.

Guenther, D.A. and J.K. Detling. 2003. Observations of cattle use of prairie dog towns. *Journal of Range Management*. **56**: 410 - 417

Hart, R.H. 2008. Land-use history on the shortgrass steppe. Pages 55-69 *in* W.K. Lauenroth and I.C Burke, eds. Ecology of the Shortgrass Steppe: A Long Term Perspective. Oxford Univ. Press, N.Y.

Hartley LM, Detling JK, Savage L. 2009. Introduced plague lessens the effects of an herbivorous rodent on grassland vegetation. J. Applied Ecology 46: 861-869.

Heisler-White, J.L., J.M. Blair, E.F. Kelly, K. Harmoney and A.K. Knapp. In press. Contingent productivity responses to more extreme rainfall regimes across a grassland biome. *Global Change Biology*, *in press.*

Hunt, H.W., D.C. Coleman, E.R. Ingham, E.T. Elliott, J.C. Moore, S.L. Rose, C.P.P. Reid, and C.R. Morley. 1987. The detrital food web in a shortgrass prairie. *Biological Fertility of Soils*. **3**: 57 - 68

Ihori, T., I.C. Burke, W.K. Lauenroth, and D.P. Coffin. 1995. Effects of cultivation and abandonment on soil organic matter in northeastern Colorado. *Soil Science Society of America Journal*. **59**: 1112 – 1119.

Knapp, A. K., C. Beier, D. D. Briske, A. T. Classen, Y. Luo, M. Reichstein, M. D. Smith, S. D. Smith, J. E. Bell, P. A. Fay, J. L Heisler, S. W. Leavitt, R. Sherry, B. Smith and E. Weng. 2008. Consequences of more extreme precipitation regimes for terrestrial ecosystems. *Bioscience* **58**:811-821.

Lauenroth, W.K., D.G. Milchunas, O.E. Sala, I.C. Burke, and J.A. Morgan. 2008. Net primary production in the shortgrass steppe. Pages 270-305 *in* W.K. Lauenroth and I.C. Burke, eds. Ecology of the Shortgrass Steppe: A Long Term Perspective. Oxford Univ. Press, NY.

Lauenroth, W. K. and O. E. Sala. 1992. Long-term forage production of North American shortgrass steppe. *Ecological Applications*. **2**: 397 - 403

McClintock, B., T., G. C. White, M. F. Antolin and D. W. Tripp. 2009. Estimating abundance using mark-resight when sampling is with replacement or the number of marked individuals is unknown. *Biometrics*. **65**:237 246

Milchunas, D. G. 2009. Estimating root production: comparison of 11 methods in shortgrass steppe and review of biases. Ecosystems 12:1381-1402.

Milchunas, D.G., A.R. Mosier, J.A. Morgan, D. LeCain, J.Y. King,and J. A. Nelson. 2005. Root production and tissue quality in a shortgrass steppe exposed to elevated CO2: Using a New Ingrowth Method. *Plant Soil*. **268**: 111 – 122

Milchunas, D.G., W.J. Parton, D.S. Bigelow, and D.S. Schimal. 1988. Factors influencing ammonia volatilization from urea in soils of the shortgrass steppe. *Journal of Atmospheric Chemistry*. **6**: 323 - 340

Milchunas, D.G., W.K. Lauenroth, I.C. Burke, and J. Detling. 2008. Effects of grazing on vegetation. Pages 389-446 *in* W.K. Lauenroth and I.C. Burke eds. Ecology of the Shortgrass Steppe: A Long Term Perspective. Oxford Univ. Press, NY.

Moore, J.C., J. Sipes, A.A. Whittemore-Olson, H.W. Hunt, D.W. Wall, P.C. de Ruiter, and D.C. Coleman. 2008. Trophic structure and nutrient dynamics of the belowground food web within the rhizosphere of the shortgrass steppe. Pages 248-269 *in* W.K. Lauenroth and I.C. Burke. Ecology of the Shortgrass Steppe: A Long Term Perspective. Oxford Univ. Press, NY.

Morgan, J.A., D.G. Milchunas, D.R. LeCain, M.S. West, and A. Mosier. 2007. Carbon dioxide enrichment alters plant community structure and accelerates shrub growth in the shortgrass steppe. Proc. Nat. Acad. Sci 104(37):14724-14729.

Peters, D.P.C., W.K. Lauenroth, and I.C. Burke. 2008. The role of disturbances in shortgrass steppe community and ecosystem dynamics. Pages 84-118 *in* W.K. Lauenroth and I.C. Burke. Ecology of the Shortgrass Steppe: A Long Term Perspective. Oxford Univ. Press, NY.

