COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 08-1 **NSF 08-1**	FOR NSF USE ONLY NSF PROPOSAL NUMBER **0823405**
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) **DEB - Long-Term Ecological Research**	

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☐ SMALL BUSINESS ☐ MINORITY BUSINESS
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TITLE OF PROPOSED PROJECT **Shortgrass Steppe Long Term Ecological Research**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 5,640,000	72 months	11/01/08	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
- ☐ BEGINNING INVESTIGATOR (GPG I.G.2)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.1)
- ☐ VERTEBRATE ANIMALS (GPG II.D.5) IACUC App. Date ________ PHS Animal Welfare Assurance Number ________
- ☐ HUMAN SUBJECTS (GPG II.D.6) Human Subjects Assurance Number ________ Exemption Subsection ________ or IRB App. Date ________
- ☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j) ________
- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.G.1)

PI/PD DEPARTMENT **Department of Biology**	PI/PD POSTAL ADDRESS **Fort Collins, CO 80523** **United States**
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CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the Authorized Organizational Representative or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), nondiscrimination, and flood hazard insurance (when applicable) as set forth in the NSF Proposal & Award Policies & Procedures Guide, Part I: the Grant Proposal Guide (GPG) (NSF 08-1). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

Conflict of Interest Certification

In addition, if the applicant institution employs more than fifty persons, by electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.A; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be dislosed to NSF.

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By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

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The following certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

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Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:

(1) community in which that area is located participates in the national flood insurance program; and
(2) building (and any related equipment) is covered by adequate flood insurance.

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(1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
(2) for other NSF Grants when more than $25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME Marilyn Morrissey	Electronic Signature	Feb 1 2008 5:07PM

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PROJECT SUMMARY

Intellectual Merit: Twenty five years of intensive study has revealed a Shortgrass Steppe (SGS) ecosystem that is resilient. Despite chronic water stress, periods of severe drought, and intensive grazing by large herbivores, the essential ecological structure and key interactions maintaining the SGS and its services have remained intact. With global change, however, we may see a range of conditions far outside those experienced on the SGS during the last several thousand years. Forecasting how ecosystems will respond to global change depends on mechanistic understanding of ecosystem drivers. The resilient SGS ecosystem, bounded within "natural" variation but interrupted by human influence, may be supplanted by an unfamiliar one, with humans playing a direct role. Research at SGS-LTER aims toward understanding how ecosystem resilience is influenced by interactions of five key drivers: climate, physiography, biotic structure, natural disturbance, and human landuse. The goal of SGS-LTER renewal is to "test the limits" of resilience, function and structure of the SGS, by both continuing our past work, and by experimentally manipulating factors we know from previous work to be important. We consider multiple temporal scales of change, and our combination of long-term monitoring, short and long-term experiments puts us in the position to forecast the impacts of global change on the SGS. Our global change experiments follow two criteria: *i)* manipulating factors that will most likely change in the future; and *ii)* selecting ecological attributes and interactions we previously identified either as vulnerable to change or likely to influence multiple other interactions. We organize and guide our research around these questions:

- *What are key functional attributes that contribute to ecological stability and resilience of the SGS?*
- *What are the key vulnerabilities to long-term resilience, which changes are likely to be most influential (e.g. climate, landuse, invasive species), and at what time scales?*
- *To what extent does the mosaic of fragmentation, both from natural disturbances and human landuse, affect the structure and function of the SGS?*
- *At what level (or scale) of change does return to previous function and structure become unlikely?*

The SGS-LTER project is organized into several research groups that focus on biotic interactions (plants, fauna, soil ecology) and ecosystem processes (biogeochemistry, global change), with multiple interdisciplinary studies united by cross-LTER studies, data synthesis and modeling.

Broader impacts: Besides publishing hundreds of peer-reviewed journal articles and scholarly books in outlets with global reach (esp. the SGS volume for the LTER series from Oxf. Univ. Pr.), SGS-LTER impacts Colorado State Univ., communities and land users within Colorado, and beyond. Activities include: outreach to ranchers, non-governmental organizations (e.g. Nature Conservancy, Rocky Mountain Bird Observatory, Crow Valley Grazing Association) and land managers (USDA Agricultural Research Service, USDA Forest Service Pawnee National Grassland); a large educational program integrated across K-12; involvement by hundreds of undergraduates as field crew, independent study students and NSF-REUs; and an active graduate program (22 dissertations and theses during 2002-2008). Much of our education work reaches out to groups underrepresented in STEM disciplines, for instance Denver high school students through regional TRIO programs (Upward Bound, Upward Bound-Math and Science). Our ability to provide outreach will vastly improve upon completion of our Grasslands Research and Education Center at the SGS-LTER headquarters, which includes a classroom building (under construction), housing (later in 2008), and a new laboratory (planned).

We publicly present our research and education programs at annual Ag Days (CSU) and the Western Stock Show in Denver, CO. Our main outlet to the public is our semi-annual "Shortgrass Steppe Symposium". The most recent one in Jan. 2007 examined changing landuse and human impacts, and was attended by ~180 including staffers for several federal and state elected officials, workers from county, state and federal agencies, members of local and state conservation groups, and ranchers from the area surrounding the SGS-LTER site.

We maintain a proactive Information Management system that works to improve access to SGS-LTER long-tem data sets. Our web page is being redesigned to facilitate data access.

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For font size and page formatting specifications, see GPG section II.C.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

<u>SECTION 1. Results from Prior Support SGS-LTER V (DEB 0217631)</u>: E.F. Kelly, I.C. Burke, M. Antolin, J. C. Moore, J. Morgan. 2002-2008. Long Term Ecological Research - Shortgrass Steppe. $4,600,000.

The six years encompassed by the previous Shortgrass Steppe Long Term Ecological Research grant (SGS-LTER V) included significant advancements in our understanding of grassland ecology as well as more general ecological principles, a broadening of research expertise within the program, an increase in multidisciplinary efforts, and planned turnover in scientific personnel and a transition in leadership. Since its inception in 1983, the project has maintained an integrated program of core ecological monitoring across multiple spatial and temporal scales coupled with short- and long-term experiments. The overarching theme for the SGS-LTER program identifies ***climate, natural disturbance, physiography, human land use, and biotic interactions*** as key determinants (forcing factors) responsible for the structure and functioning of this ecosystem. In SGS-LTER V, we extended our research to focus on the <u>vulnerability</u> of SGS ecosystems to <u>environmental change, particularly with respect to the five determinants and their interactions</u>. To accomplish the goals of SGS-LTER V, we (1) continued to evaluate the long term effects of grazers (historically important biotic drivers now under human control) on SGS ecosystem dynamics, (2) continued experiments on climate change, and human and natural disturbances, (3) initiated new experiments evaluating the influence of fire, land use, and wildlife populations on the SGS ecosystem, and (4) broadened our research program by initiating new cross site, international, and synthesis activities.

Research productivity and quality, measured as peer-reviewed publications, invited book chapters, books and scientific presentations increased substantially during this funding cycle. The SGS-LTER produced approximately 192 journal articles (including papers in *Nature, Science, and P.N.A.S.,*), 3 books, 59 book chapters, 22 dissertations and theses, and many abstracts from national and international meetings (Table 1.1). Most of these involved multiple authors, reflecting the collaborative spirit and interdisciplinary nature of the SGS-LTER research program. We are especially pleased to report that lead scientists from the SGS-LTER spearheaded completion of the book entitled ***Ecology of the Shortgrass Steppe: A Long Term Perspective*** (Lauenroth and Burke, *in press*) This volume is a comprehensive synthesis of our LTER research over the last 25 years, combining research and expertise of 23 primary authors, and further exemplifies the high degree of interaction and the interdisciplinary nature of research conducted throughout the SGS-LTER program.

During the last funding cycle, we made significant changes to our Information Management System. In addition to personnel changes, we revised the relational database management system to more efficiently organize, relate and deliver information, data and metadata. The Information Management System of the SGS-LTER program archives extensive amounts of data, metadata, and other information that is available to researchers inside and outside the SGS-LTER program. Besides normal requests for publications, the SGS-LTER presently maintains 133 data sets that are currently available on line (Table 1.2a). The use of these data sets by non-SGS-LTER scientists is substantial in that 76% of the total requests are from outside users (Table 1.2b)

Throughout its history, the SGS-LTER has been actively involved in training the next generation of scientists. Providing this experience requires the joint commitment of SGS-LTER scientists and staff who actively mentor students. During this funding cycle, we supported 22 graduate students with stipends and 24 with travel, supplies and facility access, 80 undergraduate students, 11 Research Experience for Undergraduate (REU) students, and 3 post-doctoral fellows.

The Education and Outreach component of LTER V grew significantly by increasing the number of partnerships with regional school districts, professional development and training for K-12 teachers, research internships for teachers and minority high school students, and cross-site education and outreach programs among LTER sites (AND, ARC, BES, CAP, KBS, JRN, LUQ, MCR, and SBC). These initiatives were supported by the SLTER supplements and funding from multiple state and federal agencies and foundations generated four peer reviewed publications (Kazachkov et al. 2006; Rahm, et al. 2003, 2008; Trautman et al. 2003) and two book chapters (Moore et al. 2006; Rahm et al. 2008). Additionally, the SGS-LTER contributed substantially to the development of a network-wide LTER education plan as part of the LTER Planning Grant activities.

While page limitations prevent us from discussing all of our results, we highlight some of our findings, prioritizing major syntheses of long term data and new discoveries from this most recent round of funding. A full accounting of our research accomplishments and details of experimental procedures and results can be found in our research summaries for each major research area in our ***Progress Reports*** submitted to NSF (2003 to 2007) (http://sgslter.colostate.edu/ProgressReports/proposal.htm).

The SGS Ecosystem and Grazing.

A central focus of SGS-LTER work has been the response of the shortgrass steppe to cattle grazing. The shortgrass steppe biota evolved in the presence of grazing by large herds of bison. Present-day grazing by domestic livestock is a surrogate for this integral component of the system, which favors native shortgrass fauna and flora, and limits the abundance of invasive, ruderal, or 'weedy' plant species. During this most recent round of funding we continued our long term experiments on the impacts of grazing on SGS ecosystem structure and function, and also produced several synthetic analyses (Adler et al. 2005, Diaz et al. 2007, Bakker et al. 2006, Milchunas et al. 2008).

Plant species composition in the shortgrass steppe is relatively stable when subjected to grazing of a range of intensities, more so than other grasslands (Milchunas et al. 2008). Comparisons of grazed vs. ungrazed sites indicate that ungrazed plant communities are more likely to be invaded by exotic and native weedy species. Ungrazed communities, then, are more representative of disturbed plant communities than are grazed communities. The underlying mechanism for this response is posited to be increased basal cover by native grasses in grazed areas, resulting in a more uniform exploitation of above and belowground resources, and reduction in safe-sites for 'weedy'colonization (Milchunas et al. 1992, Milchunas et al. 2008).

