

# RESEARCH

## I. Research

During 1997 and 1998, we produced 45 papers published in journals, 15 currently submitted to journals, 9 book chapters, 4 dissertations and 12 abstracts from national and international meetings. During these years, 17 graduate students and 22 undergraduates worked on research related to the shortgrass steppe LTER. Scientists at our site are involved in a number of new experiments in addition to continuing our long-term projects. This section is organized by a modified version of the LTER core areas.

### 1. Populations and Processes

Our work since our last progress report has focused on continuing to sample our long-term projects and to continue several new studies initiated with our latest grant. The new animal work involved expanding the work on prairie dogs begun in 1997. Belowground work centers on understanding the effects of grazing on microbial communities.

Spatial distribution of weeds: Weeds, especially exotic plants, represent one of the most serious challenges to the current structure and function of ecosystems. A key first step in understanding the problem in a particular area is to investigate which species are present, where they are located and how abundant they are. We initiated a study in 1998 to begin answering these questions for the Central Plains Experimental Range and western section of the Pawnee National Grassland (1024 km<sup>2</sup>). Our initial approach is to use the roads and stream courses to do the assessment. This approach assumes that the roads and the riparian areas along stream act as conduits for the movement of species as well as loci for invasion of the adjacent grassland. The products from this work will be maps of the distribution and abundance of exotic plant species (total and by species) for roadsides, riparian areas and upland grassland. Our expectation is that this information will lead to experimental work on mechanisms controlling invasion of grassland by exotic species. The work involves two graduate students, two REU's and one additional undergraduate funded by a NSF research program on campus.

The effects of increasing temperatures on shortgrass steppe vegetation: There is now general agreement that global warming is apparently primarily a result of increases in daily minimum temperatures (TMIN) rather than increases in daily maximum temperatures (TMAX). We examined long-term weather data from the SGS LTER and determined that this pattern has held true for the period 1964-1993. Evaluation of vegetation data indicates that total ANPP and density of several species, including *Opuntia polyacantha*, were most closely correlated with precipitation. However, ANPP of the dominant grass species, *Boutella gracilis*, and several other important species, was most closely and negatively, correlated with spring TMIN. Also of interest was the finding that density of plants in the "exotic forb" functional group increase significantly with an increase in TMIN. These results suggest that this ecosystem may be sensitive to increases in minimum temperatures similar to those that are being observed globally (Alward et al. in prep).

We constructed four automated shelters to cover plots from sundown to dawn from spring until fall (except during periods of precipitation) to reduce radiative heat losses and warm plots primarily during nighttime hours. Compared with adjacent plots without shelters, covered plots had 1.5 to 2.0 C higher temperatures from 10cm above the ground surface to at least 30 depth in the soil. The higher temperatures resulted in more rapid drying of the soil in covered plots. Among the major findings related to increased nighttime temperatures, we have observed (a) increased tillering rates and advanced phenology, but decreased inflorescence production, in *B. gracilis*; (b) seasonal shifts in insect herbivory damage *Pascopyrum smithii*, a common C<sub>3</sub> grass, such that there was less damage early in the growing season but more damage later; and increased cladode production but decreased flower and fruit production in the abundant and widespread cactus, *O. polyacantha* (Alward and Detling, in prep).

Animal Monitoring Programs: Since 1994, we have estimated population sizes of nocturnal small mammals, rabbits, and terrestrial carnivores on the SGS-LTER (Stapp 1997, a,b,c,d and in press). These monitoring programs continued in 1997-1998, including live-trapping studies in may and roadside counts of rabbits and canids quarterly. We continued monthly warm-season surveys of terrestrial macroarthropods. Captures of major insect tax are counted in 90 pairs of pitfall traps placed along a 1km topographic gradient in new long-term monitoring studies. In 1998, we began arthropod pitfall trapping on trapping webs established for monitoring abundance of small mammals. Pitfall traps are run for 4-5 consecutive days on thee occasions during summer months to track changes in abundance of arthropods, which are important food items for rodents in shortgrass steppe, as a possible determinant of trends in rodent numbers.

Beginning this year, we modified our roadside census route to include areas of the Pawnee national grasslands (PNG), taking advantage of the 1996 SGS-LTER site expansion. The new route 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.

Prairie Dog Studies: Prairie dogs (*Cynomys ludovicianus*) influence their surroundings in many ways. These herbivorous mammals change local plant community structure by cropping vegetation, and they modify the soil structure by burrowing and building mounds. These changes in vegetation and edaphic factors may influence insects such as beetles and grasshoppers that live in prairie dog towns. We have completed one year of research aimed at understanding the relationship between short-horned grasshoppers (Orthoptera: Acrididae), darkling beetles (Coleoptera: Tenebrionidae) and prairie dogs. Preliminary results indicate that there are fewer grasshoppers on prairie dog towns than on the surrounding prairie, suggesting that prairie dogs may alter prairie habitats in a way that may be unfavorable for grasshoppers. Tenebrionid beetles were sampled by pitfall traps once every 3 weeks from July through mid-September 1997. During 1998, traps will be set four times between late May and mid-September. This work is being conducted by a graduate student (Junell) under the direction of Bea Van Horne. An REU

student is also working with P. Stapp to assess the influence of prairie dogs on avian abundance's this summer.

We have initiated new work on the genetics of prairie dog populations (Roach, under direction of Van Horne and Antolin). Prairie dog colonies in shortgrass steppe exist in spatially isolated subpopulations that are connected by dispersal, traits typical of metapopulations. The dynamics of these subpopulations are also determined by local colony extinction, which results from plague, agricultural control efforts and recreational shooting. Difficulties in quantifying dispersal behavior have complicated efforts to document the degree of connectedness between isolated colonies. However, patterns of genetic relatedness among populations can provide an estimate of the degree of linkage between subpopulations and be used to generate hypotheses about the types of behavioral processes responsible for these patterns. In this study, we plan: 1) to establish levels of genetic heterogeneity within and among black-tailed prairie dog populations and 2) to evaluate proposed models of recolonization based on the degree of genetic differentiation among recolonized and established colonies. We sampled 13 prairie dog colonies on the SGS site from May-December 1997: 6 at Central Plains Experimental Range (CPER) and 7 at Pawnee national Grasslands (PNG). A tissue sample was collected from each individual for genetic analysis. We are currently measuring genetic variability within and among populations of prairie dogs using microsatellite loci markers. Cluster analysis of data from the microsatellite markers will reveal patterns of relatedness among populations and will be used to evaluate the role of dispersal in maintaining genetic diversity of the metapopulation. Results from this study may be used to describe patterns of prairie dog metapopulation dynamics. Determining the effects of extinction and recolonization events on genetic diversity can provide predictions about the stability of metapopulations and provide possible guidelines for maintaining rare and endangered species in highly fragmented habitats.

Last, we are studying the above prairie dog towns to distinguish between effects associated with soil churning and movement and those associated with consumption of vegetation, and to determine the magnitude of each effect. In doing so, we are characterizing changes in plant species composition, cover, and biomass in areas inhabited by black-tailed prairie dogs and in nearby uncolonized areas (Detling and Milchunas), and examining the effects of prairie dogs on plant nitrogen content and potentially mineralizable nitrogen in soil (Detling and Burke). A graduate student and REU are involved in the latter work on mineralizable nitrogen. We anticipate expanding the scope of this project during 1999 with the addition of at least one new graduate student working with Dr. Detling. Measurements of plant biomass, species composition and cover, and N content will continue as before to determine to what extent modifications induced by prairie dogs change over time as intensive grazing continues.

### ***Belowground Processes***

Impacts of Grazing on Soil Biota and Processes: This project involves manipulating cattle grazing in historically non-cattle grazed and cattle grazed pastures and tracking the changes in above and belowground communities. We moved fences in 1991 to expose

previously ungrazed exclosures and to create new exclosures and to create new new exclosures on historically grazed pastures. Yearly sampling has shown a marked shift in the microbial community. Grazed pasture that was taken out of grazing now possesses a community structure that is similar to the ungrazed pasture, and ungrazed pasture that was allowed to be grazed is similar in structure to the historically grazed pastures. The microbial communities began to diverge from one another two years following the manipulations. The complete shift has taken six years to materialize, and was only evident after the last growing season. We are in the middle of processing this year's samples from these sites (Moore in prep).