Rooney, N., K. McCann and J.C. Moore. 2008. A landscape theory for food web architecture. *Ecol. Lett.*. **11**: 867 – 881

Sala, O.E., W.K. Lauenroth, and W.J. Parton. 1992. Long-term soil water dynamics in the shortgrass steppe. *Ecology*. **73**:4 1175 - 1181

Sala, O.E. and W.K. Lauenroth. 1985. Root profiles and the ecological effect of light rain showers in arid and semiarid regions. *American Midland Naturalist*. **114**: 406 - 408

Sala et al 1988 THERE ARE TWO CHOICES IN SGS LTER DATA BASE:

Sala, O.E., M.E. Biondini, and W.K.Lauenroth. 1988. Bias in estimates of primary production: an analytical solution. *Ecological Modeling*. **44**: 43 – 55

Sala, O.E., W.J. Parton, L.A. Joyce, and W.K. Lauenroth. 1988. Primary production of the central grassland region of the United States: Spatial pattern and major controls. *Ecology*. **69**: 40 - 45

Sangster, A.G., and M.J. Hodson. 1986. Some factors influencing silica transport and deposition in grasses. Am J Botany 73(5):642-643

Scheintaub, M., Derner, J.D., Kelly, E.F. and A.K. Knapp. 2009. Response of the Shortgrass Steppe to fire. *Journal of Arid Zone Research.*

Stapp, P., M.F. Antolin, and M. Ball. 2004. Patterns of extinction in prairie dog metapopulations:plague outbreaks follow El Nino events. *Front. Ecol. Environ.*. **2**: 235 - 240

Stapp, P. 2007. Rodent communities in active and inactive colonies of black-tailed prairie dogs in shortgrass steppe. *Journal of Mammalogy*. **88**: 241 – 249

Stapp, P., B. Van Horne, M.D. Lindquist. 2008. Ecology of mammals of shortgrass steppe. Pages 132-180 *in* W.K. Lauenroth and I.C. Burke. Ecology of the Shortgrass Steppe: A Long Term Perspective. Oxford Univ. Press, NY.

Stapp, P., D.J. Salkeld, H. Franklin, J. Kraft, D.W. Tripp, M.F. Antolin, & K.L. Gage. 2009. Evidence for the involvement of an alternate rodent host in the dynamics of introduced plague in prairie dogs. *Journal of Animal Ecology*. **78**: 807 - 817

Tripp, D.W., K.L. Gage, J.A. Montenieri, & M.F. Antolin. 2009. Flea abundance on Black-tailed prairie dogs (*Cynomys ludovicianus*) increases during plague epizootics. J. Vector-Borne and Zoonotic Diseases **9**(3): 313-321.

Wilder , A.P., R.J. Eisen, S.W. Bearden, J.A. Montenieri, D.W. Tripp, R.J. Brinkerhoff, K.L. Gage, and M.F. Antolin. 2008a. Transmission efficiency of two flea species (Oropsylla tuberculata cynomuris and Oropsylla hirsuta) involved in plague epizootics amoung prairie dogs. *Ecohealth*. **5**: 205 – 212.

Wilder , A.P., R.J. Eisen, S.W. Bearden, J.A. Montenieri, K.L. Gage and M.F. Antolin 2008b. Oropsylla hirsuta (Siphonaptera : Ceratophyllidae) can support plague epizootics in black-tailed prairie dogs (Cynomys ludovicianus) by early-phase transmission of Yersinia pestis. Vector-Borne and Zoonotic Diseases 8(3):359-367.

B.) Information Management 2010 -Nicole Kaplan, Information Manager and Bob Flynn, GIS and IT Manager

The SGS-LTER Information Management Team (IM Team) works with SGS-LTER Researchers to plan and prioritize information management activities and design systems to support data and metadata integration and knowledge production. We work closely with SGS and other LTER site researchers and graduate students on improving data quality, performing data aggregation and synthesis, developing and implementing LTER standards and keywords, as well as conducting spatial analysis of our long-term datasets. Collaboration technology has allowed us to facilitate communication for coordinating our research activities, reporting findings, and discussing issues. Analytical tools on our website monitor use and data access allowing us to assess how our on-line interfaces are able to meet the needs of the broader community, as well as help to design improvements. We also continue to participate in various LTER Network-wide and cross-site efforts and have contributed to the SGS-LTER 2010 Renewal Proposal, the LTER Strategic Plan, and LTER Strategic Communications Plan.

