I. RESEARCH

During the period Nov. 1st 2002 to July 31st 2003, we produced 21 papers in refereed journals, seven book chapters, one dissertation, and numerous abstracts from national and international meetings. Ten graduate students and 17 undergraduate students worked on research related to the shortgrass steppe LTER. We continue to sample our long-term projects, as well as initiating some new short-term experiments. Following are key research progress and results in each of our three core areas: population dynamics, biogeochemical dynamics, and land-atmosphere interactions.

1. Population Dynamics

Plants

Invasive Plants

In the past, concern about plant invasions in northeastern Colorado has been largely hypothetical, because there were essentially no instances of invasive plants having influenced the native grasslands. That has changed substantially in the last several years and especially in 2001. Dalmatian toadflax (*Linaria dalmatica*), a very aggressive introduced perennial plant, has begun to become established and spread on a wide variety of upland shortgrass steppe locations throughout the SGS LTER site. Based on accounts of invasions by toadflax in other regions, there is every reason to believe that this invasion could prove to have substantial influences on native plant communities and ecosystems.

In 2002 we began a long-term demographic study of established toadflax patches. The objective of this work is to understand controls on the rate and extent of vegetative spread of established patches. The initial work is focused on characterizing the patches. The subsequent steps will involve manipulating water and nitrogen availability and the presence of the dominant species blue grama (*Bouteloua gracilis*). These manipulations will be performed around the expanding edges of the patches. The objective of the manipulations is to understand controls on rate and direction of spread.

In the fall of 2001, we located 12 patches of toadflax ranging in size from 1 to 7 m^2. For each patch, we counted the number of toadflax tillers, collected global positioning system coordinates for the center of each patch, and surveyed the boundaries of each patch. The data will be entered in to a geographic information system database and updated annually. Tiller numbers per patch ranged from 200 to 1000 varying with patch size and location.

Future work will include investigation of the ecosystem consequences of the presence of toadflax in terms of water, nitrogen and carbon balance.

Demography of Pinus flexilis

An outcropping of the Ogallala formation which occurs as an escarpment in the northern portion of the SGS LTER site contains woodlands dominated by *Pinus flexilis* and *Juniperous scopulorum*. While we have evidence from stumps and packrat middens that *Pinus flexilis* has been present on these sites since approximately 300 AD, all of the current trees are less than 160 years old. Our assumption is that essentially all of the trees were cut as settlers, especially homesteaders, moved into the area following the Civil War. Age-height relationships suggest that a few of the smallest trees may have escaped this harvest event. The relationship between age and height from 1900 to 1994 has a positive coefficient, indicating that older trees are taller than younger ones. The opposite is found for trees established before 1900, suggesting that a few old short trees were dominating the dataset. These were

likely stunted trees that were passed over by the homesteaders as unusable. As a further indication of how different these sites are from the shortgrass steppe locations that dominate the vast majority of the LTER site, the understory in these stands was surveyed. *Bouteloua gracilis* accounts for 25 to 80% of the basal cover of most shortgrass locations. It accounted for only 6-21% of the basal cover under the *Pinus flexilis* woodlands. The dominant understory grasses are *Schizachyrium scoparium* and *Bouteloua curtipendula,* two species that are characteristic of grasslands found 300 km east of the SGS LTER site

Animals

Animal Monitoring Programs Since 1994, we have estimated population sizes of nocturnal small mammals, rabbits, and terrestrial carnivores on the SGS-LTER site. These monitoring programs continued in 2002 and 2003, including live-trapping studies in May and roadside counts of rabbits and canids in October, January, April, and July. We continued monthly warm-season surveys of terrestrial macroarthropods, studies that were also initiated in 1994. Captures of major insect taxa are counted in 90 pairs of pitfall traps placed along a 1 km topographic gradient as part of new long-term monitoring studies. In addition, we continued arthropod pitfall trapping studies on trapping webs established for monitoring abundance of small mammals. Arthropods are important food items for rodents on the shortgrass steppe. Twenty traps are placed on each of three upland grassland and three saltbush sites. Pitfall traps are run for 4-5 consecutive days on three occasions during summer months to track temporal changes in abundance of arthropods as a possible determinant of trends in rodent numbers.