Impacts of Burrowing Mammals on Soil Biota and Processes: This project involves the influence of the den activity of the Swift Fox (*Vulpes velox*) on soil arthropod community structure. Active dens and those that possess pups (active/natal dens) have been compared to inactive dens and undisturbed native areas. The dens, the entrances to the dens and 1 and 10 meters from the entrances have been sampled over the past two years for arthropods, vegetation and overall occupancy/activity by the foxes. We expanded the study this summer to include soil bacteria, fungi, protozoa, and nematodes with funds provided by the RAMHSS supplement to Univ. of Northern Colorado (Moore, PI). Seven minority high school students from the Denver/Greeley area assisted us over a six-week period with sampling the dens, performing the different assays and with the data analysis. Fox dens had a marked effect on vegetation and on the soil biota. Grasses and cacti were reduced or eliminated in regions adjacent to dens. Bacterial and fungal densities were higher in natal dens compared to native soils away from the dens. Nematodes and protozoa were higher away from the dens compared to soils within or near the dens.

## **2. Biogeochemistry**

In the past year, we have continued our long-term investigations into the controls over biogeochemical pools and fluxes, at several temporal and spatial scales. Below, we summarize our most recent results, and particularly highlight those that resulted in publications this year.

CO<sub>2</sub> Fertilization Study: SGS LTER investigators (Mosier, Parton, Milchunas) have successfully received renewal funding for our CO<sub>2</sub> fertilization study, which is also supported by the SGS LTER project. The study utilizes open-to chambers to address three objectives: 1) to determine the impact of doubling CO<sub>2</sub> in shortgrass steppe mixed C<sub>3</sub>/C<sub>4</sub> plant communities on net primary production, net ecosystem CO<sub>2</sub>/H<sub>2</sub>O exchange, C and N allocation both above and below ground, and water and N use efficiency; 2) to determine the impact of doubling CO<sub>2</sub> on soil water and n dynamics on soil water content, C/N distribution in soil organic matter, changes in mineralizable N, No and N<sub>2</sub>O emissions, and consumption of atmospheric CH<sub>4</sub>; 3) to incorporate the knowledge gained from these studies into simulation models that will allow for realistic extrapolation through time and space of soil moisture, nutrient cycling, and plant productivity. Preliminary results from this study indicate significant enhancement of aboveground plant biomass in the double CO<sub>2</sub> treatment. An estimated 40% of annual N input into the

soil is re-emitted to the atmosphere as  $\text{NO}_x$  and approximately 4% as  $\text{N}_2\text{O}$ . The double  $\text{CO}_2$  soils emitted ~35% less  $\text{N}_2\text{O}$  but about the same amount of  $\text{NO}_x$  as soils under ambient  $\text{CO}_2$  (Mosier et al. 1998).

Anthropogenic Additions of Nitrogen: We have initiated several new studies on the long-term effects of additional N on ecosystem structure and function. We have recently manipulated some long-term SGS-LTER N-addition plots, under funding from a separate NSF grant, in an effort to study processes responsible for n retention and availability. In a large-scale, replicated design, we are adding humus precursors to soils to stimulate n stabilization, as well as adding microbial C sources to stimulate immobilization's.  $^{15}\text{N}$  labeled additions are being tracked through soil organic matter pools using NMR. We are following n mineralization and plant community composition, with respect to weedy vs. native species. A graduate student associated with this project is conducting greenhouse studies to assess the influence of N and water availability on weed recruitment for shortgrass steppe soils (see also weed work listed in populations section above). In a long-term N addition study completed this year, we found that nitrogen fertilization through animal deposition or synthetic N application of pastures within the Colorado shortgrass steppe results in increased nitric oxide ( $\text{NO}$ ) and nitrous oxide ( $\text{N}_2\text{O}$ ) emissions for at least the following 15 years (Mosier and Parton 1998, Parton et al. 1998).

Species Effects on Biogeochemistry: We continue to focus a number of studies on the impacts of plant species composition on biogeochemical cycling. Much of our earlier work focused on the spatial patterns in biogeochemistry created by plant distributions. Recent studies (Epstein et al in press, Epstein et al in press b, Epstein et al. submitted) have demonstrated that plant function type ( $\text{C}_3$  vs.  $\text{C}_4$ ) can affect both the spatial and temporal patterns of nitrogen cycling in shortgrass steppe. Phenological and nutrient use efficiency patterns result in seasonal patterns of interactions between plants and soil microbial communities with respect to N cycling and uptake, with significant impacts on nitrogen and carbon trace gas fluxes. These differences may result in long-term and large-scale impacts on n cycling, retention, and storage.

Carbon and Nitrogen Distributions with Depth: A great deal of our past research has focused on the controls over organic matter distributions horizontally across the landscape and across microsites, while much less research has explored what controls the depth-distribution of SOM and nutrient availability. One of the interesting inconsistencies in the literature regarding soil organic matter in grasslands derives from the observation that although a very high proportion of plant roots are located in the soil surface, soil organic matter is distributed more evenly through the profile, not the expected pattern if most grassland SOM derives from root inputs. We have recently estimated decomposition and root production through the soil profile to attempt to explain this pattern. We estimated decomposition using buried litter bags distributed among several depths, and estimated root production using minirhizotrons. The data suggest that production and decomposition alone are insufficient to explain the patterns of SOM distribution. This may be the result of (1) movement of dissolved organic matter from the soil surface to depth, (2) geomorphic processes resulting in the accumulation or loss of mass from the

soil surface, or (3) complex kinetics associated with the formation of SOM from root detritus (Gill and Burke 1998 ESA abstract, and manuscript in prep).

In a separate study, we evaluated the patterns of nitrogen availability with depth (Dodd 1997). Measurements of nitrogen availability through a loamy sand soil profile showed that the largest nitrogen resource occurred in the top 10cm, but that favorable soil moisture conditions could substantially increase available nitrogen at depths up to 60cm. This implies an important link between water and nitrogen availability.

Studies of biogeochemistry that include cross-site analysis, regional studies, and synthesis are listed under Cross-Site and Synthesis Products.

### **3. Disturbance**

In 1997, the LTER (Milchunas and others) and the USFS initiated a fire study with the dual objectives of assessing the use of fire as management practice to increase nesting habitat for mountain plovers, and examining the effects of fire on plant community structure and productivity. Fire is an integral component of many productive grassland ecosystems such as the tallgrass prairie of the North American Great Plains. A large number of comprehensive studies on fire effects have been conducted in these systems. Because of the low fuel loads, pre-settlement fires probably affected less extensive areas in systems such as the shortgrass steppe. However, small lightning fires may have been frequent in shortgrass steppe, and fire impacts in this system are poorly understood.

The vegetation component of the fire study is assessing 1) aboveground net primary production, 2) plant nitrogen concentration and yield, 3) canopy cover, 4) cactus mortality, and 5) shrub condition. Preliminary data indicate no significant effect of fire on ANPP or on aboveground plant-tissue N-concentrations. The first year's fire was, however, followed by a year of well-above-average precipitation. Although not yet statistically analyzed, some cactus cladode injury was observed, and resprouting from injured plants was greater than new cladode formation on control area. Measurements will continue through after each burn to assess further impacts.

### **4. Water and Energy Dynamics**

In addition to continuing to monitor at a number of long-term sites, we completed several short-term studies of water dynamics (Dodd and Lauenroth 1998, Dodd 1997, Dodd et al. in prep). The first study was designed to test a model that suggests that grasses use water from the upper layers of the soil, and shrubs obtain the majority of their water from the lower layers. The study involved the use of field data and simulation model. The second study answered a similar question by experimentally manipulating shrub and grass density and evaluating the effects on soil water. The third study was closely related to the first two but focused on identifying the sources of water used by grasses, shrubs and trees using an analysis of stable isotopes of water ( $\delta^{18}\text{O}$  (and carbon)  $\delta^{13}\text{C}$ ). The last study examines the interannual variability of precipitation. Finally, we have initiated a new rainshelter study to examine long term drought responses.