The IM Team continues to improve access to information and data online (http://sgslter.colostate.edu), through the creation of level 5 compliant metadata in EML (Ecological Metadata Language) and through building additional relationships within the database between metadata, data products, and our scientific understandings of site-based processes. The SGS-LTER website has been enhanced to enable users to access information and data from several related sections so discovery requires fewer clicks. We serve maps that provide useful site features, such as historical grazing treatment information, and geospatial visualizations that illustrate time-animated habitat changes for prairie dogs. Users may also customize their own maps using an interactive mapping application called ArcGIS Server. The persistent menu on the new website allows users to access tabular datasets and publications from various sections of the website. We have harvested 66 level 5 EML data packages over the past year into the LTER Metacat, a metadata catalog accessible by the broader ecological community to facilitate data discovery and access. We have taken the approach of prioritizing procedures to integrate, clean, standardize and load our long-term, core datasets and metadata for on-line access on the SGS-LTER website and harvest to the LTER Metacat. This approach produces high quality datasets and metadata spanning a longer temporal record to support analysis of long-term trends, and requires input from principal investigators to identify and document important tacit details related to the long record of metadata and data. 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 to replace the current manual processes. Staff and researchers contribute content regularly to the news and events sections of the website, which were designed to share current activities, accomplishments, and exciting findings. We have also added a new 1.5 terrabyte external drive to our cyberinsfrastructure, which was installed off-site from our SGS-LTER database, web and file server and will extend our back-up and archival capabilities.

We implemented tools locally to collect and analyze information about end-users' downloading of specific datasets as well as to report a broader overview of people and machines visiting the website. The SGS-LTER data access tracking tools allow us to record data downloads for various user requirements, such as 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. Eighty-nine individuals registered themselves on the local system and 80 of them downloaded at least one dataset. There have been a total of 195 downloads of data since July 2009 including data from long-term monitoring of primary production, meteorology and physiography at the shortgrass steppe research site.

The Google Analytics which we recently activated on our website, 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 110 other countries or territories. We also can see people are visiting mostly from our home institution, CSU, but many come from across 73 colleges and 262 universities, as well as government agencies such as the USDA, US Forest Service, National Park Service and National Science Foundation. 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.

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. Our existing GIS programs for analysis of SGS-LTER data involve studying the movement of swift fox, visualizing precipitation patterns across the greater region of the shortgrass steppe, and modeling soil properties using satellite imagery. We completed digitizing, attribute labeling, and integrating data collected over thirteen years for our "chart quadrat" project which seeks to analyze growth patterns of individual plants recorded with a pantograph within a square meter permanent quadrat located within various grazing treatments. Researchers are applying these data to projects that analyze the survival and life span of herbaceous plants, model the influence of climate variability on population growth, model species interactions, and test coexistence theory.

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 created a Video Teleconferencing (VTC) work station at our SGS-LTER field station, allowing those working in the field to stay in touch with colleagues. We are able to support VTC with up to four units on campus using local equipment in the Natural Resources Ecology Lab. In addition, researchers are planning and discussing progress of new pulsed precipitation experiments in a blog that we implemented with controlled access using WordPress.

Bob Flynn participates in cross-site working groups, including the MALS and Land Fragmentation projects. Nicole Kaplan continues to participate in Network level leadership activities. She finished a three-year term as co-chair of the IM Committee and is now leading an Information Management Committee governance working group. Bob and Nicole attended several workshops at the 2009 All Scientists Meeting and led a workshop on the Grasslands Data Integration project, a data system for integrating species level long-term net primary production data from several grassland LTER sites. She also attended the 2010 Science Council meeting and participated in strategic planning activities for education and outreach, and communications for the LTER network.

C.) Education, Outreach, and Training Activities (2009-2010)

Research Experience for Undergraduates (REU):

During the summer of 2009, two REU students worked on the SGS LTER project.

Christina Byrne (sophomore, University of California – Berkeley) worked with Dr. William Lauenroth and graduate student Kerry Byrne to calibrate destructive and non-destructive sampling measurements for ANPP.

Kristina Tosic (junior, Colorado State University) worked with Dr. Alan Knapp and graduate student Karie Cherwin investigating the impacts of drought on productivity and invasibility of shortgrass steppe.

During the summer of 2010, we are supported two REU students. Leslie Herington (sophomore, California State University – Fullerton) worked with Dr. Paul Stapp and graduate student Sean Hauser investigating the effects of herbicide application on small mammals on the shortgrass steppe in Colorado. Kristina Halliman (junior, State University of New York at Fredonia) worked with Dr. William Lauenroth and graduate Kerry Byrne investigating the effects of rainfall variability on the production and distribution of roots in two North American grassland ecosystems.

Teacher Professional Development 2009-2010: The SGS-LTER has maintained strong partnerships with K-12 schools in eastern plains and Front Range of northern Colorado. During 2009-2010 we continued the efforts reported in our 2009 annual report and we expanded our work to include efforts that are more teacher-centric in terms of professional development. The following six 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.