Beginning in July 1997, we modified our roadside census route to include areas of the Pawnee National Grassland (PNG), taking advantage of the 1996 SGS-LTER site expansion. We have continued to utilize this new route which includes more upland prairie habitats used by white-tailed jackrabbits (*Lepus townsendii*) and swift foxes (*Vulpes velox*), while continuing to allow us to monitor rabbit and canid populations on portions of the Central Plains Experimental Range (CPER).

In May 2003, SGS-LTER researchers began field work as part of new research to assess the use of cattle grazing as a tool to create nesting habitat for the threatened Mountain Plover. This project includes determining the effects of different grazing regimes on arthropods and small vertebrates, which may indirectly influence the suitability of grazing-modified areas for plovers.

Prairie Dog-Vegetation Interactions

Since 1997, aboveground plant biomass has been estimated once each growing season (near the time of peak biomass) by clipping and weighing plants from on and off each of five black-tailed prairie dog (*Cynomys ludovicianus*) towns that had been colonized for 3-5 years when the study was initiated.. Biomass of blue grama (*Bouteloua gracilis*), the dominant grass, was about 30% lower on prairie dog towns (32 g/m^2) than at off town sites (46 g/m^2). Similarly, total graminoid biomass on the active prairie dog towns (46 g/m^2) was consistently lower than off the prairie dog towns (72 g/m^2). By contrast, over the same period, forb biomass on the active prairie dog towns (14 g/m^2) averaged nearly three times more than off the prairie dog towns (5 g/m^2). While these trends towards lower grass biomass and greater forb biomass on prairie dog towns are in the same directions as those observed in mixed grass prairie, the magnitude of the differences between on and off town sites was considerably less in the shortgrass steppe. This is further evidence that the shortgrass steppe is highly adapted to grazing. Late in 1998 and early in 1999, prairie dogs in two of the colonies died off, apparently from plague. In the 1999 sampling, graminoid biomass on the extinct prairie dog towns had increased to values that were essentially identical to those off the towns, and forb biomass on extinct towns had decreased to values similar to those off the towns. Thus, it appears that the effects of prairie dog grazing on aboveground

plant biomass are reversed quickly following loss of prairie dogs at our shortgrass steppe site. Although this study will continue during the next five years, papers are currently in preparation from the first six years of the project.

Another related study was initiated during summer, 2002, and will continue during 2003 and 2004. The goal of this study is to determine the time course of vegetation change and nutrient dynamics following colonization or abandonment of towns by prairie dogs. We are monitoring plant biomass, species diversity, N concentration, and N mineralization rates on and off prairie dog towns of different ages: three towns that were about four years old in 2002, three that were more than 15 years old in 2002, and three that had been recently abandoned as a result of plague in 2002. Results of this study will give greater insights into how the magnitude of prairie dog effects changes over time.

2. Biogeochemical Dynamics

CO_2 Fertilization Study

Over the course of a 5-year field CO_2 enrichment study, we found that doubling CO_2 increased production of this grassland area by 30 -50% in any one year, but most of that production increase occurred in *Stipa comata.* Production remained unchanged in two other important perennial grasses, *Bouteloua gracilis*, the dominant warm-season grass of the shortgrass steppe, and *Pascopyrum smithii*, an important cool-season forage. Forage digestibility declined in all three species under elevated CO_2, and was least in the only dominant species that showed a production increase under elevated CO_2, *Stipa comata.* These findings are significant, as they suggest the shortgrass steppe may become more productive, but less useful as a source of forage for livestock. The results also suggest the species balance could shift away from *B. gracilis*, an important species not only in terms of its high forage quality, but also as a species that brings stability to the shortgrass steppe. This information is presently being utilized in a modeling exercise to evaluate the consequences of various CO_2 enrichment/climate change scenarios on forage production, forage quality and animal performance.