We investigated how interactions between large and small mammalian herbivores influence plant community structure and diversity by building exclosures for small mammals (other than prairie dogs, which are absent from these pastures) to complement our existing exclosure for large mammals. This was part of a cross site synthesis project in North America and Europe. The influence of large plus small herbivores on plant species richness depended on site primary production changing from negative to positive as primary production increased (Bakker et al. 2006). Species richness of the shortgrass steppe was negatively affected by both the combination of herbivore sizes and by small herbivores alone. Past work has shown small negative influences of large herbivores on plant species richness (Milchunas et al. 1998, Hart 2001). This study confirmed that most small mammals do not strongly influence plant species composition, either alone or in combination with large herbivores.

In a global synthesis of plant traits known to respond to grazing by large herbivores, we evaluated six conceptual models that may explain which plant traits become associated with each other under different combinations of climate and herbivore history, using data from 197 sites representative of all of the major grazing regions on Earth (Diaz et al. 2007). Grazing history, as proposed by the SGS model (Milchunas et al. 1988, Milchunas and Lauenroth 1993), best explains the combinations of life history, plant type, and plant morphology of species found on grasslands worldwide.

Finally, data from SGS-LTER provided the most detailed analysis to date of the relationship between prairie dog occupancy and cattle grazing. We found that cattle neither avoid or prefer prairie dog towns (Guenther and Detling 2003) and that prairie dogs only decrease cattle weight gain when they occupy more than 40% of the area within pastures (Derner et al. 2006).

SGS Ecosytem and Belowground Foodwebs.

Research at the SGS-LTER increased our understanding of food web theory as well as the way in which they are studied. This is particularly relevant to our research because of the importance of belowground ecosystem processes at the SGS. This work has 1) incorporated biogeochemical processes into the study of trophic-dynamics, 2) integrated detritus and donor-controlled dynamics, and 3) led to development of techniques to apply empirically-derived field and laboratory data to test food web theory, and to study the "dynamics of dynamics" encompassing changes in population sizes, strengths of interactions among species, and dynamic states of food webs in space and time (Moore et al. 2003, Moore et al. 2004, de Ruiter et al. 2005a, de Ruiter et al. 2005b, Rooney et al. 2006).

SGS Ecosystem and Faunal - Disease Interactions.

The population biology of prairie dogs has been altered by the introduction into North America of *Yersinia pestis,* the bacterium that causes plague. Plague converted prairie dogs into metapopulations, by causing local extinction of prairie dog towns during outbreaks, with subsequent recolonization 2-4 years after the disease wanes (Antolin et al. 2006). Analyses of long-term surveys of spatial occurrence of prairie dog towns (size and location) on the SGS-LTER site revealed that plague outbreaks are more common during years with El Niño climatic patterns (Stapp et al. 2004), but uncommon during hotter and drier years. Three factors predict the timing and location of plague outbreaks: connectivity (clustered towns), cooler-wetter summers, and soils with high moisture retention (Savage 2007). Our results demonstrate that current-year weather conditions, which affect survival of fleas, the bacterium, or both, may be better predictors of plague outbreaks than suggested from previous models (Enscore et al. 2002, Collinge et al. 2005) emphasizing indirect lagged effects of weather mediated by increases in host density.

A central question is how plague, with high virulence causing rapid mortality of mammalian hosts, persists on the grasslands. Field-parameterized modeling (Webb et al. 2006), laboratory experiments (Eisen et al. 2006, Wilder et al. in press a,b) and field surveys (Tripp 2007, Stapp et al. in press; Stapp et al. submitted) examined the role of infected fleas and other small mammals in driving plague outbreaks, and point to the role of small mammals or fleas as short-term reservoirs for the pathogen.

We examined how species associated with prairie dogs respond to the mosaic of habitats generated by prairie dog metapopulation dynamics. Characteristics differ between occupied towns, recently vacated towns after plague epizootics, later when burrows collapse and grasses recover, and newly recolonized towns. Differences among these habitat types are found in small mammals (Stapp 2007a), plant communities (Hartley 2006, Stapp 2007a), pollinators (Hardwicke 2006), harvester ants (Alba 2007), and below-ground microbial communities (Quirk 2006). We considered the possibility of a trophic cascade in this ecosystem (e.g. Yates et al. 2002), with the plague bacterium *Y. pestis* removing the dominant herbivore (i.e. prairie dogs) in this community (Stapp 2007a, b). Community responses to plague and changing prairie dog dynamics are rapid and direct, with little evidence of time lags or a trophic cascade (Savage 2007).

***SGS Ecosystem and Disturbance*.**

A major conceptual emphasis of our long term research focuses on the effects of natural and human-induced disturbance on SGS ecosystems. In general, most natural disturbances are small (1 m^2 to several ha) while most human disturbances are large (>several ha). Recent research on small scale disturbances focused on experimental removal of the dominant plant species, and yielded two surprises. First, the dominant perennial grass *Bouteloua gracilis* recovered rapidly despite thorough attempts to remove all perennial tissue, and second, removal did not change density, diversity, or evenness of other species (Munson and Lauenroth submitted). In both cases our *a priori* predictions based on results from previous research were the opposite of these results. We are still working to reconcile these results.

The most common human disturbance in the shortgrass steppe is conversion of native grassland to dry cropland. The Conservation Reserve Program (CRP) has reversed this by paying farmers to convert cropland back to perennial grassland. Recently, we initiated studies of the characteristics of CRP fields re-seeded to native shortgrass steppe species between 2 and 18 years ago. Compared to native shortgrass steppe controls, 2 year old fields had greater species diversity and 18 year old fields had lower diversity. The major differences among the different-aged fields were increased importance of perennial grasses and decreases of annuals. Net primary production also increased with time since re-seeding, and much of the increase was attributed to belowground production. While NPP for the 18-year-old field was the same as for native shortgrass steppe, the distribution between above and belowground components differed: aboveground NPP was greater and belowground NPP was lower in 18-year-old fields compared to native shortgrass steppe (Milchunas et al. 2005).

Urbanization is a relatively new but rapidly expanding disturbance along the western edge of the shortgrass steppe. Our initial experimental estimates of carbon (C) fluxes, nitrogen (N) cycling, and soil microbial community structure for urban lawns suggests large deviations from established land uses, irrigated corn and dryland wheat, and unmanaged grassland (Kaye et al. 2004; 2005). ANPP in urban ecosystems was four to five times greater than wheat or shortgrass steppe, but significantly less than corn (537 g C m^{-2} y^{-1}). In addition, soil respiration (2777 g C m^{-2} y^{-1}) and total belowground C allocation (2602g C m^{-2} yr^{-1}) in urban ecosystems were 2.5 to 5 times greater than other land-use type (Kaye et al. 2005).

SGS Ecosystem and Changing CO_2.

Recent increases in atmospheric CO_2 have tremendous implications for the ecology of native grasslands like the SGS. A central question emerging from ecosystem-level global change experiments is how ecosystem goods and services are affected by shifts in plant species composition and production caused by rising CO_2 or altered climate.

Experiments that doubled CO_2 concentration over present levels increased aboveground biomass production of native SGS vegetation an average 41% over the 5-year experiment. Most of the increase results from improved plant water use efficiency (Morgan et al. 2004). An initial analysis of the dominant species revealed that the majority of the CO_2-induced production response was due to one native C_3 perennial grass, *Stipa comata*. Production of the other two dominant perennial grasses, *B. gracilis* (C_4) and *Pascopyrum smithii* (C_3), were unaffected by CO_2 concentration. Increased CO_2 also lowered overall forage quality by lowering tissue N concentrations and shifting species composition to less desirable species (Milchunas et al. 2005). New experimental evidence shows that productivity of *Artemisia frigida*, a sub-shrub common to the SGS and to many other North American and Asian grasslands, was enhanced over 20-fold by a doubling of CO_2 (Morgan et al. 2007). This is the first evidence from a manipulative experiment demonstrating how rising atmospheric CO_2 contributes to the shrub encroachment seen in grasslands over the past two centuries.

Understanding the long-term implications of rising CO_2 requires a fundamental understanding of its impacts on nutrient cycling. Luo et al. (2004) introduced the progressive nitrogen limitation (PNL) hypothesis, which postulates that rising atmospheric CO_2 might reduce available soil N, thereby constraining the CO_2-induced stimulation in plant growth via C sequestration. Dijkstra et al. (in review) determined that greater plant N uptake in plants exposed to doubled ambient CO_2 concentrations (King et al. 2004) was caused by greater soil N mineralization. Collectively, these findings suggest that considerable uncertainty still exists about the fate of shortgrass steppe soil N in future CO_2-enriched and warmer climates. A recent modeling study by Parton et al. (2007) showed only minor reductions of soil organic N under elevated CO_2, and Dijkstra et al. (in review) observed increasing N mineralization under elevated CO_2, contrary to the notion of PNL (Luo et al. 2004).

SGS Ecosystem and Global Change.

Future climate scenarios for the central US include increasing temperatures and the potential for a shift to more extreme precipitation patterns in which growing season rainfall events will be fewer in number but larger in size. When coupled with increased N deposition, the potential impacts of invasive species and changes in patterns and occurrence of infectious diseases, suggest that the SGS, like all ecosystems, is facing an unknown future.

In an experiment conducted 35-years ago, we previously reported that short-term additions of nitrogen and water resulted in a legacy of dominance of weedy annuals with high N content (Vinton and Burke 1995, Milchunas and Lauenroth 1995). Midway through this experiment, we added carbon to some plots, with the hypothesis that we could reduce N availability and weedy species. By the beginning of LTER V, we observed both lower N and lower weed dominance. In 2005, we ceased the carbon treatments to test the hypothesis that only treatments that received recalcitrant substrates (sawdust and lignin) would remain weed-free. Indeed, the sugar treatments have reverted to high N availability as well as annual weed dominance only 2 years after ceasing C additions (see Fig. 2.27). This ongoing experiment has substantial relevance to land use management, with respect to identifying cost-effective treatments for effectively reducing invasive species on sites with high N additions.

Climate change may alter timing and intensity of rainfall events, and thus influence ANPP. We manipulated precipitation patterns by use of new experimental rainout shelters: experimental plots (n=15) received the long-term (30-yr) average growing season precipitation, distributed as 4, 6, or 12 events applied manually according to seasonal patterns for May-September (Heisler et al. in review). The long-term average (1940-2005) number of rain events at the SGS-LTER site was 14 events, with a minimum of 9 events in years of average precipitation. Thus, these experimental treatments pushed this system beyond its historic range of variability. Plots receiving fewer, but larger rain events had the highest rates of ANPP (180 ± 38 g/m^2), compared to plots receiving more frequent rainfall (105 ± 24 g/m^2). ANPP in all experimental plots was greater than long-term mean ANPP for this system (97 g/m^2), which may be explained in part by the more even distribution of applied rain events. Soil moisture data from the plots indicated that larger events led to greater soil water content and likely permitted moisture penetration to deeper zones in the soil profile. These results indicate that semi-arid grasslands are capable of responding immediately and substantially to forecast shifts to more extreme precipitation patterns.