- U.S. Department of Agriculture funded Summer Soil Institute focusing on professional development of graduate students, post doctoral fellows, faculty and K-12 teachers through a two-week summer workshop focusing on soils (USDA $150,000). We offered the program as a PD opportunity in 2010 for teachers within our MSP partnership and across the LTER network. We recruited 24 participants from the US, China, Taiwan, Korea, Iraq, Argentina, Italy. Four teachers enrolled (3 from Colorado SGS-LTER site; 1 from Oregon HJA-LTER site). Topics focused on the content and methods to study 1) soils and global change, 2) pedology, 3) soil chemistry, 4) soil organic matter, 5) soil microbiology, 6) soil fauna, and 7) soil ecology.
- NASA funded a Climate Change Education grant (NASA $400,000) where we will used NASA MODIS, Landsat, GIMMS, and Okinos or DigitalGlobe data sets to develop modules that are aligned with science content standards for integration into K-12 courses. We will scale-up by providing training to PD providers from the 26 NSF LTER sites (www.lternet.edu) so that they can adapt the modules to their regions.

Schoolyard LTER 2009-2010: 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 2009. In September 2009 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.

Bella Romero

Teacher: Jane Ortega

Fellow: Paulette Weaver

We have piloted integrating science into the 5th grade library weekly 50 minute time slot. As a direction for a starting point, we looked at the Galileo science test data and selected standards 2.3 “Matter is made up of parts to small to be seen” and 2.4 “Distinguish physical states of matter as solid, liquid, and gas”. We also selected process standard 1 “Use measurement tools to observe, document, and make comparisons. From October through December 2009, 5th grade students participated in a long term experiment using polymer “critters”. Students also participated in hands-on exposure to mixtures and solutions concepts by making a “silly putty” type of mixture using glue, water and borax solution, and food coloring. Students are currently studying six basic body systems for a PowerPoint presentation. Building background experiences and vocabulary are incorporated into instruction. The next unit will teach measurement concepts using tools such as sand timer, stop watch, ruler, calendar, thermometer, and measuring cup. Planning is in progress for development and beautification of a garden area started last year on the school grounds where students will grow seedlings for spring planting. They will also do a soil study, research suitable plants, and prepare the garden area soil for planting. Research is also in progress for the purchase of durable student cameras to document the garden beautification process. The District Six science center, Poudre Learning Center, school and recycled resources have been used extensively for materials to extend our budget.

Brentwood Middle School

Teacher: Steve Swenson

Fellow: Ann Dickinson

As always, the weather dictates when we get to go outside and this year is no different except that the expected fair- fall weather turned into the wet and cold- fall/winter. Therefore, the archeological dig/soil studies and stream table are ready and waiting in their expanded capacities. New signage is ready for the stream table and the Colorado map. The map also had some vandalism take place (first in three years) and we will be replacing the river system in the spring. Well testing continues at BMS and was expanded to include Jackson Elementary School, (part of student science fair project from 8th grade student). The garden plots are ready for planting in spring –a joint project with foods class. The Science fair was scaled down due to budget cuts and personnel issues. Three grants were applied for –did not receive two, and await word on the third grant. A new club has been created to bridge the gap between the grant supplemented activities and next year's lessons: Bengals Go Green (BG squared for the math people).

Cache La Poudre Middle School

Teachers: Jennie Russell, Mary Richmond, Paul Meyer

Fellow: Colin Quinn

Jennie Russell has been working with Colin Quinn on the science of the Cache La Poudre River. In Fall of 2009, all 8th graders participated in River Week. During this week, students learned about the river with an interdisciplinary approach. In science they did the chemistry and biodiversity of the river, in US History they learn about Water in the West, in English they write about the river and in Math they calculate the speed and volume of the river. In addition, Jennie had a Science Adventures class that extended the River Week and looked at the watershed, did site maps and learned river order. This spring in Honors Science-8 students will be working with Colin every Monday gathering data on the river by visiting the river. Mary Richmond has been working with her 6th grade students on a Phenology Project in conjunction with Colorado State University. Every class of students adopted a different tree from around the school grounds. Then once a week they went outside to observe the changes in the trees with leaf color and leaf drop. They recorded their data in a logbook, that was turned into the National Phenology Project. The information from the project was then presented at the National Phenology Network Symposium in Tucson, AZ in the Fall of 2009. In the Spring of 2010, the students will again go outside and observe Bud Burst on their adopted trees. Colin has helped with this project by taking the students outside, and helping to organize the project. Paul Meyer is also a member of the CLPMS team. He is the computer teacher. He has been working with Google Earth and his 6th grade students. They have been taking GPS points of the six adopted trees that Mary's 6th grade students have adopted. The students then took the GPS waypoints and put them into Google Earth and made a Google tour of the trees. They included in the tour the latitude, longitude, date, scientific name of each tree and a picture of the students by each tree. His classes rotate each nine weeks, so he has had all of his 6th grade students doing this portion of the project.