Effect of water addition and nitrogen fertilization on the fluxes of CH_4, CO_2, NO_x, and N_2O following five years of elevated CO_2 in the Colorado Shortgrass Steppe

An open-top-chamber (OTC) CO_2 enrichment study was conducted in the Colorado shortgrass steppe to determine the effect of elevated CO_2 (~720 µmol mol^{-1}) on plant production, photosynthesis, and water use of this mixed C_3/C_4 plant community, soil nitrogen (N) and carbon (C) cycling and the impact of changes induced by CO_2 on trace gas exchange. Weekly measurements of CO_2, CH_4, NO_x and N_2O fluxes within control (unchambered), ambient CO_2 and elevated CO_2 OTCs and soil water and temperature were measured at each flux measurement time from early April 1997, year round, through October 2001. Even though aboveground plant biomass increased under elevated CO_2 and soil moisture content was typically higher than under ambient CO_2 conditions, none of the trace gas fluxes were significantly altered by CO_2 enrichment over the 55 month period of observation. During early summer of 2002, following the removal of the OTCs from the CO_2 enrichment sites, we conducted a short term study to determine if soil microbial processes were altered in soils that had been exposed to double ambient CO_2 concentrations during the growing season for the past five years. Microplots were

established within each experimental site and 10 mm of water or 10 mm of water containing the equivalent of 10 g m^{-2} of ammonium nitrate-N was applied to the soil surface. Fluxes of CO_2, CH_4, NO_x and N_2O fluxes were measured within control (unchambered), ambient CO_2 and elevated CO_2 OTCs soils at one to three day intervals for the next month. With water addition alone, CO_2 and NO emission did not differ between ambient and elevated CO_2 soils, while CH_4 uptake rates were higher and N_2O fluxes lower in elevated CO_2 soils. Adding water and mineral N resulted in increased CO_2 emissions, increased CH_4 uptake and decreased NO emissions in elevated CO_2 soils. The N addition study confirmed previous observations that soil respiration is enhanced under elevated CO_2 and N immobilization is increased, thereby decreasing NO emission.

Effect of grazing and topography on 15N retention

We re-sampled permanent 15N addition plots originally established at the SGS-LTER in 1987 to examine the effects of grazing and topographic position on plant and soil 15N retention and cycling. The re-sampling occurred in mid-May 2003. We successfully located 34 of the original 36 plots. One soil core (30 cm deep) was extracted from each plot and separated into 0-10 cm and 10-30 cm depth increments. Processing includes particulate organic matter separations, texture analysis, and total C and N determinations. Quantification of the amount of 15N in both the particulate organic matter fractions and the total soil N pool is planned to occur in the Fall of 2003 using a mass spectrometer in the Duke University DEVIL isotope lab. The major product of this re-sampling effort will be a scientific paper including data from the original 1988 sampling, a follow-up sampling in 1992, and the current 2003 re-sampling.

Silica Biogeochemistry

Primary objectives of the current study are examining the role of biogenic silica in the overall silica cycle and subsequent mineral stability of grassland systems, as well as clarifying the link between terrestrial and aquatic silica. In addition to the silica mass balance/compartmentalization approach of this study, two different isotopic techniques will be employed. The current study will focus on the role of biogenic silica cycling and fractionation of Ge/Si to further elucidate the role of vegetation in the terrestrial silica cycle. As most studies to date have taken place in the tropics, we will also look at the utility of Ge/Si in temperate grassland sites. Different components and mechanisms (clay mineral fractionation) will be analyzed, but the focus will be on biogenic cycling and fractionation. A second isotopic tool, $\delta^{30}Si$, will be employed both to compare against Ge/Si in the same study, and as a backup against potential coal contamination within the study sites. To address the stated objectives, climatic/vegetation impacts on Si cycling in grassland ecosystems, a pre-selected climosequence will be sampled during the 2003 field season. The climosequence includes shortgrass, mixed grass, and tall grass prairie sites from Colorado to Kansas, where productivity data will allow for data extrapolation to the watershed scale. Age (10 to 30 ka), parent material (Pleistocene till and alluvium overlain by late Wisconsin age loess), relief (nearly level uplands) are kept as constant as possible. Other sites may be added as needed in order to increase the spatial sensitivity of the analysis and to locate 'Ge-uncontaminated' sites if necessary. Temporal sampling of stream water (multiple seasons and/or years) and ground water at each site or nearby wells (where stream water is not available) will help determine the impact of variability in stream flow on Si flux. Water samples will be collected in acid-rinsed polypropylene or HDPE bottles. Soils will be sampled by genetic horizon down to the parent material or bedrock. Parent material and/or bedrock samples will also be taken at each site. Soil and rock samples

will be stored in polypropylene bags. Separate samples for bulk density will also be taken in order facilitate the Si mass balance of each system. Three replicates per site will be taken to examine spatial variability. Dominant plant species will also be taken at each of the soil sites.