Cross-Site and Synthesis Work.

SGS-LTER scientists have been involved in a leadership capacity in data synthesis for one of the first and most extensive cross-site LTER studies – the Long-term Intersite Decomposition Experiment Team (LIDET) (Parton et al. 2007, Adair et al. in press). Parton et al. (2007) focused on N dynamics during decomposition found that litter decomposition is the primary source of mineral nitrogen (N) for biological activity in most terrestrial ecosystems. The 10-year decomposition data from 21 sites (seven biomes) found that net N release from leaf litter is primarily driven by initial tissue N concentration and mass remaining, regardless of climate, edaphic conditions, or the biota. Arid grasslands exposed to high UV radiation were an exception, where net N release was insensitive to initial N. Roots released N linearly with decomposition and exhibited little net N immobilization. This analysis suggests that fundamental constraints on decomposer physiology lead to predictable global-scale patterns in net N release during decomposition.

In a separate LIDET study, we used model selection techniques to parameterize a statistical analysis of global patterns of litter decomposition (Adair et al. in press). Loss of mass was best represented by a three-pool negative exponential model, with a rapidly decomposing labile pool, an intermediate pool representing cellulose, and a recalcitrant pool. The initial litter lignin/nitrogen ratios defined the size of labile and intermediate pools. Below- and aboveground material decomposed at notably different rates, depending on the decomposition stage. Decomposition in certain ecosystem-specific environmental conditions was not well represented by our model; this included roots in wet/cold soils and aboveground litter in N-rich and arid sites. Despite these limitations, this model is still useful for global modeling (R^2 = 0.6804), predicting general patterns of long-term global decomposition for a wide array of litter types from minimal climatic and litter quality data. Finally, a group of SGS-LTER graduate students synthesized the LIDET grassland database, focusing on the unique patterns of decomposition that occur across all grassland sites (Bontti et al. in revision). This was a superb opportunity for graduate education, exposing the group to long-term, multi-site, multi-investigator experiments, as well as metadata management and analysis. Among the most interesting findings was from grasslands, which are usually dominated by belowground processes: aboveground decomposition was faster than belowground decomposition when different substrates were compared (i.e. leaves aboveground and root belowground). The opposite was found when above-and belowground dowels of homogeneous composition were compared, supporting the idea that the belowground environment accelerates decomposition. However, when leaf litter is decomposed aboveground, factors other than temperature and moisture favor decomposition.

Additional results from SGS-LTER V are presented throughout the remainder of this proposal where they are relevant to research activities that make up SGS-LTER VI. As with virtually all LTER programs these new results and our emerging understanding of the structure, dynamics and interactions integral to the focal SGS ecosystem form the basis for much of the new research proposed.

SECTION 2: CONCEPTUAL FRAMEWORK AND RESEARCH PLAN

INTRODUCTION

After more than 25 years of intensive study, the emergent view of the Shortgrass Steppe (SGS) ecosystem is one of resilience. Despite chronic water stress, periods of severe drought, and intensive grazing by large herbivores, the essential ecological structure and key interactions maintaining the SGS and its services have remained intact. With global change, however, we may see a range of climatic conditions far outside those experienced by the SGS during the last several thousand years. Ecologists now recognize the pervasive influence of humans on natural systems, collectively referred to as *global change* (Vitousek 1994**)**, and that global change is sure to become more pressing. Forecasting how ecosystems can respond to an altered future depends on mechanistic understanding of ecosystem drivers. The resilient SGS ecosystem, bounded within "natural" variation but interrupted by human influence, may be supplanted by an unfamiliar one, with humans playing a direct role. Our ability to predict the effects of global change on ecosystems will impact how society responds to these changes, and ultimately determine the cost of responding.

Research at SGS-LTER aims toward understanding how ecosystem resilience is influenced by interactions of five key drivers: climate, physiography, biotic structure, natural disturbance, and human landuse (Fig. 2.1). During SGS-LTER V (2002-2008), we focused on "Biotic and abiotic thresholds, and vulnerability to change in factors regulating structure and function of SGS". The goal for this SGS-LTER is to "test the limits" of function and structure, by both continuing our past work, and by experimentally manipulating factors we know from previous work to be important. We consider multiple temporal scales of change, and our combination of long-term monitoring and short-term experiments puts us in the position to forecast the impacts of global change on the SGS. We organize and guide our research around these questions:

- *What are key functional attributes that contribute to ecological stability and resilience of the SGS?*
- *What are the key vulnerabilities to long-term resilience of the SGS, which changes are likely to be most influential (e.g. climate, landuse, invasive species), and at what time scales?*
- *To what extent does the mosaic of fragmentation, both from natural disturbances and human landuse, affect the structure and function of the SGS?*
- *At what level (or scale) of change does return to previous function and structure become unlikely?*

Our ongoing interdisciplinary studies, development of new techniques and synthesis through modeling promise substantial advances in understanding SGS structure and function. We also propose a number of global change experiments that follow two criteria: *i)* manipulating factors that will most likely change in the future (IPCC, 2007); and *ii)* selecting ecological attributes and interactions we previously identified either as vulnerable to change or likely to influence multiple other interactions. In the following sections, we present background that supports our conceptual framework, our focal hypotheses, ongoing long-term studies, and future plans for short- and long-term experimental research.

BACKGROUND AND CONCEPTUAL FRAMEWORK

Our conceptual model (Fig. 2.1) posits that the origin, current state and future vulnerability of the SGS depends on interactions among five key drivers: climate, physiography, biotic structure, natural disturbance, and human landuse. These drivers influence the long term capability of the SGS to provide ecosystem services (Fig. 2.2). The prospect of global change, however, suggests that long-lasting shifts are possible (Burke et al. 1991, Coffin et al. 1995, Kaye et al. 2004). Grasslands are predicted to be sensitive to an array of global change phenomena (Samson and Knopf 1994, Field et al. 2000, Buckland et al. 2001, Reich et al. 2001b), and little doubt remains that grassland responses will have local, regional and global significance. Increased CO_2 (Morgan et al. 2007), higher night time temperatures (Alward et al. 1999), and modified timing and/or intensity of rainfall (Coffin and Lauenroth 1996) have the potential to change biotic interactions and plant communities, with implications for changing primary productivity, decomposition, nitrogen availability, and ultimately, carbon capture. Climate changes are also likely to locally affect plant distributions (Dodd and Lauenroth 1997), soil microbial communities (Moore et al. 2003), behavior and physiology of animals like prairie dogs (Lehmer et al. 2006) and transmission of diseases that infect them (Stapp et al. 2004, Savage 2007). Increases in nitrogen and water availability generate dramatic changes in plant community structure and productivity that perpetuate over decades (Milchunas and Lauenroth 1995, Vinton and Burke 1995). Finally, land use changes associated with human population growth are very likely to dramatically alter ecosystem structure and function (Burke et al. 1991, Parton et al. 2003). Here we briefly summarize the 5 key drivers of SGS ecosystems, and point out how global change may affect each.

Climate -- Annual precipitation, and its seasonal distribution, profoundly influence this semi-arid grassland. Average annual precipitation across the SGS-LTER ranges from 320 mm on the western edge to 420 mm in the northeast. Most precipitation occurs between March and September, with two distinct periods (Lauenroth and Burke 1995, Pielke and Doeskin 2008). In spring, long-lasting storms provide soil-penetrating rains, while summer brings intermittent afternoon thundershowers that can be locally heavy. Inter-annual variation is dramatic (Lauenroth and Sala 1992), with either or both periods failing in any year. For instance, in 2002, both spring and summer rains failed, and it became one of the driest years on record, rivaling the hottest and driest periods of the 1930s. Precipitation-induced changes cascade through the ecosystem. Fluctuations in vegetative structure (Grant et al. 1977) alter the supply of plant tissues, seeds and arthropods (Crawford 1991); change abundance and species composition of animal communities; and affect ecosystem functions such as net primary productivity (NPP: Lauenroth and Sala 1992), nitrogen (N) mineralization (Hook and Burke 2000), and trace gas flux (Mosier et al. 1991). Feedbacks from the SGS ecosystem to the atmosphere also occur, including reflected radiation, water vapor (Pielke et al. 1997), and trace gases (Mosier et al. 1991). *Global climate change models consistently predict increased variability and intensity of extreme weather events, such as drought in arid regions (IPCC 2007). Thus we focus much of our attention on effects of altered climatic regimes on all aspects of SGS ecosystem responses*.

Biotic Interactions -- Biotic interactions provide mechanisms that link ecosystem structure and function, and in turn feed back to other drivers (Fig. 2.1). While the SGS ecosystem will not rival others (e.g. tropical and temperate rainforests, coral reefs) in terms of productivity or species diversity, it is clear that biotic interactions, particularly among plants, consumers, and soil (microbial) communities shape the SGS ecosystem (Milchunas et al. 1988, Lauenroth and Sala 1992, Moore et al. 2003, Stapp et al. 2008). The biota are particularly well-adapted for drought, with species such as blue grama (*Bouteloua gracilis)*, prickly-pear cactus (*Opuntia polyacantha*), large herbivores (currently cattle, and previously bison), and burrowing animals (e.g. black-tailed prairie dogs: *Cynomys ludovicianus*) often playing dominant or keystone roles, with inordinate effects (nonlinear with abundance) on species diversity and ecosystem processes (Whicker and Detling 1988, Stapp 1998, Kotliar 1999, Lomolino and Smith 2003). The SGS resists invasion by exotic plant species because of the ability of native long-lived C_4 grasses, especially blue grama, to dominate under characteristic dry conditions by efficiently accessing available water (Milchunas et al. 1992, Sala et al. 1992). The SGS stores most biomass and resources belowground, so that aboveground disturbances do not drastically alter biota or ecosystem processes (Burke et al. 1997). Because the SGS depends upon stored carbon and nitrogen in soils, the potential for soil microbial communities to affect structure and function is also relatively large. *Our studies of biotic interactions focus on patterns of biological diversity, the role of species and communities in governing ecosystem resilience, responses of plant, animal and soil microbial communities to abiotic factors and assessing vulnerability to future species extinctions and invasions.*