Cameron Elementary

Teachers: Christine Sanchez, Juan Verdugo

Fellow: Madan Guatam

In collaboration with the Cameron Elementary School 21st Century After School Program Grant, we have implemented physical science, life science and mathematics at all grade levels. We have combined the National Geographic Curriculum along with the FOSS Kits to provide various general science activities based on the Colorado Standards. We have also launched the Greening Project at the Cameron Garden which involves students of all grade levels studying entomology and the life process of plants and animals that live in the garden. The final phase of project includes an upcoming ecology field trip on April 16th to Poudre Learning Center for all students in grades 3rd, 4th, and 5th. They will study the ecosystem, niche, different habitats, the properties of soil and water. Primary students in grades Kinder, 1st and 2nd will participate in a Raptor presentation from the Rocky Mountain Raptor Program in Fort Collins.

Dos Rios Elementary

Teachers: Rachel Landon, Lynn Perrich, Veronica Simpkins

Fellow: Yeni Garcia

During the later part of summer and the fall our focus was to provide students with a Service Learning Project that they could start and finish within the year. This was indeed a way to give students an opportunity to learn about gardening, what needs to be done and how to work together during their 5th grade year. It was indeed a way for them to see something they did for someone else take form with a yearlong plan and hard work. Students have been very focused and task committed in this project. With the help of the staff at the Poudre Learning Center we were able to focus on two sections of the garden for planting purposes and selected a variety of plants that appeal to the senses. Our plan of action was to build the brick wall for the raised beds for wheel chair children, widen walkways as well as make an additional one. Students hauled brick and learned to build a wall 21 inches high, wheel barrow soil, mix compost, plant initial plants and weed. Each time we came out for a science content lab, the garden was one of our rotations. With the help of the 21st Century Grant we were able to additionally bring the after school science students to work in the garden over 5 times during the fall. This spring we will also have times where students will come in the after school SCI*FIVE program to work on planting the many plants that need planting. The children feel strong ownership to the Poudre Learning Center and value the time they spend there each time. The goal is to have a variety of plants, planted in the two sections by early May. On April 16 our 1st grade buddies will join our 5th graders to do some planting and to help the younger students see what we have completed and help in the planting process. 1st graders are studying pebbles, sand and silt, so our students will help them with their field activities in April as well. Graduation is on May 18, 2010 at the Poudre Learning Center, a perfect site for parents to see first hand the Service Learning Project that has been worked on by their child. Our study this semester in the after school SCI*FIVE PROGRAM is energy of all types, and the impact on people and the planet.

Eaton Middle School

Teachers: Nicole Bishop, Stacy Marostica

Fellow: Amanda Lease

We have been working with the seventh graders at Eaton Middle School to implement more inquiry-based science, while sticking to the standards put forth by the Colorado Department of Education. Our students had a field trip to the **Error! Contact not defined.** this fall. While there, they independently found a spot and made observations in their journals ("Sit Spot"). They also worked in teams to follow a protocol and collect data on topics ranging from water transparency to dissolved oxygen in the Poudre River. When they returned to the classroom, they analyzed their data and drew conclusions. They were then asked to present their project to their classmates. Since then, the students have been practicing the investigation methods, use of tools, and observations at school. They will return to the PLC again in the spring to both monitor how things have changed in their "Sit Spots" and continue to develop their skills as budding scientists using the scientific method to collect and analyze data.

Greeley West High School

Teacher: Kelly Longacre

Fellow: Madan Guatam

GK-12 project at Greeley west includes an outdoor ecology program integrated with the school curriculum based on physical, life and geo science. We have created an inquiry based self-learning experience through interactions and direct involvements of our students (juniors) with organisms in their environment, i.e. outdoors in the school yard and nearby city park (Greeley West Lake). Last semester we met twice a week every week in the classroom, briefed them the general guidelines of the activities we were doing that day and the expectations to be met in order to accomplish the goals based on our curricula. We then headed out to the Greeley West Park adjacent to the school and conducted various mini ecology projects followed by lessons about food chain and food web, park ecosystem, Lake Ecosystem, pollution and environmental degradation, water conservation etc. Our students also conducted various water tests at the lake at various sites, measured parameters like Ph, temperature, acidity, nitrogen and phosphorus contents etc. The results were analyzed and compared to those of last year's. The final phase of this project will include soil test and analysis by the lake and the park at the end of the spring semester.

Heath Middle School and Chappelow K-8 Magnet

Teachers: Alejandro Melendez, Lynn Green, Laura Grissom

Fellows: Amanda Takacs, Sarah Rozner

The focus of the past 6 months has been on organizing and obtaining approval for an "Eco-Trip" to the YMCA of the Rockies. Heath Middle School and Chappelow K-8 are working on forging the way for District 6 schools to get their students into a different classroom setting, the Great Outdoors! After finding an available site, YMCA of the Rockies, we dealt with the issues of transportation, funding and approval from the Board of Education. Now that the contract has been signed, we are starting to put together an itinerary, fill out the necessary forms, break students into groups, and fill in all of the missing pieces. Open inquiry investigations have been emphasized throughout first semester. A rubric has been created to guide students through the process of recording and reporting scientific results and processes. We will be concentrating on teaching the students specific protocols of collecting data, which will be used on our trip to Estes Park.