Water Dynamics and Vegetation Structure: Soil texture has a large influence on soil water dynamics especially with respect to the depth of penetration and storage of water. We used field data from three locations each with a different soil texture, for which we have soil water data (1986-1990), to calculate available water by soil layer and to estimate parameters for a daily time step soil water model. The simulation model was used to calculate the fifty-year average behavior of soil water at each location. The two key results from this study were: 1) coarse textured soils had a larger deep water resource than fine textured soils and this was associated with a greater relative abundance of shrubs; and 2) the additional water available in coarse textured soils resulted in higher plant productivity. These results support the idea that woody plants have greater access to soil water resources stored deep in the soil than grasses.

Manipulation of Grass and Shrub Density: We selectively removed grasses, shrubs, both or neither from pots on which we subsequently monitored soil water content by depth (0-180cm). Removal of grasses resulted in increases in soil water content of the top 60 cm of the soil profile. A portion of this water eventually moved deeper in the soil where it was used by shrubs. Removal of shrubs had no effect on soil water storage indicating that grasses were able to use all of the available water. Further, removal of shrubs had no effect on grass productivity.

Stable Isotope Analysis of Water Use: The  $\delta^{18}\text{O}$  abundance of potential sources can be compared to the  $\delta^{18}\text{O}$  abundance of water extracted from plants to identify source of sources from which a plant obtains its water. We investigated the role of precipitation and ground water in providing growing season water resources to grasses, shrubs and trees. We further evaluated the significance of water resources by examining the  $\delta^{13}\text{C}$  abundance as an indication of whether the plants had been subjected to water stress. Our results indicated that trees (*Populus sargentii*) used only ground water and that grasses (*Bouteloua gracilis*) used only soil water from precipitation. Results for the shrub, *Atriplex canescens*, indicated that it likely uses a mixture of precipitation and ground water sources. The general conclusion from this work also suggested that woody plants have greater access to and rely more heavily on deep soil water than do grasses.

Rainout Shelters: Our climatic analyses of the region have indicated that variability in precipitation increases with decreasing average annual precipitation; our site has very high interannual variability. Our long-term studies have assisted us in understanding interannual variability, but there has not been a persistent drought since the 1950's. We have recently completed the construction of two rainshelters that are now functioning. Both shelters automatically close when precipitation is sensed. Within the shelters, we have control plots (all water from this week's precipitation added back in), half precipitation (half the water added back), and on-third precipitation treatments.

## **II. Information Management**

### **1. Progress to Date**

In a continuing effort to bring all of our datasets in line with NSF's 2-year public accessibility guidelines, we have opened 6 new datasets to the public; currently 120 of 213 datasets are open to the public and the data management staff received nearly all of the closed datasets within the past three years. These datasets are available via our website at <http://sgs.cnr.colostate.edu>. We continue to contact principal investigators on a regular basis regarding the status of their datasets. Along with this effort, we have uncovered metadata for older datasets from the International Biome Project (IBP). To date we have located complete metadata for 20 of the 65 IBP datasets and partial metadata for all 65 IBP datasets.

One of the goals of the SGS data management program is to utilize our website as our primary communication tool within our group and to the public. We are currently developing an integrated information management system for linking personnel, publications and datasets. This system, which is nearly two thirds complete, will allow a guest to our website to move seamlessly between related information in any of these three data types. In another effort to improve the effectiveness of our information, all of the species present on the shortgrass steppe have been cataloged into a searchable index available via our website.

## **2. Goals for the Upcoming Year**

In the coming year, we plan to focus on three aspects of our information management system. First, we plan to complete the link between our publications and our datasets. In addition, we plan to migrate our database management system out of Oracle and into MS Access. This will allow us to utilize integrated software solutions for serving information via the World Wide Web. It is hoped that this structure will reduce development time for new applications. Along with new web software, we plan to redesign and update our entire web site to provide a consistent look and feel throughout our site. Ongoing activities include opening more datasets to public access, entering the abstracts of older publications, and improving our website content and design.

## **3. Geographical Information Systems**

In the past year a large emphasis has been placed on developing a system to georeference all of the study sites on the Shortgrass Steppe LTER site. We have identified many of these research sites and have begun to georeference them using a hand-held GPS unit. Ultimately we will incorporate these data into our Information Management System.

# **III. Outreach Activities**

## **1. Shortgrass Steppe Symposium**

In 1994, we began cooperating with the Agricultural Research Service to sponsor an annual symposium with the goal of reaching out to the research, management, and user

communities that have an interest in the shortgrass steppe. The all-day symposium is characterized by a high degree of interaction, through poster presentations, short plenary sessions, focal discussions groups, and even games that focus on the shortgrass steppes. This past winter, we completed the 4<sup>th</sup> symposium, which was attended by 85 people, including scientists and managers from the ARS, managers and scientific staff from the U.S. Forest Service Pawnee national Grasslands, the rancher president of the Crow Valley Grazing Association, and representatives of the academic community (professors, graduate and undergraduate students, and technical support staff). We are finding that our relationship with the ARS, U.S. Forest Service, and the livestock operators has improved markedly over the past 4 years, based upon a shared understanding of the ecology of the site and our priorities for new research.

## **2. Education**

In the past year we have continued our Research Experience for Undergraduate (REU) program with four students working on the following projects: 1) the effects pocket gophers on nitrogen availability, 2) avian abundance associated with prairie dog towns, 3) species composition, water, and nitrogen concentrations along roadsides, and 4) species composition, water and nitrogen concentrations along riparian areas. This REU program has been extremely successful and we consider it an integral part of education at the shortgrass steppe LTER. In the coming year, we hope to expand this program by re-applying for status as a NSF REU site.

With funding from NSF-DUE (spring 1998), we established schoolyard LTER demonstration plots on the campus of UNC that mimics an experiment at the SGS LTER site. Our objectives are to study the effects of nitrogen availability on the development of the plant and soil communities following a major disturbance. Baseline samples will be taken this summer and the treatments will be imposed in the fall. The samples will be taken and analyzed by 7 first-generation low-income high school students that are part of the UNC Upward Bound Program (funded by the DOE) and that are receiving fellowships from the NSF-FAMHSS supplement we were awarded through the SGS-LTER this spring. We have also applied for funding from NSF to support permanent links between our schoolyard LTER program and local K-12 schools. We envision the schoolyard LTER program becoming a permanent feature of the SGS LTER.

## **3. Media Coverage**

In December 1997 Channel 9 News of Denver and Rocky Mountain news each released a story detailing grazing research conducted by the SGS LTER. This story was released through the associated press and was subsequently picked up by many local newspapers throughout Colorado and Rocky Mountain region. The media reported on research results that suggest that grazing by cattle does not alter the structure of shortgrass steppe systems. Later this year we hope to release a story detailing prairie dog research conducted on the SGS LTER.

## **4. Field Trips and Other Uses of Shortgrass Steppe LTER Field Site**

One of the important contributions we make in the area of outreach is to lead field trips for interest groups to our research site. In addition, each year we host several non-LTER groups who are conducting classes or research at our field site. 1997-98 visitors included: students and professors from the University of Wyoming and West Greeley High School, University of Dayton-Ohio, St. Mary's College, University of Oklahoma, University of Colorado; a large professional group organized out of the US Geologic Survey and Bureau of Land Management Washington office, US Department of Agriculture, US Forest Service; and visiting scientists from Argentina, Hungary, and Spain.

## **IV. Cross-site, Synthesis, and Network-level Activities**

We have initiated and continued a number of new cross-site and synthesis studies over the past year. We will divide these into Field Studies, Regional Analyses, and Other Synthesis Activities.