3. Land-Atmosphere Interactions

Atmospheric-biogeochemical model

The application of the coupled atmospheric-biogeochemical model continues, with the plan to validate its skill at simulation using the observational data for different levels of grazing intensities and for different years. The comparison of the interaction between the atmosphere and the shortgrass steppe during the three years of data (which includes a serious 1 year drought) will be a major emphasis of the work. The role of land use type is also being investigated using the coupled modeling system.

DAYCENT modeling

We used DAYCENT to investigate the effects of elevated atmospheric [CO_2] on plant growth, soil water levels, and soil respiration rates at the shortgrass steppe. Model results agreed with data collected from OTC plots at the shortgrass steppe showing higher NPP and higher soil respiration under elevated [CO_2] largely due to higher soil water contents for this treatment. In collaboration with a group from Australia using the G'DAY model, DAYCENT was applied to study long term effects of elevated [CO_2] and climate change for the shortgrass steppe, the tallgrass prairie, and a boreal forest. Results have been submitted to *Tellus* and included in the LTER book. DAYCENT simulations of N gas emissions from cropped and grazed soils for 27 counties in the Front Range of Colorado were compared with N emissions from industry and vehicles in the same counties.

UV Radiation Project

The shortgrass steppe UV project focuses on three aspects of UV-radiation effects: litter decomposition, litter-dwelling arthropods, and aboveground primary production/tissue quality/plant community composition. For all three, we assess how UV interacts with other multiple stressors under field conditions.

Initial results show that aboveground plant primary production is reduced under greater UVB exposure, but responses vary by species and by precipitation levels. A significant negative effect of UV radiation on ANPP was observed for *B. gracilis* in the dry year but not the wet year, and a significant negative effect of UV on production was observed for *S. hystrix* in the wet year but not the dry year. The reduction in ANPP translated to only C_4 grasses as a whole group, and this resulted in a reduction for total vegetation as well. The different species responses to UV treatment could potentially lead to changes in species abundances and composition in this native grassland community, and this will be assessed in subsequent treatment years. No interactions between UV and grazing treatment on primary productivity were observed in this study. Grazing stimulated primary production of all functional groups and species in the wet year, but this was often not the case in the dry year. We observed only a few significant effects of UV treatment on soluble-fiber fractions of plants, and these responses were small in magnitude. The UV response was positive in terms of forage quality, except for an increase in lignin in *S. comata* in the autumn of the wet year. Responses to UV were also positive for nitrogen content of

B. gracilis in the drought year.

Litter decomposition, measured as percent mass loss, was affected by UV conditions, CO_2 conditions under which the litter was grown, and precipitation level. Mass loss was greatest under wet conditions for plant material grown under ambient versus elevated CO_2. Overall, plant material grown under elevated CO_2 decomposed more slowly than that grown under ambient CO_2. Under dry conditions, reduced UV radiation resulted in lower mass loss. By contrast, in wet conditions UV treatment had little effect. UV treatment had no significant effect on litter fiber quality. The largest differences in litter quality occur between litter grown under ambient versus elevated CO_2 conditions. Litter grown under elevated CO_2 tended to have lower solubles and lignin content and higher hemicellulose and cellulose content. These relative proportions are consistent with the initial quality of the litter at the start of the decomposition study. Precipitation levels had little effects on fiber fractions. Plant litter decomposed under wet conditions tended to have higher lignin and solubles content and lower cellulose.

UV treatment had as large effect on arthropod numbers as did dry versus wet year conditions. Exclusion of UV-B resulted in nearly twice as many total arthropods as the ambient UV treatment ($p=0.0021$), while wet-year conditions compared to drought conditions also resulted in nearly twice as many total arthropods ($p= 0.0035$). The response of different groups of arthropods to UV-B exclusion compared to ambient treatment mirrored the response to wet-year compared to dry-year conditions, with the exception of Cryptostigmata. Furthermore, impacts on root-feeding insects indicate that changes at the surface may have important effects on belowground processes.