Irish Elementary

Teachers: Marion Wells, Julie O'Farrell, Carolyn Gillis, Diane Williams, David Autenrieth, Tracy Acosta

Fellow: Andrew Tredennick

Our efforts have focused on 5^{th} Grade science education and the further development of an *Advanced Science Group* (ASG) that is comprised of selected 4^{th} and 5^{th} grade students. The main thrust of the ASG this past semester was to undertake a water quality study of the Cache le Poudre River in Northern Colorado, an ecologically and economically important water-source for the area. ASG students collected water samples at various sites and conducted pH and alkalinity analysis of the samples. Currently, ASG students are in the process of analyzing the collected data and drawing conclusions. This work will be presented at the "World Water Day" event at Colorado State University on March 22, 2010. The Fellow has assisted 5^{th} Grade throughout the semester on enhancing the standard scientific curriculum using hands-on experiments and the integration of math and science. Work with 4^{th} Grade will expand in 2010 and has thus far focused on the scientific method and earth materials. Work with 3^{rd} Grade will begin during the spring and will include an emphasis on water resources and a field trip to the Environmental Learning Center.

John Evans Middle School

Teachers: Bob Fredrick, Donna Stevenson

Fellow: Mitch Burke, Tom Noel

Repair of the stream table and pump was the first order of business when we started. Then the 6^{th} grade students made grids and mapped the stream table. During this time the 7^{th} graders did periodic sampling of grounds of the school, including making grids and doing some transit lines. They took samples during the fall and winter. During the winter months the two different grade levels are getting together to share data and experiences so that when the weather gets better they can begin some more specific sampling techniques such as using probes to sample soil and any water sources on the grounds. Before we begin sampling in the spring students will need to be trained on the use of the probe ware and how to utilize the computer to organize and display data.

McAuliffe Elementary

Teacher: Chuck Call

Fellow: Amanda Takacs

The fourth grade students at McAuliffe Elementary School spent a large portion of the year learning about the scientific method and walked, first hand, through the process of a scientific investigation. This fall the students conducted their own research using LabQuest technology to test hypotheses and answer a research question. The LabQuest's are small, handheld devices the size of a gameboy, which are mini computers used to read digital probes and record data. The students at McAuliffe were trained how to use these devices with the help of the Poudre Learning Center staff and successfully used them during a scientific investigation. Students were testing to see how environmental factors influenced macro-invertebrate habitat. Using the LabQuest probes, they recorded factors such as air and soil temperature, soil moisture and light intensity near bug pit-fall traps in the school garden and at the Poudre Learning Center. Although little was discovered from the scientific investigation, the students learned teamwork, data recording methods, scientific research protocol and spent time outside learning about environmental conditions.

Meeker Elementary

Teachers: Peggy Hoerner, Caroline Street

The second graders have studied insects in order to develop an understanding of their characteristics and two forms of metamorphosis. An Energy After-school Club was offered. Thirty 2nd and 3rd grade students participated in building, testing and modifying a variety of vehicles, including solar cars. As a portion of a year-long project "Changes in the Greeley Area" students participated in, The Secret School, through a read-aloud, discussions and short-constructed responses. An ongoing timeline, internet research, field trips and teacher prepared materials are being developed. Several new Take Home Back Packs have been designed and assembled to meet the current interests and Science/Social Studies standards. Eighty children have participated in the Home backpacks building research skills while learning about birds. Lesson plans have been shared with other teachers at Meeker and throughout the District.

Mountain View Elementary

Teacher: Mikaela Perea

Fellow: Casey Brown

This fall, the 3rd graders took a field trip to Arapahoe Natural Bend to conduct field experiments and learn about local wildlife. Master Naturalists taught the students about the water cycle, native plants and animals, and conservation. During our science unit on plants we learned about their life cycle, plant parts, and native plants to Windsor. We made observations, conducted experiments, and collected data. This was followed by our unit on animals. We learned about classification, food chains and webs, and local species. Our field journals have helped us document our experiences throughout the year. We feel very fortunate to be a part of the GK12 grant and look forward to a second semester filled with science, learning, and fun!