### **1. Field Studies**

We have collected data for numerous cross-site studies this year. We are using a  $^{15}\text{N}$  tracer to assess the importance of soil organic matter (SOM) and soil texture on N retention in native grasslands (Barrette and burke 1998). In the spring of 1996, we applied 50 and 2.5g of  $^{15}\text{N}$  labeled  $\text{NH}_4\text{SO}_4\text{-N}$  to 1 m<sup>2</sup> plots on coarse and fine textured soils at 5 sites along a temperature gradient between the panhandle of Texas and southeastern Montana. We collected soils and plant material at the end of the 1996 and 1997 growing seasons to estimate N retention of plant biomass and SOM pools, and have just completed sample  $^{15}\text{N}$  analysis. Retention of the low addition of N was close to 100% for all sites. Fine textured soils and soils with high SOM content retained more  $^{15}\text{N}$  than coarse textured soils and sites with low SOM content. Our results suggest that soils can be an important sink of anthropogenic nitrogen in grassland ecosystems.

In a second study, we have been utilizing several semiarid sites to evaluate how plant life form influences nutrient cycling (Gill and Burke 1997, 1998). Many semiarid ecosystems have experienced a change in dominant plant life form. In the SW United States, many former grasslands and savannas have had an increase in woody vegetation's in the last century, and many shrublands in the Great Basin of the United States have been invaded by annual grasses. Associated with these changes are shifts in the dominant rooting patterns and aboveground plant structure. We utilized soil isotopic techniques to assess how changes in plant life form alter the depth distribution of soil organic matter (SOM) at sites in southern Texas, New Mexico, and Utah. We found that in all three invasions, woody vegetation had higher SOM content in surface soils than did grasses, and that annual grasses influence soils to only 30 cm, but there is evidence of perennial grass influence to a depth of 1 meter.

Third, in conjunction with an LTER cross-site grant, small mammal exclosures (lagomorphs and rodents) were constructed in 1997 at three of six SGS large-herbivore exclosure sites. This will allow us to compare the roles of small selective herbivore to large generalist herbivores in the shortgrass steppe, and across sites that differ in

productivity and evolutionary history of grazing. Other sites included in the study are Konza, Cedar Creek, Deseret montane, Deseret bunchgrass, and Badlands. Baseline data for ANPP, plant species cover, and soil C&N were collected in 1996. In 1997, baseline data was also collected for shrub density and volume by measuring every individual shrub in the small mammal exclosures and in equal areas of the new large mammal exclosures and adjacent long-term grazed areas. Previous casual observations suggest that small mammals may have large impacts on shrub abundance and structure in this system through winter browsing activities. Cover and ANPP estimates after the first year of treatment will be collected early August 1998.

Fourth, in collaboration with Imanuel Noy-Meir and the U. S.-Israel BSF, a comparative study of the importance of natural grazing refugia in U. S. and Israel grasslands was initiated in 1998. The grasslands in Israel and shortgrass steppe of North America both have a long history of grazing by domestic animals, but geologically formed grazing refugia are common in Israel and rare in the U.S. Great Plains. The role of these refugia in harboring rare plant species was examined. A second aspect involves the potential of *Opuntia polyacantha* cacti to provide short-term refugia from grazing. The potential interaction between large-scale refugia with a large seed pool and the small-scale cacti refugia is being examined by Dr. Salvador Rebollo of Alcala University, Spain. Preliminary analyses of the data indicate that cacti refugia do not influence plant species richness, but have a large influence on seed production. Detailed analyses of these data are currently underway.

Fifth, although funding for our cross-site project on decomposition and productivity with our Argentinean collaborators has ceased, we are continuing our field studies and manipulations of water, increased temperature, and nitrogen additions. We recently submitted our progress report for this study.

Finally, we have recently received funding as an LTER supplement to conduct new transect studies from the SGS-LTER to the Konza LTER site, and to initiate new cross-site work with the Sevilleta beginning with a workshop at the Sevilleta this fall. The work with the Konza will follow up on work by Vinton and Burke (1997) that suggested that there are significant changes in plant-soil interactions across the precipitation gradient.

## **2. Regional Analyses**

We continue to conduct many regional analyses as part of our larger grassland region research group. SGS-LTER investigators were recently funded by EPA to continue our regional analysis; the LTER and EPA activities are very closely related with respect to our research questions, but the EPA project extends our questions to address the cropland systems that are such an important part of the region. Under LTER funding, we have recently completed two regional analyses of plant species distributions and productivity (Epstein et al. 1997, 1998), and one on the similarity of grasslands and shrublands in N. and S. America (Paruelo et al. 1998). We recently completed an analysis of landuse patterns, and found that environmental variables explain 81% of the variance in landuse management in the Central Grasslands region (Burke et al. 1998). A study comparing

primary productivity of native grasslands and wheat fields across regional gradients was completed (Lauenroth et al. submitted). Finally, a graduate student recently conducted a cross-site analysis of IBP and LTER data to assess the patterns in litter quality across large scale climatic gradients (Murphy et al. submitted).

The coupling of the climate version of the Regional Atmospheric modeling System (RAMS) and the biogeochemical model (CENTURY) has been successfully completed (Liston and Pielke in prep). Annual runs with the coupled system have been performed and show different results than when the models are run separately from each other (i.e. with the vegetation condition specified for RAMS, and, alternatively, the weather conditions specified for CENTURY). In addition, a new biophysics module (LEAF-2) has been introduced into RAMS which permits more realistic partitioning of surface heat and moisture fluxes from spatial scales which are smaller than the meteorological model grid.

### **3. Synthesis**

Modeling continues to be an important synthesis activity for the SGS-LTER investigators. We have developed and tested a new daily version of the CENTURY model (DAYCENT) (Parton et al. submitted). The monthly version of the CENTURY nutrient cycling, organic matter cycling, and plant growth submodels were modified to run using a daily time step and the trace gas model (NGAS) was incorporated into the nutrient cycling submodel. We have written a series of papers describing the structure of the DAYCENT model and comparing the model results with observed data. The comparisons included observed vs. simulated soil temperature and water, plant production, nutrient mineralization rates, soil respiration rates and trace gas fluxes.

Among our highlights for synthesis, we synthesized data concerning bird and rodent community and species responses to livestock grazing from studies across North America (Milchunas et al. in press). Dissimilarities of bird community species composition in response to differences in grazing intensities were generally higher in systems with a short than a long evolutionary history of grazing. Preliminary assessment of the rodent data indicates a strong and generally negative effect of grazing on richness and diversity of rodent species in most plant communities.

Other important synthesis works that have resulted from SGS work include: a re-evaluation of the role of prairie dogs in Great Plains ecosystems (Stapp, in press), synthesis of methodologies for estimating root production (Lauenroth submitted) and conducting regional analyses (Burke submitted), evaluation of stable isotope signatures as paleoenvironmental indicators (Kelly et al. 1998), summary of controls over trace gas flux in shortgrass steppe ecosystems (Mosier et al. 1998), and synthesized long term data on soil water dynamics in shortgrass steppe (Singh et al. 1998).

## **SECTION 1: POPULATIONS AND PROCESSES**

Our work since our last progress report has focused on continuing to sample our long-term projects and to continue several new studies initiated with our latest grant. The new animal work involved expanding the work on prairie dogs begun in 1997. Belowground work centers on understanding the effects of grazing on microbial communities.

Spatial distribution of weeds: Weeds, especially exotic plants, represent one of the most serious challenges to the current structure and function of ecosystems. A key first step in understanding the problem in a particular area is to investigate which species are present, where they are located and how abundant they are. We initiated a study in 1998 to begin answering these questions for the Central Plains Experimental Range and western section of the Pawnee national Grassland (1024 km<sup>2</sup>). Our initial approach is to use the roads and stream courses to do the assessment. This approach assumes that the roads and the riparian areas along stream act as conduits for the movement of species as well as loci for invasion of the adjacent grassland. The products from this work will be maps of the distribution and abundance of exotic plant species (total and by species) for roadsides, riparian areas and upland grassland. Our expectation is that this information will lead to experimental work on mechanisms controlling invasion of grassland by exotic species. The work involves two graduate students, two REU's and one additional undergraduate funded by a NSF research program on campus.