Natural Disturbance -- Natural disturbances are responsible for some of the spatial variability in the SGS, and ultimately may determine the resilience of the SGS to change. Most disturbances are small (0.1 m^2 to several hectares), with an inverse relationship between size and frequency (Coffin and Lauenroth 1989b). The most frequent disturbances are digging and burrowing by small mammals (badgers, ground squirrels, pocket gophers, and prairie dogs), outbreaks of root-feeding invertebrates, and nest building by harvester ants. Grazing by large generalist herbivores was an important part of the evolutionary history of the SGS, such that we do not consider herbivory to be a disturbance. Disturbances related to soil erosion and deposition occur over longer time scales and at larger spatial scales (Blecker et al. 1997), and are linked to regional shifts in climate. *Fire is a major driver of tallgrass and mixed grass ecosystems, but its role in the SGS is poorly understood. Investigation of the importance of fire relative to other disturbances is a new area of research for the SGS-LTER.*

Physiography -- Most ecological processes are controlled by short-term climatic and human induced perturbations to biota, mediated through the hydrologic and biogeochemical cycles. Over centennial to millennial time scales, ecosystem dynamics are regulated by regional physiography. Biotic systems respond to periodic large-scale shifts in climate, constrained by the slow release of nutrients from parent materials and aeolian deposition (Kelly et al. 2008). Physiographic features within the SGS are formed by interactions between soil materials and landscapes, and vary predictably as a function of landscape age, landscape morphometry, and the origin and composition of geologic materials (Blecker et al. 1997, Loadholt 2001, Kelly et al. 2008). Aspects of physiography that regulate the SGS include landscape position, soil age, water holding capacity, soil depth and surface texture, which in turn determine soil moisture and NPP (Singh et al. 1998), N availability (Burke et al. 1999, Hook and Burke 2000), and distribution of animals such as prairie dogs and pocket gophers (Stapp et al. 2008, Savage 2007). *Although structural aspects of soils and landscapes (age and morphometry) are well characterized, global change forecasting will require better understanding of functional aspects that influence the exchange of gas, water and nutrients.*

Human Use – Since the late 1800s, the dominant human landuse regime included livestock grazing and farming (both dryland and irrigated row-crop agriculture). Sixty percent of the SGS is currently cultivated (Lauenroth et al. 1994), and conversion to cropland drastically alters biological diversity, bigoechemical dynamics and soil organic matter (SOM: Haas et al. 1957, Burke et al. 1989), and temporal and spatial distribution of plant biomass. Because of the regional importance of cropland and long recovery period following abandonment, we focus some of our work on the influence of cultivation. *Cultivation is a key threshold for ecological responses because of the effects of disturbing soils (plowing) on carbon and nutrient stores, and on microbial activity. With the potential of biofuel production (i.e. with greater irrigation), land conversion may become a primary threat to the ecological functioning of the SGS.*

However, over recent decades, the western portion of the SGS, close to our research site, has been subjected to very rapid population growth (Parton et al. 2003; Fig. 2.3). Urbanization and exurban development is now more common than at any time in the past 25 years of SGS-LTER research. While land-use formerly varied at relatively large spatial extents (from field scale to several km^2), humans continue to fragment the SGS, with privately owned lands rapidly being subdivided from large ranches/farms to smaller "horse properties" for commuters to the cities (Maestas et al. 2003). The effects of human disturbances on biotic interactions are addressed to some degree in every research area (Fig 2.1, 2.2). *Our initial studies (Kaye et al. 2004) suggest that urbanization will directly impact biota, hydrology, biogeochemistry and land-atmosphere interactions on the SGS.*

Summary

Our approach has been to balance long-term monitoring with new measurements and experiments that examine functional aspects of the SGS ecosystem that foster resilience. For this SGS-LTER we will:

1) Continue the array of core LTER observations and experiments initiated over 25 years ago, with the goal of further refining our understanding of the *structure* and *function* of the SGS as they are influenced by the 5 key drivers;
2) Develop our capabilities for environmental forecasting with regard to *thresholds* and *changes* in *determinants* that regulate the structure and function of the SGS, using ongoing and new long and short-term experiments; and
3) Expand our *synthetic activities* based on both SGS-LTER and network-wide data and experiments, and use these to advance and test current ecological theory.

SHORTGRASS STEPPE LTER SITE

The SGS-LTER site encompasses a large portion of the Colorado Piedmont of the western Great Plains (Fig. 2.3, 2.4). The extent is defined as the boundaries of the Central Plains Experimental Range (CPER), managed by the Agricultural Research Service (ARS), and the Pawnee National Grasslands (PNG), managed by the U. S. Forest Service. Expansion into the PNG allowed us to explore biotic interactions within the SGS ecosystem across a range of climatic, geologic, topographic and landuse conditions. The CPER has a single ownership and landuse (livestock grazing), whereas the outer boundary of the PNG comprises a mosaic of ownership that includes federal, state and private, and landuse is livestock grazing or row-crops. In addition, non-governmental conservation groups exert influence over the area, particularly on federal lands. This diversity of ownership, landuse, and management underscores the importance of our long-term ecological research program, and we increased our spatial extent, and our use of remotely-sensed data to encapsulate this diversity and its potential to influence ecosystem interactions (Burke and Lauenroth 1993). The SGS-LTER site is at the northernmost boundary of the SGS, with cool-season, mid-height grasses more common in mixed prairies in south-central Wyoming (Fig 2.3). Climate-related changes in composition and structure of the SGS ecosystem may be most apparent at our site, at the transition between these two major Great Plains grasslands.

CONTINUING AND PROPOSED RESEARCH

We distribute our ongoing and proposed work into two areas (Fig. 2.1, 2.2): Population, Community, and Landscape Ecology (with ecosystem interactions affecting plants, animals and soil microbial communities) and Biogeochemistry and Global Change. Within each area, we describe long-term and short-term monitoring and experiments, and modeling for synthesizing our understanding. The research is tightly integrated, such that all research questions encompass multiple connections among the different sections. We use tables to summarize our experiments and related data sets (Tables 1.2, 1.3 and 1.4). Published experiments are cited in the text and described in less detail than new experiments. We are constrained by space, but in cases where details of experimental design or sampling could not be described we reference our web page (http://sgs.cnr.colostate.edu/), using the notation ***WEB***. On the home page, there is a link to Proposal 2009, and then to Methods. Our presentation is centered around major hypotheses under each major heading, and we note which of the ongoing or new proposed activities (***NEW***) are long-term monitoring or experimentation (***LT***), short-term experimentation (***ST***), synthesis (***SYNTH***), or cross-site activities (***XSITE***).

1. POPULATION, COMMUNITY AND LANDSCAPE ECOLOGY

1.A. Plant Dynamics

Plants and plant communities are the foundation of the biotic layer of our conceptual framework. We have invested heavily in studies of plant population and community dynamics since the inception of the SGS-LTER project. In this proposal we continue and expand that work.

1.A.I. Monitoring plant populations and communities

Grasses, shrubs, forbs and succulents are the major components of the vegetation structure of the SGS. Because of its overwhelming importance to cover and biomass, our plant population work has focused heavily on the grass *B. gracilis* (blue grama; Fig. 2.5). Associated with our long-term study of blue grama population dynamics, we also collect data on other species in the same permanent quadrats.

Population dynamics of blue grama: LT 1 and LT49 WEB

We currently sample annual seed production as well as examining the relationship between environmental variability and recruitment, growth, and mortality, on permanent plots mapped in association with a long-term grazing study (**LT32-41**). We map 6 grazed and 6 ungrazed 1 m^2 plots annually in June using a pantograph (Weaver and Clements 1938, Harper 1977, Silvertown and Lovett Doust 1993, Lauenroth and Adler submitted). This work is guided by the following hypothesis:

P1: *The long-term sustainability of SGS ecosystems is dependent upon sustainability of populations of B. gracilis, because it is the most grazing and drought tolerant plant species in the ecosystem. It is the key species for management for both conservation and livestock production.*

Recruitment of blue grama is infrequent, controlled by availability of viable seed, temperature, soil

H_2O and competition from established plants (Lauenroth et al. 1994, Aguilera and Lauenroth 1995). Requirements for germination and establishment are well known; we therefore focus our efforts on other processes. To date we have learned that seed production is strongly influenced by soil texture, grazing and neighboring plants, and that seed storage is limited and variable in time (Coffin and Lauenroth 1989a, 1992, Aguilera and Lauenroth 1993b, 1995, Hook et al. 1994). Simulations using an individual plant-based model (Coffin and Lauenroth 1990, Peters and Lauenroth 2008) suggest an important role for seed dispersal in recovery of blue grama from disturbances (Coffin and Lauenroth 1989a,b, Peters et al. 2008; Fig. 2.6), while field work (Fraleigh 1999) indicates important roles of wind and cattle on seed dispersal.

Population dynamics of plains prickly-pear: LT49

We study the long-term population dynamics of prickly-pear using permanent 1 m^2 plots located inside and outside cattle exclosures, associated with an existing long-term grazing study (**LT32-41**). Annually, we take a perpendicular digital image of each of 6 grazed and 6 ungrazed plots. From these we extract information about the numbers of live (green) and dead (brown) cladodes. Images are scanned and digitized into GIS; the data allow us to estimate birth rate of new and death rates of existing cladodes. This work is guided by the following hypothesis:

P2: *O. polyacantha is a key species for long-term sustainability of SGS ecosystems because it affords protection from grazing to other plant species within the area influenced by its spines (Fig. 2.7), and because it traps wind- and water-transported organic and inorganic material.*

A potentially interesting indirect effect of the refugia provided by prickly-pear to other plant species (Rebollo et al. 2002, 2005) is the influence on small mammal populations. Many SGS small mammals are granivores, and some plants that find refuge around cactus have large seeds favored by granivores. A large-scale herbicide application for cactus control scheduled for 2008 will provide an opportunity to study the role of prickly-pear in SGS plant communities. We will sample on and off the treated areas and measure plant community structure, composition and diversity, as well small mammal abundance and diversity. We expect that small mammals will be reduced by the removal of prickly-pear.

Plant phenology: LT2_WEB

The timing of major events in the life cycle of plants (phenology) provides a plant-integrated assessment of environmental conditions. A meta analysis by Parmesan (2007) found that in the Northern Hemisphere, organisms initiated spring responses 2.8 d earlier each decade: for plants the response was 1.1 to 3.3 d. In 1996, we began a long-term project to assess seven major phenological events for 31 species. These data are collected near our micromet station and employ an "average individual" approach. The hypothesis that guides this work is:

P3: *Plant phenology is a sensitive monitor of climate change because it is an integrated expression of the effect of abiotic environment.*

1.A.II. Global Change and Plant Population Dynamics

Evidence that CO_2, air temperature and precipitation are changing is now overwhelming (http://www.ipcc.ch/). We propose to initiate new research to investigate the effects of these changes on plant populations. The hypothesis that will guide this research is:

P4: *Changing CO_2, temperature and water availability will influence population dynamics directly via growth, survival and reproduction, and indirectly by interactions with other species.*

Plant demography responses to prairie heating, watering and CO_2 Enrichment (PHACE): NEW LT

The combined effects of global change and management on SGS plants will influence their ecology and agricultural utility by changes in both plant species composition and NPP (Morgan et al. 2007). Despite decades of research on species and functional group responses to CO_2, temperature and precipitation, we can only partially predict how different plant species might respond to global changes (Reich et al. 2001). The SGS-LTER is coordinating with a major new global change experiment initiated by the USDA-ARS to explore additional topics not currently part of that experiment (see below: *Prairie heating, watering and CO_2 enrichment (PHACE) experiment*).