Poudre Learning Center

Staff: Raymond Tschillard, Paulette Weaver, Mitch Burke

Fellow: Yeni Garcia

This past school year we focused our attention on training teachers to use 21st century technology for water sampling purposes as outlined in our project goals. We extended our goal to include the use of technology to include carbon and soil studies. We determined that the majority of the teachers we are working with have little experience with data collection using these tools. Teachers have applied their new skills in the classroom by having students conduct inquiry based investigations on water quality, invasive species, and microclimates. They are currently exploring ways to incorporate the new technology into soil studies. Another aspect of our project implementation has been the use of science notebooks with the teachers during professional development and by the students for experimental designs and data collection during their investigations. Students can reflect on the temporal changes occurring in the Poudre River watershed. For the remainder of the school year, we plan on focusing our attention on developing curriculum associated with the technology teachers are using and developing a system for long-term data storage that would be accessible by anyone visiting the PLC webpage.

Poudre High School

Teacher: Cristi Carpenter

Fellow: Colin Quinn, Tom Noel

At the beginning of the fall semester 9th grade biology teacher Cristi Carpenter and GK-12 fellow Colin Quinn, along with teacher-in-residence Tom Noel, established plant phenology curriculum for 9th graders. Students initially learned how to use a dichotomous key to identify multiple tree species. Students also monitored trees weekly for changes in leaf color and leaf drop and analyzed why different species may have different phenology. In the spring semester students will observe phenology through studying bud bursts of multiple species. In addition to the phenology project, we have developed a unique method using leopard geckos to study genetics. Leopard geckos provide a unique opportunity for students to study phenotype and genotype and dominant and recessive alleles, similar to the method Mendel used to study genetics using his pea plants. Leopard geckos have three phenotypes, blizzard, albino and non-albino. At Poudre, the ninth grades have one male breeding with three females with varying phenotypes. Based on the result of offspring's phenotypes students will determine the genotype of the parent and offspring generations. So far, we have not been able to get the geckos to breed, but we are hopeful for the spring and hope that these studies can supplement Punnett squares, which students find boring. Another project at Poudre has been an after school program monitoring the Poudre River. Once a month Cristi takes students to the Poudre River to measure multiple characteristics of the river, including river flow, pH and electroconductivity. After these values are recorded they are submitted to the State of Colorado. This is an excellent opportunity for student to participate in citizen science and provides students with a sense of entitlement. In addition, we have been working with Greg Newman to establish a citizen science program where student help monitor location of invasive plant species. The final project at Poudre is the planning of an experiment to study how metal polluted soils affect crop species and how this may affect human health. This project will be implemented in the spring 2010 semester. The objectives are to determine crop species tolerance to various metals and to determine how this affects the nutritional value of the crop.

Preston Middle School

Teachers: Mary Klass, Erin Panozzo, Mary Hunter-Laszlo, Brian Reidel

Fellows: Alexa Sutton, Jennifer Soong

This fall at Preston Middle School, our goals have been to improve our ecology related activities as well as expand them to include concepts and activities that we developed during the summer workshop. We have had the additional challenge of coping with the changeover from a junior high to a middle school, so some lessons and trips will not be able to be included in our curriculum until spring semester. This fall Erin Panozzo's science 7 classes studied characteristics of the Poudre River such as origins, water quality and macro-invertebrate populations as related to the health of the river, with the help of our graduate fellows. The classes took a field trip to the Environmental Learning Center to carry out water quality testing procedures and bug identification, as well as ph, temperature, etc. Data were compared above and below the water treatment facility. The other science 7 classes, as well as the science 8 classes, have plans for ecology field trips in the spring. Mary Klass' Science Olympiad class has studied various ecological and anatomical topics with the help of our fellows.

Riffenburgh Elementary

Teachers: Merin Bruinsma, Bob Faris

Fellow: Casey Brown

The focus of this year's study, with 5th graders, remains the habitat, soil, and water of the Cache la Poudre River and its relationship with the life zones in which it travels. Sub Alpine, Foothills, Grassland, and the Riparian zone itself are the focus of this study. Students develop an understanding of the relationships of micro and macro organisms in these various life zones. Working outside the class room, students have compared soil, water, and habitat on the Spring Creek, Fort Collins, CO., as well as the South Branch of the Cache La Poudre, Pingree Park, CO. Students have investigated habitat and relationships on the Grassy Steppe, LTER. Spring investigation will include the Poudre Learning Center, Greeley, CO.

Rocky Mountain High School

Teachers: Scott Kemp, Martha Marvin, Diana Fremaint, Darcie Peale, Michelle Bartholomew

Fellow: Justin Neu

Our work has focused on observations from the Maxwell Natural Area on the west edge of Fort Collins. Last fall on consecutive weeks, we took two field trips with nearly 150 students throughout the day and hiked to three predetermined sites: a prairie dog town, a montaine area and an undisturbed prairie “off town” site. In each site, student’s used Daubenmeyer frames to determine plant diversity, set pitfall traps to collect insects, and used labquest temperature probes to determine surface and subsurface temperatures of soil. Data are being analyzed to determine what effect prairie dogs have on the ecosystems plant and insect life as well as the soil temperatures. This project has been instrumental as a capstone activity in our ecology unit. By the school year’s end the project will introduce more than 300 students to a nearby natural area and the diversity of life in a transition area between the prairie and foothills.