The effects of increasing temperatures on shortgrass steppe vegetation: There is now general agreement that global warming is apparently primarily a result of increases in daily minimum temperatures (TMIN) rather than increases in daily maximum temperatures (TMAX). We examined long-term weather data from the SGS LTER and determined that this pattern has held true for the period 1964-1993. Evaluation of vegetation data indicates that total ANPP and density of several species, including *Opuntia polyacantha*, were most closely correlated with precipitation. However, ANPP of the dominant grass species, *Boutella gracilis*, and several other important species, was most closely and negatively, correlated with spring TMIN. Also of interest was the finding that density of plants in the "exotic forb" functional group increase significantly with an increase in TMIN. These results suggest that this ecosystem may be sensitive to increases in minimum temperatures similar to those that are being observed globally (Alward et al. in prep).

We constructed four automated shelters to cover plots from sundown to dawn from spring until fall (except during periods of precipitation) to reduce radiative heat losses and warm plots primarily during nighttime hours. Compared with adjacent plots without shelters, covered plots had 1.5 to 2.0 C higher temperatures from 10cm above the ground surface to at least 30 depth in the soil. The higher temperatures resulted in more rapid drying of the soil in covered plots. Among the major findings related to increased nighttime temperatures, we have observed (a) increased tillering rates and advanced phenology, but decreased inflorescence production, in *B. gracilis*; (b) seasonal shifts in insect herbivory damage *Pascopyrum smithii*, a common C3 grass, such that there was less damage early in the growing season but more damage later; and increased cladode production but decreased flower and fruit production in the abundant and widespread cactus, *O. polyacantha* (Alward and Detling, in prep).

Animal Monitoring Programs: Since 1994, we have estimated population sizes of nocturnal small mammals, rabbits, and terrestrial carnivores on the SGS-LTER (Stapp 1997, a,b,c,d and in press). These monitoring programs continued in 1997-1998, including live-trapping studies in may and roadside counts of rabbits and canids quarterly. We continued monthly warm-season surveys of terrestrial macroarthropods. Captures of major insect tax are counted in 90 pairs of pitfall traps placed along a 1km topographic gradient in new long-term monitoring studies. In 1998, we began arthropod pitfall trapping on trapping webs established for monitoring abundance of small mammals. Pitfall traps are run for 4-5 consecutive days on thee occasions during summer months to track changes in abundance of arthropods, which are important food items for rodents in shortgrass steppe, as a possible determinant of trends in rodent numbers.

Beginning this year, we modified our roadside census route to include areas of the Pawnee national grasslands (PNG), taking advantage of the 1996 SGS-LTER site expansion. The new route 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.

Prairie Dog Studies: Prairie dogs (*Cynomys ludovicianus*) influence their surroundings in many ways. These herbivorous mammals change local plant community structure by cropping vegetation, and they modify the soil structure by burrowing and building mounds. These changes in vegetation and edaphic factors may influence insects such as beetles and grasshoppers that live in prairie dog towns. We have completed one year of research aimed at understanding the relationship between short-horned grasshoppers (Orthoptera: Acrididae), darkling beetles (Coleoptera: Tenebrionidae) and prairie dogs. Preliminary results indicate that there are fewer grasshoppers on prairie dog towns than on the surrounding prairie, suggesting that prairie dogs may alter prairie habitats in a way that may be unfavorable for grasshoppers. Tenebrionid beetles were sampled by pitfall traps once every 3 weeks from July through mid-September 1997. During 1998, traps will be set four times between late May and mid-September. This work is being conducted by a graduate student (Junell) under the direction of Bea Van Horne. An REU student is also working with P. Stapp to assess the influence of prairie dogs on avian abundances this summer.

We have initiated new work on the genetics of prairie dog populations (Roach, under direction of Van Horne and Antolin). Prairie dog colonies in shortgrass steppe exist in spatially isolated subpopulations that are connected by dispersal, traits typical of metapopulations. The dynamics of these subpopulations are also determined by local colony extinction, which results from plague, agricultural control efforts and recreational shooting. Difficulties in quantifying dispersal behavior have complicated efforts to document the degree of connectedness between isolated colonies. However, patterns of genetic relatedness among populations can provide an estimate of the degree of linkage between subpopulations and e used to generate hypothese about the types of behavioural processes responsible for these patterns. In this study, we plan: 1) to establish levels of genetic heterogeneity within and among black-tailed prairie dog populations and 2) to

evaluate proposed models of recolonization based on the degree of genetic differentiation among recolonized and established colonies. We sampled 13 prairie dog colonies on the SGS site from May-December 1997: 6 at Central Plains Experimental Range (CPER) and 7 at Pawnee national Grasslands (PNG). A tissue sample was collected from each individual for genetic analysis. We are currently measuring genetic variability within and among populations of prairie dogs using microsatellite loci markers. Cluster analysis of data from the microsatellite markers will reveal patterns of relatedness among populations and will be used to evaluate the role of dispersal in maintaining genetic diversity of the metapopulation. Results from this study may be used to describe patterns of prairie dog metapopulation dynamics. Determining the effects of extinction and recolonization events on genetic diversity can provide predictions about the stability of metapopulations and provide possible guidelines for maintaining rare and endangered species in highly fragmented habitats.

Last, we are studying the above prairie dog towns to distinguish between effects associated with soil churning and movement and those associated with consumption of vegetation, and to determine the magnitude of each effect. In doing so, we are characterizing changes in plant species composition, cover, and biomass in areas inhabited by black-tailed prairie dogs and in nearby uncolonized areas (Detling and Milchunas), and examining the effects of prairie dogs on plant nitrogen content and potentially mineralizable nitrogen in soil (Detling and Burke). A graduate student and REU are involved in the latter work on mineralizable nitrogen. We anticipate expanding the scope of this project during 1999 with the addition of at least one new graduate student working with Dr. Detling. Measurements of plant biomass, species composition and cover, and N content will continue as before to determine to what extent modifications induced by prairie dogs change over time as intensive grazing continues.

### *Belowground Processes*

Impacts of Grazing on Soil Biota and Processes: This project involves manipulating cattle grazing in historically non-cattle grazed and cattle grazed pastures and tracking the changes in above and belowground communities. We moved fences in 1991 to expose previously ungrazed exclosures and to create new exclosures on historically grazed pastures. Yearly sampling has shown a marked shift in the microbial community. Grazed pasture that was taken out of grazing now possesses a community structure that is similar to the ungrazed pasture, and ungrazed pasture that was allowed to be grazed is similar in structure to the historically grazed pastures. The microbial communities began to diverge from one another two years following the manipulations. The complete shift has taken six years to materialize, and was only evident after the last growing season. We are in the middle of processing this year's samples from these sites (Moore in prep).

Impacts of Burrowing Mammals on Soil Biota and Processes: This project involves the influence of the den activity of the Swift Fox (*Vulpes velox*) on soil arthropod community structure. Active dens and those that possess pups (active/natal dens) have been compared to inactive dens and undisturbed native areas. The dens, the entrances to the

dens and 1 and 10 meters from the entrances have been sampled over the past two years for arthropods, vegetation and overall occupancy/activity by the foxes. We expanded the study this summer to include soil bacteria, fungi, protozoa, and nematodes with funds provided by the RAMHSS supplement to Univ. of Northern Colorado (Moore, PI). Seven minority high school students from the Denver/Greeley area assisted us over a six-week period with sampling the dens, performing the different assays and with the data analysis. Fox dens had a marked effect on vegetation and on the soil biota. Grasses and cacti were reduced or eliminated in regions adjacent to dens. Bacterial and fungal densities were higher in natal dens compared to native soils away from the dens. Nematodes and protozoa were higher away from the dens compared to soils within or near the dens.

## SECTION 2: BIOGEOCHEMISTRY

In the past year, we have continued our long-term investigations into the controls over biogeochemical pools and fluxes, at several temporal and spatial scales. Below, we summarize our most recent results, and particularly highlight those that resulted in publications this year.