II. INFORMATION MANAGEMENT

The SGS-LTER Information Management (IM) team accomplished their goals to focus more resources on information management. SGS-LTER now has the equivalent of a full time Information Manager who is assisted by many students with Computer Science majors who help design, develop, and implement new tools for the SGS-LTER database and web site. The flow of data and metadata from the field to release on the web site has been streamlined. We have set new goals to be accomplished during the next funding cycle, including the implementation of a more centralized and flexible IM system, participation in Network-wide IM activities and continued professional development for IM staff.

SGS-LTER continues to participate in cross site and other community driven IM activities. Nicole Kaplan, Information Manager, participated in a DataBank workshop at The Evergreen State College in May 2003 with four other Information Managers (Ims) from LTER sites (http://canopy.evergreen.edu/bcd/home.asp). At the workshop, IMs developed templates for database designs, statistical analysis, and visualization tools for data collected on the growth of roots belowground. Other grassland ecology sites within the LTER Network that collect similar data will be able to implement these IM tools. IMs and Principal Investigators from the Jornada and Sevilleta sites are interested in continuing to develop these tools. Future workshops and a presentation at the 2003 All Scientists Meeting are being planned. In addition, SGS-LTER has contributed to a "data cooperative" to accelerate the sharing, standardization, completeness, and accessibility of data on the distribution and abundance of non-native plants, animals, and diseases across the United States. Strong partnerships

between government and non-governmental organizations administratively housed in the U.S. Geological Survey's Fort Collins Science Center in Colorado have demonstrated the importance and success of data synthesis. Participants plan to present this project, which is part of the National Biological Information Infrastructure (http://www.nbii.gov/issues/invasive/home.html), at a data synthesis workshop at ASM in Seattle this September.

III. OUTREACH ACTIVITIES

Education

The SGS-LTER educational activities are coordinated through the Math and Science Teaching (MAST) Institute at the University of Northern Colorado. The project supports research for K-12 students, professional development for K-12 teachers, and research opportunities for science educators on various aspects of K-16 education.

Schoolyard Ecology: The project is funded by annual supplements to the SGS-LTER. Currently, funds are used to support programs at seven schools in NE Colorado (1 elementary, 1 middle school, and 5 high schools). The programs include activities from formal research plots to science fair programs.

Research Assistance for Minority High School Students (RAMHSS): The RAMHSS program works closely with the UNC Math and Science Upward Bound (COSMOS) and the UNC Frontiers of Science Institute (FSI) operated through MAST. In 2002-2003 nine students from across the state of Colorado were supported in research activities. Students are recruited for a six-week residence summer internship program, and for those living within commuting distance to UNC, an academic year research internship. Funds were used to house students, provide transportation to the site, support graduate students for supervision, provide stipends or wages for the minority students, tuition assitance for the credits earned, and supplies.

GK-12: The project is funded by NSF through the GK-12 program. The project's theme is "Human Impact Along the Front Range of Colorado." This dovetails nicely with current emphasis at the SGS-LTER. The SGS-LTER serves as a hub for the GK-12 project, in terms of research, faculty interaction, and graduate students. The GK-12 project supports two SGS-LTER graduate students and has adopted the LTER schoolyard ecology model.

CLT-W: The Center for Learning and Teaching in the West, funded by NSF through the CLT program, provides GRA appointments for graduate students, on-line course development for K-12 teachers and graduate students on topics ranging from traditional courses on teaching and learning theory, diversity and equity issues in education to practical topics such as lab and field safety. The CLT-W is developing a M.A. program in Natural Sciences for teachers. SGS-LTER scientists are assisting in the development of content for courses in ecology, and will serve as advisors for prospective teachers.

Teachers on the Prairie: The project is funded by NSF through a Teacher Enhancement grant to Portland State University, and patterned after the Teacher in the Woods program at PSU and the H.J. Andrews LTER. The project offers K-12 teacher professional development opportunities through workshops and research internships on topics germane to the SGS-LTER. Much of 2002-2003 was spent making contacts throughout NE Colorado and planning for the workshops, the first of which

occurred in June 2003.