Measures of plant demography will be initiated at PHACE to examine how global change alters plant population dynamics. Seedling emergence, seedling survival and adult survival will be assessed on dominant plant species in a factorial combination of two CO_2 (ambient and 600 ppm CO_2) by two temperature (ambient and 1.5/3^o C day/night) treatments (Williams et al. 2007). Inflorescences will be counted during flowering, and inflorescence sub-sets destructively sampled for seeds set.

Woody plant dynamics: NEW LT

On the SGS, shrubs are locally abundant on sandy sites and small trees exist in southernmost portions (Lauenroth and Milchunas 1992). Our research suggests that sub-shrubs such as fringed sagewort (*Artemisia frigida*) may increase under rising CO_2 (Morgan et al. 2007; Fig. 2.8). Expansion of shrubs/small trees, such as mesquite (*Prosopis glandulosa* and *P. velutina*) in grasslands and savannas of southwestern U.S. (Buffington and Herbel 1965, Brown and Archer 1989), may result from a combination of management and climate change. To the extent that northern boundaries of sub-tropical woodland/savanna plants are determined by minimum temperatures, future warmer temperatures and rising CO_2 may promote their expansion northward into the central SGS (Fig. 2.9). To evaluate how present and future climates may affect the establishment and growth of woody plant species in the northern SGS, we propose manipulating seeds and seedlings of woody plants at the CPER. Seeds and seedlings will be introduced into pastures with and without removal of existing vegetation, in factorial combinations with N (to anticipate N deposition effects) and water additions. Introductions will be conducted every five years to develop a time-line of recruitment and subsequent plant responses to environmental changes.

1.A.III. Effects of Natural Disturbance on Plant Communities

Our ongoing work focuses on the effects of natural and human-induced disturbance on SGS ecosystems. Most natural disturbances are small (1 m^2 to several ha) while most human disturbances are large (>several ha). We use experimental studies and simulation modeling to improve our understanding of disturbances and recovery on SGS ecosystems. Most studies of recovery in SGS systems focus on large-scale disturbances, and in particular the cultivation and abandonment of agricultural fields. Small, patch-producing disturbances are also important, and were largely ignored until 1984 (Coffin and Lauenroth 1988, 1989a,b, Peters et al. 2008), but may have the greatest effect on plant community structure. We currently evaluate the effects of western harvester ants, burrows from skunks and badgers, mounds from pocket gophers and prairie dogs, and patches from larvae of June beetles (Aguiar and Lauenroth 2001). A natural disturbance we have ignored in the past is fire, but here we add new long-term investigations of fire. The following hypothesis guides our work on natural disturbances:

P5: *Small-scale disturbances have a major influence on sustainability of the SGS. They are the most important source of plant mortality and thus profoundly influence plant community composition because: i) natural disturbances are frequent; ii) B. gracilis represents a major proportion of plant biomass; and iii) B. gracilis removal can dramatically alter SGS ecosystem structure and function.*

Long-term sampling of recovery from small-scale disturbance: LT27 WEB

We will continue to examine responses to small-scale disturbances by sampling plant cover and density at regular intervals on disturbed areas. This work, initiated in 1984, focuses on disturbances from 0.1 to <5 m^2, and uses gap dynamic concepts to explain the response of plant communities. We will also continue to measure soil heights in and out of these disturbed areas at regular intervals to determine the time required for small-scale soil heterogeneity to recover. In addition, we follow the recovery of vegetation from natural small-scale disturbances such as ant mounds. Data from these studies have been critical in our plant community modeling work (Coffin and Lauenroth 1990, Peters and Lauenroth 2008).

Blue grama removal experiment: LT57 WEB

Both field (Milchunas et al. 1990) and simulation results suggest increases in plant species diversity following removal of blue grama. We initiated an experiment in 1997 to test this prediction and other impacts of removal of the dominant species (Fig. 2.10). The experiment consists of two grazing treatments (grazed, ungrazed), two removal treatments (removal, control), and six replicates. The surprising result to date is that blue grama removal had no significant influence on species density, diversity, or evenness (Munson and Lauenroth submitted).

Recovery from white grub disturbance: LT30 WEB

We continue to sample plant dynamics at regular intervals on patches of vegetation killed by white grubs, the larvae of June beetles. Field studies of these patches began in 1977, where 32 areas have been re-sampled six times. Some comparisons were between areas inside and outside cattle exclosures to analyze effects of grazing on recovery. We reported the first 14 years of recovery in Coffin et al. (1998).

Small mammal grazing effects on plant communities: LT 32, 37 and 38 WEB and NEW LT

In 1996, an LTER cross-site study was initiated to assess the relative importance of large vs. small herbivores across gradients of NPP and evolutionary history of grazing. We propose to continue sampling mammal exclosures on the SGS under the following hypothesis:

P6: *Because they are selective, small herbivorous mammals exert a greater influence on SGS plant community structure than large generalist herbivores that consume greater amounts of dry matter.*

Short- and long-term responses to fire: LT 59 and LT 69 WEB and NEW LT

Considerable research points to the role of fire in tallgrass and mixed grass prairies (Knapp and Seastedt 1986, Hobbs et al. 1991), but almost no work on fire effects in SGS exists. The average low standing biomass of the SGS means there is a low probability of carrying fire. Nonetheless, in wet years aboveground biomass on SGS is equivalent to the mixed grass prairie, and frequent summer lightening provides the necessary spark. Our new work has two components. First, a patch burn experiment examines interactions among fire, livestock grazing behavior and plant community production and composition. Second, a replicated small plot experiment will assess fire frequency and seasonality.

Patch burning: Rotational burning of patches within pastures can increase heterogeneity of vegetation and benefit native fauna without compromising cattle production (Fuhlendorf and Engle 2001). We propose a replicated pasture-scale study, applying prescribed burns to portions of pastures and allowing cattle free selection between burned and unburned areas. We predict the burning will create heavily grazed burned patches and lightly grazed unburned patches within the same pasture. We will measure: *i)* vegetation heterogeneity (community composition and structure); *ii)* forage production and quality; *iii)* livestock foraging and weight gains; *iv)* weed invasion; *v)* wind erosion; and *vi)* animal communities (See below *1.B.III. Effects of natural disturbance on animal communities*).

Small Plots: This study provides a comparison to Konza LTER and two other sites in the western Great Plains (Miles City, MT and Woodward, OK). We will use twenty 20x20 m ungrazed plots and controls, allocated among four treatments - annual spring burn, annual fall burn, 3-year spring burn and 3-year fall burn - to investigate effects of fire on plant community composition and diversity including weed invasions, aboveground NPP, C storage, N cycling and trace gas flux.

1.A.IV. Effects of Human-Induced Disturbance on Plant Communities

Our work on human disturbances encompasses long-term effects of cattle grazing and successional dynamics following cultivation and nutrient enrichment (the latter two are described below, under *Biogeochemistry and Global Change*). The following hypothesis guides our work in this area:

P7/BGC12: *Disturbances of aboveground components (fire, livestock grazing) are minor relative to disturbance of both above-and belowground components (cultivation, construction, mining, etc.,) (Burke et al. 1997). Most organic matter and energy processing occurs belowground in the SGS, thus, disturbances targeting belowground pools have a large impact and generally result in complete removal of the plant community and large losses of nutrients.*

We have conducted many short- and long-term studies on effects of cattle grazing on various aspects of SGS ecosystems, from physiological responses of plants to population dynamics, plant and animal community structure, and rates of ecosystem processes (e.g. Milchunas and Lauenroth 1993, Milchunas et al. 1988, 1989, Coffin and Lauenroth 1989, 1990, Aguiar and Lauenroth 2001). We will continue our long-term studies and initiate two new studies on the effects of grazing.

Long-term evaluation of grazing effects on primary producers LT31 WEB

We have been studying the long-term effects of grazing on plots established by the USDA Agricultural Research Service (ARS) in 1939 that represent ungrazed, lightly, moderately, and heavily grazed treatments (0, 20, 40, and 60% removal of annual forage production). The ARS sampled these treatments for aboveground NPP and species composition through 1964, they were intensively sampled for plant and consumer groups during the International Biological Program (IBP, mid-1960's) and we have continued work in these treatments since 1984.

Long- and short-term effects of grazing: an interdisciplinary study: LT32-38, 39, and 41 WEB

As mentioned above, our previous work demonstrates that cattle grazing does not negatively influence SGS plant communities (Milchunas et al. 1989). However, it appears that litter accumulation, small mammal disturbances and SOM were higher in cattle exclosures than outside. We began an experiment in 1991 to address the short- and long-term effects of grazing on SGS ecosystems, and how these effects interact with soil texture. We will continue this experiment, which consists of treatments associated with 71-year-old exclosures in six locations across a soil textural gradient: long-term grazed, currently grazed; long-term grazed, recently protected; long-term protected, currently protected; and long-term protected, currently grazed. Our large-scale sampling program assesses plant communities, individual plant survival, aboveground and belowground biomass and NPP, SOM dynamics, soil fauna, small-scale disturbances, aboveground foliar N content, and belowground food web structure.

Effects of grazing on recovery from disturbance: NEW LT

As part of the USDA-sponsored Conservation Reserve Program (CRP), many agricultural fields have been planted with non-native or non-local mid-height and tall grasses. In addition, most CRP fields have abundant native and non-native weedy species. Samson et al. (2004) suggested that taller grasses contribute to declines in habitat availability and quality for native wildlife. Native SGS grasses are adapted to grazing (Milchunas et al. 1988), and plants with greater aboveground allocation (annuals and tall grasses) are less tolerant of disturbances (Milchunas and Lauenroth 1995). Grazing of late-seral SGS species also reduces abundance and invasion of exotic and native weed species (Milchunas et al. 1998). Succession in grassland communities is controlled by grazing, but studies of grazing impacts on succession in the SGS region are lacking. The following hypotheses guide this research:

P8: *Grazing of CRP will: i) speed succession towards native SGS species by reducing abundance of weeds and tall grasses; ii) shift plant biomass to a greater proportions of belowground allocation; iii) increase amounts of carbon in SOM because of the greater belowground allocation to roots.*

Livestock as ecosystem engineers: LT66 and NEW LT.