Skyview Elementary

Teacher: Amy Nicholl

Fellow: Mitch Burke

We met earlier in the year and discussed some of the things that we could do to test the micro-climates at the Poudre Learning Center. After that meeting, Mitch and I set up a time for him to come to Skyview to teach my students how to use the probes. That was great. The students were able to use the different probes and record their readings. We then took a field trip to the Poudre Learning Center on October 19, 2010 and used the probes to test different areas. We split the students into four groups; the students predicted where they thought different micro-climates would exist. The groups went to each of the sites that they chose and used the probes to collect data. Each student had a lab book where they recorded their observations, sketches and data. (This is something we will tweak before we go the next time. Parts of the charts were a bit confusing for the students.) The students have are looking forward to going to the Poudre Learning Center again this spring. At Skyview, the students have continued to use the probes. We have gathered data in different areas of our playground and wetland areas. We will discuss the similarities and differences when we look at the Poudre Learning Center and the data that we have from our school.

Union Colony Prep School

Teachers: Cathy Hoyt, Ron Lamb, Jennifer Parrish, Todd Dolesholl

Fellow: Sarah Rozner

At Union Colony we have three different projects. We are working to implement a recycling and composting program at our school. We hope to incorporate curricula that using the recycling/composting program in the math and science classes. Middle school science will use the recycling program as they study energy resources and high school biology classes will utilize the composting program as they study biochemical recycling. Math class in both middle and high school will analyze data collected in the science classes.

In response to the RET experience in the summer of 09, Cathy Hoyt has led two field trips that incorporated soil studies. Students collected soil samples at Rocky Mountain National Park and conducted student-designed experiments back in the classroom. Students also conducted experiments at the Poudre learning Center involving soil respiration and ecology. Fellow Sarah Rozner has worked closely with the teachers at Union Colony to help integrate learning from science into the math classrooms. She continues to work on the recycling/composting project which we expect to be completed by April 2010.

Winograd K-8

Teacher: Kathleen Sage

Fellow: Mitch Burke

As new participants, it took a bit to get our feet on the right path, but once we did, we have taken off quickly. We ordered and received a LabQuest along with a variety of probes and devices that are used to capture data about different functions by the human body. We originally planned to save the device for that unit; however, we have found multiple ways to use it in our other units including Landforms and Mixtures/Solutions. In the Landforms unit, we used it to measure flow rate and soil temperature. In the Mixtures/Solutions unit, we used it to measure flow rate, acidity levels, nitrogen content, and dissolved oxygen levels in both a river and lake. In addition to the new equipment, we worked with Mr. Burke, our GK-12 Fellow, as he provided pre-teaching on each of the experiments to be done with the LabQuests. With his support, we have tightened the field study experiences for both units of study. In addition, we are beginning our study of the Human Body and will finally be able to use the many attachments we purchased to make the study more interesting and relevant.

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.
- NASA CCE 2010-present: The goals of the NASA Climate Change Education grant are to (1) improve the science content knowledge and preparedness of middle and high school teachers, (2) increase the science content knowledge of middle and high school students, (3) increase the awareness, opportunities and participation of middle and high teachers in content-based professional development activities, and (4) Broadly disseminate our model to districts across the country. NASA MODIS, Landsat, GIMMS, and Okinos or DigitalGlobe data sets will be used to develop modules that are aligned with science content standards for integration into K-12 courses. We will scale-up by providing training to PD providers from the 26 NSF LTER sites (www.lternet.edu) so that they can adapt the modules to their regions.

D. Project Management

Project management at SGS LTER continues as it has since it was changed in 2009. Central management of the project is by an Executive Committee (SGS-EC), Mike Antolin (lead PI until 11/1/2010), John Moore, Justin Derner, Eugene Kelly, and Nicole Kaplan (Information Manager). The Executive committee works with the PI both to manage project budgets 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. We use video-conferencing to include members from several institutions at different locations.

The direction of scientific research is guided by Science Steering Group, comprised of active scientists on the project who provide specific advice 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.

Currently the Science Steering Group includes: Amy Angert (CSU), Mike Antolin (CSU), David Augustine (USDA-ARS), Cynthia Broun (CSU), Indy Burke (UWyo), 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), Bill Parton (CSU), Paul Stapp (Cal State Fullerton), Heidi Steltzer (now Fort Lewis College in Durango, CO), Joe von Fischer (CSU), Matt Wallenstein (CSU).

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 will be in the upcoming year during January, 2011 at the SGS Research and Interpretation Center at the field site 8 miles north of Nunn, CO.

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.