### *CO<sub>2</sub> Fertilization Study*

SGS LTER investigators (Mosier, Parton, Milchunas) have successfully received renewal funding for our CO<sub>2</sub> fertilization study, which is also supported by the SGS LTER project. The study utilizes open-to chambers to address three objectives: 1) to determine the impact of doubling CO<sub>2</sub> in shortgrass steppe mixed C<sub>3</sub>/C<sub>4</sub> plant communities on net primary production, net ecosystem CO<sub>2</sub>/H<sub>2</sub>O exchange, C and N allocation both above and below ground, and water and N use efficiency; 2) to determine the impact of doubling CO<sub>2</sub> on soil water and n dynamics on soil water content, C/N distribution in soil organic matter, changes in mineralizable N, NO and N<sub>2</sub>O emissions, and consumption of atmospheric CH<sub>4</sub>; 3) to incorporate the knowledge gained from these studies into simulation models that will allow for realistic extrapolation through time and space of soil moisture, nutrient cycling, and plant productivity. Preliminary results from this study indicate significant enhancement of aboveground plant biomass in the double CO<sub>2</sub> treatment. An estimated 40% of annual N input into the soil is re-emitted to the atmosphere as NO<sub>x</sub> and approximately 4% as N<sub>2</sub>O. The double CO<sub>2</sub> soils emitted ~35% less N<sub>2</sub>O but about the same amount of NO<sub>x</sub> as soils under ambient CO<sub>2</sub> (Mosier et al. 1998).

### *Anthropogenic Additions of Nitrogen*

We have initiated several new studies on the long-term effects of additional N on ecosystem structure and function. We have recently manipulated some long-term SGS-LTER N-addition plots, under funding from a separate NSF grant, in an effort to study processes responsible for n retention and availability. In a large-scale, replicated design, we are adding humus precursors to soils to stimulate n stabilization, as well as adding microbial C sources to stimulate immobilization's. <sup>15</sup>N labeled additions are being

tracked through soil organic matter pools using NMR. We are following n mineralization and plant community composition, with respect to weedy vs. native species. A graduate student associated with this project is conducting greenhouse studies to assess the influence of N and water availability on weed recruitment for shortgrass steppe soils (see also weed work listed in populations section above). In a long-term N addition study completed this year, we found that nitrogen fertilization through animal deposition or synthetic N application of pastures within the Colorado shortgrass steppe results in increased nitric oxide (NO) and nitrous oxide (N<sub>2</sub>O) emissions for at least the following 15 years (Mosier and Parton 1998, Parton et al. 1998).

### *Species Effects on Biogeochemistry*

We continue to focus a number of studies on the impacts of plant species composition on biogeochemical cycling. Much of our earlier work focused on the spatial patterns in biogeochemistry created by plant distributions. Recent studies (Epstein et al in press, Epstein et al in press b, Epstein et al. submitted) have demonstrated that plant function type (C<sub>3</sub> vs. C<sub>4</sub>) can affect both the spatial and temporal patterns of nitrogen cycling in shortgrass steppe. Phenological and nutrient use efficiency patterns result in seasonal patterns of interactions between plants and soil microbial communities with respect to N cycling and uptake, with significant impacts on nitrogen and carbon trace gas fluxes. These differences may result in long-term and large-scale impacts on n cycling, retention, and storage.

### *Carbon and Nitrogen Distributions with Depth*

A great deal of our past research has focused on the controls over organic matter distributions horizontally across the landscape and across microsites, while much less research has explored what controls the depth-distribution of SOM and nutrient availability. One of the interesting inconsistencies in the literature regarding soil organic matter in grasslands derives from the observation that although a very high proportion of plant roots are located in the soil surface, soil organic matter is distributed more evenly through the profile, not the expected pattern if most grassland SOM derives from root inputs. We have recently estimated decomposition and root production through the soil profile to attempt to explain this pattern. We estimated decomposition using buried litter bags distributed among several depths, and estimated root production using minirhizotrons. The data suggest that production and decomposition alone are insufficient to explain the patterns of SOM distribution. This may be the result of (1) movement of dissolved organic matter from the soil surface to depth, (2) geomorphic processes resulting in the accumulation or loss of mass from the soil surface, or (3) complex kinetics associated with the formation of SOM from root detritus (Gill and Burke 1998 ESA abstract, and manuscript in prep).

In a separate study, we evaluated the patterns of nitrogen availability with depth (Dodd 1997). Measurements of nitrogen availability through a loamy sand soil profile showed that the largest nitrogen resource occurred in the top 10cm, but that favorable soil

moisture conditions could substantially increase available nitrogen at depths up to 60cm. This implies an important link between water and nitrogen availability.

Studies of biogeochemistry that include cross-site analysis, regional studies, and synthesis are listed under Cross-Site and Synthesis Products.

### SECTION 3: DISTURBANCE

In 1997, the LTER (Milchunas and others) and the USFS initiated a fire study with the dual objectives of assessing the use of fire as management practice to increase nesting habitat for mountain plovers, and examining the effects of fire on plant community structure and productivity. Fire is an integral component of many productive grassland ecosystems such as the tallgrass prairie of the North American Great Plains. A large number of comprehensive studies on fire effects have been conducted in these systems. Because of the low fuel loads, pre-settlement fires probably affected less extensive areas in systems such as the shortgrass steppe. However, small lightning fires may have been frequent in shortgrass steppe, and fire impacts in this system are poorly understood.

The vegetation component of the fire study is assessing 1) aboveground net primary productions, 2) plant nitrogen concentration and yield, 3) canopy cover, 4) cactus mortality, and 5) shrub condition. Preliminary data indicate no significant effect of fire on ANPP or on aboveground plant-tissue N-concentrations. The first year's fire was, however, followed by a year of well-above-average precipitation. Although not yet statistically analyzed, some cactus cladode injury was observed, and resprouting from injured plants was greater than new cladode formation on control area. Measurements will continue through after each burn to assess further impacts.

### SECTION 4: WATER AND ENERGY DYNAMICS

In addition to continuing to monitor at a number of long-term sites, we completed several short-term studies of water dynamics (Dodd and Lauenroth 1998, Dodd 1997, Dodd et al. in prep). The first study was designed to test a model that suggests that grasses use water from the upper layers of the soil, and shrubs obtain the majority of their water from the lower layers. The study involved the use of field data and simulation model. The second study answered a similar question by experimentally manipulating shrub and grass density and evaluating the effects on soil water. The third study was closely related to the first two but focused on identifying the sources of water used by grasses, shrubs and trees using an analysis of stable isotopes of water ( $\delta^{18}\text{O}$ ) and carbon ( $\delta^{13}\text{C}$ ). The last study examines the interannual variability of precipitation. Finally, we have initiated a new rainshelter study to examine long term drought responses.

Water Dynamics and Vegetation Structure: Soil texture has a large influence on soil water dynamics especially with respect to the depth of penetration and storage of water. We used field data from three locations each with a different soil texture, for which we

have soil water data (1986-1990), to calculate available water by soil layer and to estimate parameters for a daily time step soil water model. The simulation model was used to calculate the fifty-year average behavior of soil water at each location. The two key results from this study were: 1) coarse textured soils had a larger deep water resource than fine textured soils and this was associated with a greater relative abundance of shrubs; and 2) the additional water available in coarse textured soils resulted in higher plant productivity. These results support the idea that woody plants have greater access to soil water resources stored deep in the soil than grasses.

Manipulation of Grass and Shrub Density: We selectively removed grasses, shrubs, both or neither from pots on which we subsequently monitored soil water content by depth (0-180cm). Removal of grasses resulted in increases in soil water content of the top 60 cm of the soil profile. A portion of this water eventually moved deeper in the soil where it was used by shrubs. Removal of shrubs had no effect on soil water storage indicating that grasses were able to use all of the available water. Further, removal of shrubs had no effect on grass productivity.

Stable Isotope Analysis of Water Use: The  $\delta^{18}\text{O}$  abundance of potential sources can be compared to the  $\delta^{18}\text{O}$  abundance of water extracted from plants to identify source of sources from which a plant obtains its water. We investigated the role of precipitation and ground water in providing growing season water resources to grasses, shrubs and trees. We further evaluated the significance of water resources by examining the  $\delta^{13}\text{C}$  abundance as an indication of whether the plants had been subjected to water stress. Our results indicated that trees (*Populus sargentii*) used only ground water and that grasses (*Bouteloua gracilis*) used only soil water from precipitation. Results for the shrub, *Atriplex canescens*, indicated that it likely uses a mixture of precipitation and ground water sources. The general conclusion from this work also suggested that woody plants have greater access to and rely more heavily on deep soil water than do grasses.