A clear but unacknowledged role for cattle grazing is to engineer ecosystems by changing vegetation structure and composition, and thus directly and indirectly influencing availability of resources to other organisms (Jones et al. 1997). Concerns about declining grassland birds have broadened interests in grazing research (Knopf 1996), and we propose to investigate whether cattle can modify SGS vegetation to meet particular specifications. Our test case is to create nesting habitat for mountain plover (*Charadrius montanus*), widely recognized as declining on the Great Plains (Dreitz and Knopf 2007). The plover represents an extreme along the grazing-habitat gradient, preferring heavily grazed sites (Knopf 1996). Its decline is attributed to loss of nesting habitat after several decades of relatively wet conditions and widespread moderate grazing. Engineering nesting habitat for plovers requires grazing pressure that is outside the well-accepted model that guides our grazing research: moderate to heavy grazing during the growing season. Plovers establish nest sites in late March and early April, suggesting two alternatives for engineering plover habitat. First, we use spatially focused heavy grazing in the spring for a month preceding the arrival of plovers, in pastures that were not grazed the previous season. We use supplemental feed to attract and concentrate cattle to the target portions of the pasture, which should result in small areas that are very heavily grazed within pastures receiving light grazing. Pilot data suggest our approach is feasible (Fig. 2.11). Second, we use traditional summer grazing, but at twice the usual heavy grazing intensity. In this treatment, aboveground biomass of entire pastures, rather than target nest sites, will be reduced to levels of typical plover habitat (Dechant et al. 2003). The experiment entails replicate pastures (65 ha) of each treatment; two moderately summer-grazed pastures serve as controls. Response variables include plant biomass, cover and community diversity, cattle weight gain, and abundance of small mammal, arthropods and birds (see *Faunal Dynamics* for more detail).

1.B. Faunal Dynamics

The faunal subgroup emphasizes long-term spatial and temporal studies of populations of representative species with large effects on SGS ecosystem structure and function. We combine long-term monitoring, experiments, and comparative analyses to assess faunal populations and diversity across the SGS landscape, and determine how the five key ecosystem drivers alter interactions between animals and their resources. Ongoing and new research is centered on three main areas: *i)* long-term population monitoring; *ii)* ecology of prairie dogs, a species of conservation concern that plays a key role in the SGS; and *iii)* new experimental studies of effects of fire, grazing and climate change on SGS fauna.

1.B.I. Monitoring Animal Populations and Communities

During the past funding cycle we focused our animal monitoring on small mammals because they are important as consumers of seeds, arthropods and other small vertebrates, and as prey for a wide range of predators (Stapp et al. 2008). They also alter the system by burrowing and mound-building, and by consuming key plant species. Thus, dynamics of small mammals simultaneously reflect and affect both the structure and function of the SGS ecosystem.

Long-term population monitoring: LT 4, LT 5, LT 6, LT 7, LT 8, LT 10, and LT 53 WEB

Surveys of rodents, rabbits, and mammalian carnivores began in 1994, including live-trapping rodents on grassland and shrubland sites twice yearly, spotlight surveys of rabbits four times yearly along an established route through representative SGS habitats, counts of coyote and swift fox scats four times yearly (Fig. 2.12), and changes in vegetation and abundance of arthropod prey during the growing season. Bird populations are sampled in conjunction with continent-wide annual Christmas Bird Counts and Breeding Bird Surveys. In addition to providing data for other SGS-LTER research, these studies are part of ongoing long-term cross-site analyses of consumer populations across the SGS, SEV and JRN LTER sites (see below). The data will be synthesized into models of both single-species and community dynamics (Fig. 2.13) under one general hypothesis:

F1: *Populations of small consumers vary spatially and temporally, in relation to climate-driven variation in vegetation, habitat, and availability of arthropod prey. Predator populations mirror but lag behind prey, reflecting inter- and multi-annual variation in precipitation and grazing.*

Prairie dog dynamics: LT 61, LT 62, ST 35 WEB and NEW LT

Black-tailed prairie dogs were once abundant on the SGS (Koford 1958), but were reduced by poisoning, shooting, habitat loss through cultivation, and plague (Fig. 2.14). Prairie dogs were candidates for listing under the Endangered Species Act, and their status continues to be controversial. Plague is now the major controller of prairie dogs. The causative agent, *Yersinia pestis*, was introduced into the western U.S. in 1900, spread eastward to the 100th meridian (Barnes 1993, Antolin et al. 2002), and was first recorded in Colorado in 1946 (Ecke and Johnson 1952). It is transmitted by fleas, and may have reservoirs in other resistant small mammals (Gage and Kosoy 2005), although it is possible that plague is maintained solely within prairie dogs. Plague epizootics in prairie dogs are "explosive", causing ~100% mortality of towns every 3-5 y (Cully and Williams 2001). Our data, based on >25 y of surveys on the SGS-LTER, show fluctuations in prairie dog abundance in the face of plague and climatic variability (Fig. 2.15, 2.16). Over the last 5 years, acreage of prairie dog towns increased dramatically as towns expanded and new towns were founded during drought, then, declined during recent large-scale epizootics (Fig. 2.16). Approximately 20-40% of active towns experience complete die-offs in a given year (Fig. 2.17).

Prairie dog monitoring provides data for assessing population dynamics of both prairie dogs and associated species. In annual September surveys, we record GPS coordinates of the outside boundaries of all active towns (Fig 2.14, 2.17). In the past six years we implemented visual counts on standard-sized plots (Severson and Plum 1998). This population index was useful for analyzing effects of prairie dogs on cattle grazing and weight gain (Derner et al. 2006), but estimates of long-term fluctuations are biased by locations of fixed plots. We tested a precise and unbiased method based on visual counts of marked prairie dogs on entire towns (Magle et al. 2007, McClintock et al. in review). The method yields estimates of sightability, necessary for determining biases in counts of burrowing animals like prairie dogs. Town densities are now estimated visually by counting prairie dogs each year on all towns on the CPER and western PNG, using four visual counts between July 1 and August 31.

Our long-term surveys (Stapp et al. in review) suggest that prairie dog towns expand during dry years, a counterintuitive result given the effects of rainfall on NPP and food availability. One hypothesis is that town area increases during dry years as local food supplies are depleted and animals move beyond town boundaries in search of forage. By combining measurements of town area and count-based estimates of densities, we will better understand how population sizes and disturbances of prairie dogs vary as a function of climate. The hypothesis to be tested with these data is:

F2: *In times between plague epizootics, prairie dog towns increase in size, but decline in density, especially in the centers of towns. Population densities increase during wet years, but town expansion slows or is limited by other factors such as topography, soils, and land use.*

Metapopulation dynamics and connectivity of prairie dog towns in SGS landscapes: NEW SYNTH

Our long-term studies of extinction and re-colonization of prairie dog towns across both natural and human-altered landscapes provide an excellent opportunity to study the landscape context of connectivity and persistence of prairie dog metapopulations. Such analyses are timely because of the marked increases in human urban and exurban landuses in northern SGS (Stapp et al. 2008). We currently are developing first-generation metapopulation models for prairie dog towns. The models will be expanded and combined with spatial (GIS) information to refine estimates of functional connectivity of towns embedded in different landscape configurations. These models will also be used to examine similar patterns for species associated with prairie dogs, including several of conservation concern.

F3: *Extinction and re-colonization of prairie dog towns are a function of proximity to sources of plague, the sizes and distances (connectivity) between extant towns, available habitat and viscosity of different landuses to prairie dog dispersal.*

Estimating habitat suitability for prairie dogs and associated species via remote sensing: NEW ST

Estimates of historical losses of prairie dog towns is controversial because accurate pre-settlement data do not exist (Virchow and Hygnstrom 2002, Knowles et al. 2002, Vermeire et al. 2004). While several studies used soils, topography, and vegetation to model prairie dog habitat suitability (Belak 2001, Proctor et al. 2006), these models are based on limited temporal and spatial extents. Our records of occupancy from 1981 to present (Fig 2.14), from digitally scanned maps (1981-91) and GPS (1992-present) were entered into GIS with a digital elevation model. We will combine the GIS with contemporary field surveys and ecosystem productivity measures (NDVI) to create and validate a habitat suitability model for the SGS. Additional data sets gathered from other grasslands will allow broader validation of the model to other parts of both SGS and mixed-grass ecosystems. The models also will be used to test habitat suitability for associated species of conservation concern (see below).

F4: *Prairie dog habitat depends on physiography, climate and forage; potential distributions can be estimated by combining data on extant populations with modeling of landscape attributes.*

1.B.II. Global Change and Animal Communities

Consumer responses to climate change-induced changes in vegetation: NEW LT

Diversity and abundance of small mammal communities in SGS are determined by vegetation structure, notably grass height and the presence of shrubs (Stapp et al. 2008; Fig. 2.19). Recent open-top chamber experiments (Morgan et al. 2007) suggested that increasing CO_2 could increase cool-season grasses (e.g. *Stipa comata*) and shrubs (*Artemesia frigida*). We propose to establish long-term measurements to investigate potential changes in vegetation and SGS fauna. Given the importance of herbivory in the SGS, we predict that changes in vegetation, habitat and food availability for consumers will be mediated by changes in grazing, which is expected to vary across the N-S extent of SGS from Wyoming to New Mexico. To examine these changes, we will establish replicated 1-ha trapping plots in three types of long-term grazing pastures at the CPER: long-term grazing exclosures; moderately grazed prairie dog colonies; and moderately grazed grasslands (controls). Although we envision establishing these treatments at sites throughout the geographical extent of SGS (e.g. at Thunder Basin, Comanche, Kiowa/Rita Blanca National Grasslands) later in SGS-LTER VI, we will first implement trapping grids in similar replicated plots in mixed grass sites at the USDA-ARS High Plains Grasslands Research Station, 55 km miles north in Wyoming. In each plot we will sample populations of arthropods and small mammals 2-4 times per year, and measure vegetation and habitat characteristics.

F5: *During wet years, increases in cover of cool-season grasses and shrubs at SGS-LTER lead to increases of species associated with mixed grass prairie (deer mice, harvest mice). Bare ground and disturbance, i.e. from grazing and drought, will favor heteromyid granivores (kangaroo rats, small pocket mice). Effects of grazing will be more pronounced at the northern site, and during wet years.*

Biotic and abiotic drivers of small mammal communities NEW XSITE SYNTH

Small mammals are integral components of semiarid and arid systems because they consume plants, seeds and arthropods, disturb soil, and serve as food for predators. Small mammals have been the focus of long-term studies in these systems worldwide (Ernest et al. 2000, Dickman et al. 2001, Meserve et al. 2003), and contribute to our understanding of species interactions in community structure and assembly, mechanisms of habitat selection and foraging behavior, the roles of disturbance and climate, ecology of infectious disease, and top-down vs. bottom-up control of ecological communities. With the support of the LTER Network Office, in 2007 we initiated a cross-site analysis of long-term temporal patterns of small mammal (rabbits, rodents) populations at three LTER sites (SGS, SEV, JRN) and one ILTER site (Mapimi) in Mexico, where similar data on small mammal populations, food resources and predators have been collected for >12 years. Preliminary analyses focused on effects of drought and wet-year cycles on small mammal diversity (Fig. 2.19). We will continue these efforts by developing time-series models of population change for representative species across sites, and by examining relationships between mammal populations and long-term variation of vegetation and arthropod abundance. These studies provide a foundation for understanding effects of climate change on SGS animal communities throughout the region.