Rainout Shelters: Our climatic analyses of the region have indicated that variability in precipitation increases with decreasing average annual precipitation; our site has very high interannual variability. Our long-term studies have assisted us in understanding interannual variability, but there has not been a persistent drought since the 1950's. We have recently completed the construction of two rainshelters that are now functioning. Both shelters automatically close when precipitation is sensed. Within the shelters, we have control plots (all water from this week's precipitation added back in), half precipitation (half the water added back), and on-third precipitation treatments.

## INFORMATION MANAGEMENT

### 1. Progress to Date

In a continuing effort to bring all of our datasets in line with NSF's 2-year public accessibility guidelines, we have opened 6 new datasets to the public; currently 120 of 213 datasets are open to the public and the data management staff received

nearly all of the closed datasets within the past three years. These datasets are available via our website at <http://sgs.cnr.colostate.edu>. We continue to contact principal investigators on a regular basis regarding the status of their datasets. Along with this effort, we have uncovered metadata for older datasets from the International Biome Project (IBP). To date we have located complete metadata for 20 of the 65 IBP datasets and partial metadata for all 65 IBP datasets.

One of the goals of the SGS data management program is to utilize our website as our primary communication tool within our group and to the public. We are currently developing an integrated information management system for linking personnel, publications and datasets. This system, which is nearly two thirds complete, will allow a guest to our website to move seamlessly between related information in any of these three data types. In another effort to improve the effectiveness of our information, all of the species present on the shortgrass steppe have been cataloged into a searchable index available via our website.

## **2. Goals for the Upcoming Year**

In the coming year, we plan to focus on three aspects of our information management system. First, we plan to complete the link between our publications and our datasets. In addition, we plan to migrate our database management system out of Oracle and into MS Access. This will allow us to utilize integrated software solutions for serving information via the World Wide Web. It is hoped that this structure will reduce development time for new applications. Along with new web software, we plan to redesign and update our entire web site to provide a consistent look and feel throughout our site. Ongoing activities include opening more datasets to public access, entering the abstracts of older publications, and improving our website content and design.

## **3. Geographical Information Systems**

In the past year a large emphasis has been placed on developing a system to georeference all of the study sites on the Shortgrass Steppe LTER site. We have identified many of these research sites and have begun to georeference them using a hand-held GPS unit. Ultimately we will incorporate these data into our Information Management System.

# **OUTREACH ACTIVITIES**

## **1. Shortgrass Steppe Symposium**

In 1994, we began cooperating with the Agricultural Research Service to sponsor an annual symposium with the goal of reaching out to the research, management, and user communities that have an interest in the shortgrass steppe. The all-day symposium is characterized by a high degree of interaction, through poster presentations, short plenary

sessions, focal discussions groups, and even games that focus on the shortgrass steppes. This past winter, we completed the 4<sup>th</sup> symposium, which was attended by 85 people, including scientists and managers from the ARS, managers and scientific staff from the U.S. Forest Service Pawnee national Grasslands, the rancher president of the Crow Valley Grazing Association, and representatives of the academic community (professors, graduate and undergraduate students, and technical support staff). We are finding that our relationship with the ARS, U.S. Forest Service, and the livestock operators has improved markedly over the past 4 years, based upon a shared understanding of the ecology of the site and our priorities for new research.

## **2. Education**

In the past year we have continued our Research Experience for Undergraduate (REU) program with four students working on the following projects: 1) the effects pocket gophers on nitrogen availability, 2) avian abundance associated with prairie dog towns, 3) species composition, water, and nitrogen concentrations along roadsides, and 4) species composition, water and nitrogen concentrations along riparian areas. This REU program has been extremely successful and we consider it an integral part of education at the shortgrass steppe LTER. In the coming year, we hope to expand this program by re-applying for status as a NSF REU site.

With funding from NSF-DUE (spring 1998), we established schoolyard LTER demonstration plots on the campus of UNC that mimics an experiment at the SGS LTER site. Our objectives are to study the effects of nitrogen availability on the development of the plant and soil communities following a major disturbance. Baseline samples will be taken this summer and the treatments will be imposed in the fall. The samples will be taken and analyzed by 7 first-generation low-income high school students that are part of the UNC Upward Bound Program (funded by the DOE) and that are receiving fellowships from the NSF-FAMHSS supplement we were awarded through the SGS-LTER this spring. We have also applied for funding from NSF to support permanent links between our schoolyard LTER program and local K-12 schools. We envision the schoolyard LTER program becoming a permanent feature of the SGS LTER.

## **3. Media Coverage**

In December 1997 Channel 9 News of Denver and Rocky Mountain News each released a story detailing grazing research conducted by the SGS LTER. This story was released through the associated press and was subsequently picked up by many local newspapers throughout Colorado and Rocky Mountain region. The media reported on research results that suggest that grazing by cattle does not alter the structure of shortgrass steppe systems. Later this year we hope to release a story detailing prairie dog research conducted on the SGS LTER.

## **4. Field Trips and Other Uses of Shortgrass Steppe LTER Field Site**

One of the important contributions we make in the area of outreach is to lead field trips for interest groups to our research site. In addition, each year we host several non-LTER groups who are conducting classes or research at our field site. 1997-98 visitors included: students and professors from the University of Wyoming and West Greeley High School, University of Dayton-Ohio, St. Mary's College, University of Oklahoma, University of Colorado; a large professional group organized out of the US Geologic Survey and Bureau of Land Management Washington office, US Department of Agriculture, US Forest Service; and visiting scientists from Argentina, Hungary, and Spain.

## CROSS-SITE, SYNTHESIS, & NETWORK-LEVEL ACTIVITIES

We have initiated and continued a number of new cross-site and synthesis studies over the past year. We will divide these into Field Studies, Regional Analyses, and Other Synthesis Activities.

### 1. Field Studies

We have collected data for numerous cross-site studies this year. We are using a  $^{15}\text{N}$  tracer to assess the importance of soil organic matter (SOM) and soil texture on N retention in native grasslands (Barrett and burke 1998). In the spring of 1996, we applied 50 and 2.5g of  $^{15}\text{N}$  labeled  $\text{NH}_4\text{SO}_4\text{-N}$  to  $1\text{ m}^2$  plots on coarse and fine textured soils at 5 sites along a temperature gradient between the panhandle of Texas and southeastern Montana. We collected soils and plant material at the end of the 1996 and 1997 growing seasons to estimate N retention of plant biomass and SOM pools, and have just completed sample  $^{15}\text{N}$  analysis. Retention of the low addition of N was close to 100% for all sites. Fine textured soils and soils with high SOM content retained more  $^{15}\text{N}$  than coarse textured soils and sites with low SOM content. Our results suggest that soils can be an important sink of anthropogenic nitrogen in grassland ecosystems.

In a second study, we have been utilizing several semiarid sites to evaluate how plant life form influences nutrient cycling (Gill and Burke 1997, 1998). Many semiarid ecosystems have experienced a change in dominant plant life form. In the SW United States, many former grasslands and savannas have had an increase in woody vegetations in the last century, and many shrublands in the Great Basin of the United States have been invaded by annual grasses. Associated with these changes are shifts in the dominant rooting patterns and aboveground plant structure. We utilized soil isotopic techniques to assess how changes in plant life form alter the depth distribution of soil organic matter (SOM) at sites in southern Texas, New Mexico, and Utah. We found that in all three invasions, woody vegetation had higher SOM content in surface soils than did grasses, and that annual grasses influence soils to only 30 cm, but there is evidence of perennial grass influence to a depth of 1 meter.