F6: *Changes in community structure in response to periods of extreme weather (droughts, El Niño) at the northern and southern ranges of SGS will be predictors of future patterns in a changed climate.*

1.B.III. Effects of Natural Disturbance on Animal Communities

We plan to initiate new studies that focus on two sources of natural disturbance: fire and prairie dogs. Recent work on the effects fire in the southern SGS (Ford 2007) suggests that animal populations are resilient following fire, but that responses differ between species. Prairie dogs are a major prey source for both mammalian and avian predators, engineering habitat by modifying vegetation and soils, creating habitat for other species including some of special conservation concern. Because of this important role, we consider prairie dogs to be a natural disturbance in terms of their effects on other SGS species.

Short- and long-term responses of animal communities to fire: NEW LT

In 2007, we initiated a long-term experiment to determine responses of arthropods, small mammals and nesting birds to the combination of prescribed burning in the fall, followed by free-choice grazing by livestock on burned and adjacent unburned patches (see section *1.A.III. Short- and long-term responses to fire*). We will estimate the abundance of each group on replicated plots of each treatment two times during the growing season (April-September), using the same procedures described below under *Consumer responses to exotic and native grazing.*

F7: *Species dependent on low plant cover and bare ground, e.g. mountain plover, horned larks, killdeer, grasshopper mice and darkling beetles, will increase in abundance in burned plots, whereas cover-dependent species such as lark buntings, longspurs, deer mice and grasshoppers, will decline.*

Effects of prairie dogs on biodiversity of SGS: NEW ST

Prairie dog towns are widely recognized as centers of high biodiversity in the Great Plains and increasing diversity at the landscape scale. Imbedded in a matrix of relatively undisturbed grassland, towns represent unique habitat for many species, and prairie dogs themselves are major prey for raptors and carnivores (Stapp 1998, Kotliar 1999, Antolin et al. 2002, Stapp et al. 2008). In the past decades prairie dogs recovered from nearly a century of persecution, but increasing pressures from agricultural landuse and urban and exurban development eliminated some towns and reduced connectivity among others. These changes likely affect species that depend upon or are associated with prairie dog towns, including several species of conservation concern: mountain plovers, burrowing owls (*Athene cunicularia*), and swift fox (*Vulpes velox*). We will extend our studies on effects of prairie dogs on biodiversity by examining how prairie dog metapopulation dynamics (Fig. 2.13) affect these species, either directly by reducing prey availability, or indirectly by removing the engineering effects of prairie dogs. Over the past decade, SGS-LTER provided logistical support for studies of population and behavioral ecology of swift fox (Darden 2006) and burrowing owl, species that depend upon prairie dogs for burrows and prey. We will continue to band owls on prairie dog towns on the western PNG (Fig 2.14, 2.17) to track numbers and nest productivity as towns are affected by and recover from plague. Movements of swift foxes will be monitored by radio-telemetry to determine the extent to which they exhibit functional (behavioral) responses to prairie dog abundance.

F8: *Density and productivity of burrowing owls will decline on prairie dog towns after plague epizootics, which cause collapse of burrows and declines in local prey. Swift foxes will relocate dens to active towns after epizootics decimate their local prey base.*

1.B.IV. Effects of Human-induced Disturbance on Animal Communities

Consumer responses to exotic and native grazing: NEW LT

We implemented a long-term experiment to determine responses of arthropods, small mammals and nesting birds to grazing conditions that extend the usual range (see above: *1.A.IV. Effects of Human-Induced Disturbances on Plant Communities: Livestock as ecosystem engineers*). In addition to the livestock grazing treatments described above, we sample long-term (>75 yr) exclosures and grazed prairie dog towns, which represent additional natural endpoints along a grazing continuum. Two grazing treatments (intensive spring grazing, intensive summer grazing) are more extreme than the norm for grazing on the CPER, with the goal of testing the limits of the SGS ecosystem to grazing pressure. We compare consumer abundance and changes in vegetation in large (0.81 ha) replicated plots (n=25), sampled at least twice per year on an annual or bi-annual basis. We also record plant cover, vegetation structure and the amount of soil disturbance by small mammals. Collectively, preliminary data indicate that small mammal communities are affected by long-term grazing conditions (prairie dogs, exclosures), but that, overall, most consumer communities are resistant to grazing pressure (Newbold et al. *in prep*.).

We plan to continue this experiment, and in addition, we will add a fourth treatment by adding livestock exclosures in prairie dog towns (currently, prairie dog plots are grazed by cattle). This treatment will permit grazing by other native herbivores (rabbits, pronghorn, prairie dogs) and will allow us to isolate the effects of cattle and prairie dogs on consumers.

F9: *Responses of consumers, particularly small mammals and birds, will closely track grazing-mediated changes in vegetation structure. Consumer diversity will be highest in exclosures. Grazed sites will have lower diversity, but with species that tolerate grazing and disturbance.*

1.C. Soil Molecular Ecology

This group is new to SGS-LTER, and will apply state-of-the-art genetic techniques to study belowground communities of microbes, protozoa and invertebrates. Soil communities likely represent the majority of SGS biodiversity and account for a significant portion of ecosystem pools and fluxes. Three objectives build on 25 years of SGS-LTER research: we will *i)* use molecular techniques to characterize temporal and spatial variability of communities; ii) measure responses of communities to altered resources and environmental perturbations; and *iii)* relate community composition to ecosystem function.

Continuing advances in molecular and genomic approaches offer opportunities not technically feasible a decade ago. To meet objective *i* we will construct a database of species diversity at two levels. For invertebrates and protozoa, we will match DNA sequence data to traditional morphological features. For microbes, we envision an ambitious and pioneering effort: soil microbial diversity remains 'terra incognita', with the vast majority of belowground biological diversity at SGS (and elsewhere) uncharacterized and largely unknown. We are in fact much like 19th century naturalists who originally described plant and animal diversity across the globe (but we know more about ecosystem processes).

The second two objectives will build on the database from the first. Objective *ii* connects soil community structure and composition to ongoing SGS-LTER studies of environmental gradients, abiotic drivers, and changes in plant/animal diversity. Objective *iii* positions us to study mechanisms underlying key soil processes, including dynamics of N, C, and reactive trace gases (e.g. CH_4) and provides a unique opportunity to understand how ecosystem-level processes are regulated at the functional gene level.

1.C.I. Monitoring and Surveying Soil Communities: NEW LT

Soil communities play an integral role in the functioning and sustainability of the SGS ecosystem (Elliott et al. 1977, Coleman et al. 1983, Hunt et al. 1987, Moore et al. 1988, Moore et al. 2003, Rooney et al. 2006). Belowground processes account for over 50% of annual NPP, most standing biomass, over 99% of (estimated) species diversity, and most key biogeochemical transformations. Better understanding of the roles of soil microflora requires measures of the inherent variability in soil community composition across spatial and temporal scales, given their influence on decomposition, nutrient supply and spatial structure of plant communities (Ettema and Wardle 2002). We are guided by the following hypotheses:

S1: *Composition of soil communities is determined in large part by spatial and temporal variability in plant communities, but also modulated by soil moisture, texture, pH, and temperature.*

S2: *Compared to other terrestrial ecosystems the SGS will have low diversity of soil biota because of relatively low rates of production and low plant diversity.*

We will establish a 100 m x 100 m study area with native dominant vegetation and sample on a seasonal basis during years 1 and 2. To begin, the main spatial issue is across depths within individual soil profiles. Temporally, we anticipate the structure of belowground communities will shift seasonally and these shifts will be predictable, as the communities largely respond to changes in soil temperature, moisture, and resource availability (i.e. plant C inputs). High cost of DNA extraction and sequencing limit us to 24 soil samples per year, where "samples" are derived from 3 pooled soil cores. Newly-developed molecular approaches allow us to survey presence of archaea, bacteria, fungi, Protozoa, and invertebrate. Despite the seemingly small number of samples, this survey is larger in scope than similar studies, in terms of phylogenetic and sample diversity (Lozupone and Knight 2005, Fierer et al. 2007).

Sampling – We will collect three samples (0-10cm depth) at each of four time periods: at the onset of green-up (usually March); the peak growth period (June); during the dry late-summer (August); and after senescence but before soil freeze-up (typically late October or November). Variation within soil profiles will be evaluated from 3 additional samples from the 10-20cm depths during June. We will probe lateral variability at the site at two spatial scales. Burke et al. (1999) found that biogeochemical processes differed between islands of vegetation and bare soils within 1 m of each other. We will sample (0-10cm depth) from each of these areas in the June sampling to explore the microbial community variation associated with these vegetation changes. Second, we will evaluate lateral variation across our study area with additional (n=5) samples during the June sampling. Results will guide longer-term sampling and more detailed studies of spatiotemporal variability of belowground microbial communities in the SGS.

Microbial Community Composition – Ribosomal RNA genes (rRNA) will be sequenced as fundamental biomarkers. After extracting DNA from soils with commercially available kits (MoBio), we will use PCR with universal rRNA primers to amplify rRNA genes from the soil metagenome. The PCR amplicons will then be cloned, and 500 colonies will be randomly selected per sample for sequencing (Chelius and Moore 2004, Fierer et al. 2007, Wallenstein et al. 2007). Initially, fluorescently-based cycle sequencing will be used, with upgrades to high-throughput sequencing when it becomes cost-effective.

Protozoa and Invertebrates – These organisms will be characterized using the same molecular techniques described above - PCR and cloning - but with protozoan and metazoan-specific primers that target 18S rRNA genes and the more rapidly evolving ITS1 (internal transcribed spacer) rRNA gene.

Data Management –Sequence data will be fully annotated with environmental metadata and will be made publicly available through GenBank and environmental genome databases such as CAMERA, as well as the SGS-LTER website. We will work with other LTER sites to develop standard protocols for comparisons among LTER sites. Taxon-specific abundance data will also be made available on the SGS-LTER website to generate wider use of our microbial data. We will analyze the sequence data to evaluate patterns in species richness and community composition using tools such as UniFrac (Lozupone and Knight 2005), which provide quantitative methods for comparing community phylogenies across large numbers of samples. We will also use standard phylogenetic techniques to identify the types of organisms found at our sites.