Third, in conjunction with an LTER cross-site grant, small mammal exclosures (lagomorphs and rodents) were constructed in 1997 at three of six SGS large-herbivore exclosure sites. This will allow us to compare the roles of small selective herbivore to

large generalist herbivores in the shortgrass steppe, and across sites that differ in productivity and evolutionary history of grazing. Other sites included in the study are Konza, Cedar Creek, Deseret montane, Deseret bunchgrass, and Badlands. Baseline data for ANPP, plant species cover, and soil C&N were collected in 1996. In 1997, baseline data was also collected for shrub density and volume by measuring every individual shrub in the small mammal exclosures and in equal areas of the new large mammal exclosures and adjacent long-term grazed areas. Previous casual observations suggest that small mammals may have large impacts on shrub abundance and structure in this system through winter browsing activities. Cover and ANPP estimates after the first year of treatment will be collected early August 1998.

Fourth, in collaboration with Imanuel Noy-Meir and the U. S.-Israel BSF, a comparative study of the importance of natural grazing refugia in U. S. and Israel grasslands was initiated in 1998. The grasslands in Israel and shortgrass steppe of North America both have a long history of grazing by domestic animals, but geologically formed grazing refugia are common in Israel and rare in the U.S. Great Plains. The role of these refugia in harboring rare plant species was examined. A second aspect involves the potential of *Opuntia polyacantha* cacti to provide short-term refugia from grazing. The potential interaction between large-scale refugia with a large seed pool and the small-scale cacti refugia is being examined by Dr. Salvador Rebollo of Alcala University, Spain. Preliminary analyses of the data indicate that cacti refugia do not influence plant species richness, but have a large influence on seed production. Detailed analyses of these data are currently underway.

Fifth, although funding for our cross-site project on decomposition and productivity with our Argentinian collaborators has ceased, we are continuing our field studies and manipulations of water, increased temperature, and nitrogen additions. We recently submitted our progress report for this study.

Finally, we have recently received funding as an LTER supplement to conduct new transect studies from the SGS-LTER to the Konza LTER site, and to initiate new cross-site work with the Sevilleta beginning with a workshop at the Sevilleta this fall. The work with the Konza will follow up on work by Vinton and Burke (1997) that suggested that there are significant changes in plant-soil interactions across the precipitation gradient.

## **2. Regional Analyses**

We continue to conduct many regional analyses as part of our larger grassland region research group. SGS-LTER investigators were recently funded by EPA to continue our regional analysis; the LTER and EPA activities are very closely related with respect to our research questions, but the EPA project extends our questions to address the cropland systems that are such an important part of the region. Under LTER funding, we have recently completed two regional analyses of plant species distributions and productivity (Epstein et al. 1997, 1998), and one on the similarity of grasslands and shrublands in N. and S. America (Paruelo et al. 1998). We recently completed an analysis of landuse patterns, and found that environmental variables explain 81% of the variance in landuse

management in the Central Grasslands region (Burke et al. 1998). A study comparing primary productivity of native grasslands and wheat fields across regional gradients was completed (Lauenroth et al. submitted). Finally, a graduate student recently conducted a cross-site analysis of IBP and LTER data to assess the patterns in litter quality across large scale climatic gradients (Murphy et al. submitted).

The coupling of the climate version of the Regional Atmospheric modeling System (RAMS) and the biogeochemical model (CENTURY) has been successfully completed (Liston and Pielke in prep). Annual runs with the coupled system have been performed and show different results than when the models are run separately from each other (i.e. with the vegetation condition specified for RAMS, and, alternatively, the weather conditions specified for CENTURY). In addition, a new biophysics module (LEAF-2) has been introduced into RAMS which permits more realistic partitioning of surface heat and moisture fluxes from spatial scales which are smaller than the meteorological model grid.

### **3. Synthesis**

Modeling continues to be an important synthesis activity for the SGS-LTER investigators. We have developed and tested a new daily version of the CENTURY model (DAYCENT) (Parton et al. submitted). The monthly version of the CENTURY nutrient cycling, organic matter cycling, and plant growth submodels were modified to run using a daily time step and the trace gas model (NGAS) was incorporated into the nutrient cycling submodel. We have written a series of papers describing the structure of the DAYCENT model and comparing the model results with observed data. The comparisons included observed vs. simulated soil temperature and water, plant production, nutrient mineralization rates, soil respiration rates and trace gas fluxes.

Among our highlights for synthesis, we synthesized data concerning bird and rodent community and species responses to livestock grazing from studies across North America (Milchuna et al. in press). Dissimilarities of bird community species composition in response to differences in grazing intensities were generally higher in systems with a short than a long evolutionary history of grazing. Preliminary assessment of the rodent data indicates a strong and generally negative effect of grazing on richness and diversity of rodent species in most plant communities.

Other important synthesis works that have resulted from SGS work include: a re-evaluation of the role of prairie dogs in Great Plains ecosystems (Stapp, in press), synthesis of methodologies for estimating root production (Lauenroth submitted) and conducting regional analyses (Burke submitted), evaluation of stable isotope signatures as paleoenvironmental indicators (Kelly et al. 1998), summary of controls over trace gas flux in shortgrass steppe ecosystems (Mosier et al. 1998), and synthesized long term data on soil water dynamics in shortgrass steppe (Singh et al. 1998).

## GRANTS RECEIVED

**Table 1:** Grants received which utilize the SGS LTER site or are associated with the SGS LTER project.

Title	Funding Agency	CSU Principle Investigators	Total Budget Dollars	% of Fieldwork at LTER Site
Long-term ecological research: shortgrass steppe	NSF	Burke, Lauenroth, Coffin, Detling, Kelly, Milchunas, Parton, Pielke, and Van Horne	\$3,360,000	100%
Ecosystem significance of soil as a long-term sink for anthropogenic additions of N	NSF	Burke, Lauenroth	\$678,000 CSU portion	100%
Presidential Faculty Fellow Award	NSF	Burke	\$500,000	100%
The relationship of climate to the stable isotope composition of hackberry	NSF	Kelly	\$118,867	100%
The role of natural grazing refuges in grassland biodiversity	US-Israel Bi-national Foundation	Milchunas	\$64,415 CSU portion	100%
Declining native plant diversity caused by invasive weeds and interactions	USGS	Stohlgren	\$75,000	66%
Effects of different-sized herbivores on grassland plant diversity: a cross-site study	NSF	Detling, Milchunas	\$66,481	50%
Integrated assessment of climate and land use changes in the central US	DOE	Ojima, Parton	\$215,867	50%
A regional assessment of land use effects on ecosystem structure and function in the Central Grassland region of the US	EPA	Burke, Lauenroth, Paruelo, Parton, Pielke, and Mosier	\$1,500,000	50%
Developing a multi-agency, multi-scale vegetation sampling program for the central grasslands	USGS	Stohlgren	\$180,908	45%

Land use and climate change impacts on carbon fluxes	NIGEC	Ojima, Parton	\$164,449	20%
Population and environment in the US Great Plains	NIH	Parton, Burke	\$349,021	20%
US-Hungary comparison: response of vegetation to environment	NSF	Coffin, Freckman	\$156,076	20%
Long-term impact of elevated CO2 on shortgrass steppe ecosystem dynamics and trace gas exchange	NSF	Mosier, Morgan, Milchunas, Parton, and Ojima	\$614,935	10%
Biotic controls on soil C dynamics and N cycling under elevated CO2	NSF	Milchunas, Freckman, Ojima	\$499,587	10%
Using multi-sensor data to model factors limiting carbon balance in global grasslands	NASA	Schimel, Ojima, Parton	\$3,109,969	10%

**Table 2:** Current grants focusing on research education for undergraduate and graduates.

<b>Student</b>	<b>Agency</b>	<b>Amount of Award</b>	<b>% of Fieldwork at LTER site</b>
Rich Alward- Ph.D.	NASA	\$66,000	100%
Tamera Minnick- Ph.D.	NSF	\$69,000	100%
Elizabeth Sulzman- Ph.D.	NASA	\$66,000	100%
2 Undergraduates	NSF/REU Supplement to LTER project	\$10,000	100%
1 Undergraduate	NSF/REU Supplement to Lauenroth Humus project	\$5,000	100%
1 Undergraduate	NSF/REU Supplement to Burke PFF grant	\$5,000	100%