Soil communities, resource availability and environmental perturbations: NEW LT

Knowledge gained from initial surveys will allow us to detect changes in soil microbial community composition that may fall beyond the normal range of variability, especially in relation to environmental perturbations and altered resources. Water and N represent two major limits to biological activity in the SGS; their availability may be altered by increased drought frequency and inputs of anthropogenic N. Grazing also affects the SGS ecosystem, with changes in soil C inputs (Hamilton and Frank 2001), microbial functional groups (Patra et al. 2005), and soil trophic interactions (Neilson et al. 2002). We will analyze soil microbial communities in established long-term SGS-LTER experiments that manipulate N inputs and grazing. This adds a new dimension to ongoing studies of perturbation effects on aboveground biodiversity, productivity, and ecosystem functions. Our current working hypothesis is:

S3: *The tight linkage between plants and soil communities can be decoupled by disturbances that alter the belowground environment outside the normal range of variability.*

Our current understanding of belowground responses to disturbance is limited to coarse changes in biomass and soil food web structure. We cannot currently predict responses at finer taxonomic resolution, particularly in microbial communities. We will characterize communities along axes of nutrient availability and grazing. We will then develop a new suite of food web models to detect shifts among the fungal and bacterial pathways *sensu* Moore et al. (2003) and Moore et al. (2008), among plant communities, variations in detritus (quantity, C:N, recalcitrant:labile), and/or changes in the belowground communities themselves. We will evaluate the consequences of these changes to mathematical notions of stability and to key ecosystem processes (e.g. decomposition and N-cycling)

Relationship of soil microbial communities to ecosystem function, LT67 WEB and NEW LT

Relationships between microbial communities and ecosystem function (Schimel 2001, McCulley and Burke 2004) are critical to biogeochemical processes in the SGS, but are not fully predictable based on environmental drivers alone. For instance, although methane uptake is thought to be regulated by gas movement into the soil (diffusivity), under hot dry conditions this fails because of physiological stress to methane oxidizing (methanotrophic) bacteria. Nitrification rates are not tightly linked to NH_4 availability, but rather are controlled by responses of nitrifying bacteria to soil moisture (Schimel and Parton 1986). Conant et al. (2008) showed that resistant SOM pools in grasslands are more sensitive to warming than are labile pools. In sum, these processes may be driven either by the thermodynamics of microbial enzymes or by changes in microbial community composition. To disentangle the alternatives, we will study three functional genes: methane monooxygenase (*pmoA*) for methane consumption, ammonia monooxygenase (*amoA*) for nitrification, and laccase for lignin decomposition. The following hypothesis addresses specific functions of these genes:

S4: *The physiochemical regime determines the distribution of pmoA, amoA, and laccase genes, and the resulting genetic structure modulates the instantaneous relationship between the environment and ecosystem function (methane consumption, ammonia oxidation, and lignin decomposition).*

Preliminary results indicate that the SGS methanotroph community (Judd et al. 2007) is composed of unique strains (JR2 and JR3) only reported from one other study of a dry annual grassland. We will measure the abundance (qPCR) and taxonomic diversity (clone libraries) of functional genes in methanotrophs alongside the biogeochemical processes under control and experimental conditions (see below: *Net methane fluxes, environmental controls and links to soil microbial communities*). For methane oxidation, we will monitor methane flux and its controls (diffusivity, methanotroph activity) across existing soil texture and topographic gradients at a biweekly frequency over the growing season. We will also expand these measures to the soil warming experiment (see below). Likewise, we will study the *amoA* gene and associated nitrification rates in the N fertilization plots and the lactase genes and associated turnover of resistant carbon pools in the soil warming experiment.

2. BIOGEOCHEMISTRY AND GLOBAL CHANGE

The SGS-LTER has a 25-year history of monitoring and experimentally testing ecosystem processes, especially NPP, biogeochemistry, and their responses to key drivers (Fig. 2.1). In the last seven years enrichment experiments were instituted to test the effects of rising CO_2 (Morgan et al. 2001, 2007). The key question guiding this groups' research is "To what extent are ecosystem processes vulnerable to shifting ecosystem drivers in the face of global change (Fig. 2.20, 2.21)?"

We describe 12 major hypotheses, tested by an array of ongoing long-term measurements, short term experiments, new long-term experiments, and modeling. We focus much attention to ongoing experiments, and initiate new studies evaluating potential responses to altered precipitation-pulse dynamics expected under global change. We direct major new efforts on soil biology and physiography because of their strong influences on biogeochemical dynamics.

2.A. Key Biogeochemical Drivers and Processes

Biogeochemical monitoring captures important dynamics of annual NPP, monthly N availability during the growing season, trace gas fluxes biweekly during the growing season, and SOM pools at decadal intervals.

2.A.I. Monitoring Key Drivers

Here we describe measurements that fall under "monitoring", but also serve as controls for experiments described below.

Microclimate LT22, LT23, LT24, LT25 and LT26:

Variable precipitation is key to the structure and function of SGS (Lauenroth and Sala 1992). Long-term records include years with total precipitation two st. dev. below average (1964; 107 mm) and almost three st. dev. above average (1967; 588 mm). Because the SGS also experiences substantial intra-annual and seasonal variability, documenting variation in H_2O is critical to the SGS-LTER: *i)* Automated measures of precip., wind direction and speed (3 heights), air T, surface T, dew point T, vapor pressure, total radiation, soil H_2O (3 depths), heat flux, soil T (4 depths), manual records of air T, RH, precip., open pan evaporation, soil T at 7 depths; *ii)* A 3 m diameter weighing lysimeter measures season-long patterns of evapotranspiration; *iii)* A network of 11 rain gauges at the CPER measures the spatial variability of rainfall; *iv)* Soil H_2O during the growing season by neutron moisture gauges (Troxler Scientific Instruments). We expect that:

BGC1: *Soil H_2O is the key driving variable for SGS ecosystem structure and function; soil H_2O is controlled by low and locally variable precipitation, soil texture and atmospheric demand for H_2O.*

Sampling aboveground NPP: LT11, 12, and 13, and belowground NPP LT 32-38, 39, 40 and 41.

We will continue to annually sample aboveground NPP (ANPP) and plant N concentration in relation to climate/weather, topography, and grazing. We sample six sites representative of topography, soil texture, and grazing (since 1983). In addition, data from the ARS on forage production (related to ANPP, Lauenroth and Sala 1992) date back continuously to 1938, and are comparable to sampling of ANPP in each of four treatments at five sites initiated in 1992 to study effects of grazing (see above: **LT37**).

Long-term measures include belowground NPP (BNPP), responses of BNPP to grazing and comparisons between methods (Milchunas et al. 1985, 1989, 1992a, b). We sample BNPP in six locations and four treatments associated with our plant grazing work (**LT 32-41**: see plant section above). Our monitoring of ANPP and BNPP addresses the following hypothesis:

BGC2: *Key abiotic drivers of biogeochemical pools and processes (C and N storage, NPP and nutrient exchange dynamics) are soil H_2O availability and variation in soil texture across landscapes. N availability is less important, except where humans have altered it.*

Net methane fluxes, environmental controls and links to soil microbial communities NEW LT

Closing the link between biogeochemical processes and microbial communities is a new focus of SGS-LTER VI. Methotrophs, methane-consuming bacteria in upland soils, provide an initial model study because they are physiologically (and phyolgenetically) distinct and well-characterized. Work on methane uptake in soils at the SGS has revealed strong spatial and temporal variation (Mosier et al. 2008). We developed a new chamber-based approach to separately quantify roles of methanotroph activity and soil diffusivity in determining rates of methane uptake (von Fischer et al. in review). Both are important controls: even though methanotroph activity drops by 100-fold under hot, dry conditions, these conditions also increase soil diffusivity. In sum, changes in methane fluxes are relatively small. We will continue to monitor methane flux and its controls (see above: *Relationship of soil microbial communities to ecosystem function*).

Paleoclimate, biotic interaction, and long-term distribution of water: NEW LT, ST

Understanding potential for global change to cause long-lasting effects on ecosystems requires understanding long-term dynamics of physiographic and hydrological processes. This research is guided by this hypothesis:

BGC3: *Pre-historic-conditions: contemporary soils and paleosols record the biogeochemical development and paleoenvrionmental record (dust deposition, temperature, precipitation, soil water distribution and content)) because these factors continuously control SGS structure and function.*

Reconstructing Distribution of Soil H_2O: "Long-term" measurements of soil H_2O from recent decades, including effects of topography and soil texture, may not reflect the range of variability and trends over centuries or millennia. Knowing this variation is important for bounding future uncertainties in precipitation (IPCC 2007). Here we ask: "What was the characteristic distribution of water across the SGS landscape over paleo-ecological time, and what range of soil chemical properties *reflects* biogeochemistry and long-term water in the unsaturated zone?" We will sample >200 pedons across gradients of topography, age and parent material. By using the chloride mass balance model we will relate changes in chloride concentration in soil profiles to quantities and patterns of water penetration. Chloride undergoes no chemical transformations in soil, so measuring changes over time of *i)* total chloride in soil and *ii)* concentration of chloride in water draining from root zones provides estimates of water movement through soil during specified time periods.

Reconstructing Biota: Dust, vegetation, soil development and climatic records in the western Great Plains during the Holocene (<11,500 ybp) provide key insights into ranges of variability in the SGS. Climate and biota can by reconstructed by: *i)* establishing isotopic records of SOC, $CaCO_3$ and phytoliths (identifiable fossils of plant species) from paleosols; *ii)* finding episodic pulses of dust associated with large changes in vegetation cover in loess/paleosol stratigraphc sequences; *iii)* identifying key faunal and botanical remnants to create models of plant community composition. We initiated work during SGS-LTER V by describing and sampling the Old Wauneta site because, at six meters deep, it is arguably the thickest and most complete Holocene loess section on the western and central Great Plains (Jacobs and Mason 2005). Holocene Bignell loess at Old Wauneta contains as many as five buried A horizons (Fig. 2.22). Soil horizons will be measured for a full suite of paleoclimatic indicators for the region, as outlined previously (Blecker et al. 1997, Kelly et al. 1998, Stevenson et al. 2005).

2.A.II. Measuring Nitrogen-Carbon Interactions

Measuring biogeochemical processes in the SGS is a mainstay of our work, and represent both ongoing and new measurements.

Long term ^{15}N studies in the SGS: LT18 and LT19

In 1988, we initiated a long-term ^{15}N study to evaluate the interaction of topographic position and grazing on N retention and distribution. We labeled plots on summits and toeslopes in each of three catenas, and in heavily grazed and exclosed areas, as well as across a series of cultivated sites nearby. We plan to continue to sample these treatments on a decadal scale for an indefinite period of time; we sample for ^{15}N in plant material and in mineralizable, slow (particulate SOM, Cambardella and Elliott 1992), and recalcitrant fractions of SOM. An important aspect of this research is that both C content and soil texture increase N retention at a regional scale (Barrett and Burke 2000, 2002), but it is not clear how patterns hold at landscape scales and with landuse. We are currently writing an NSF Ecosystems proposal to synthesize two decades of ^{15}N experiments on the SGS, associated with grazing, long-term cropping treatments and a temperature gradient (Barrett and Burke 2000, 2002).

BGC4: *C balance exerts the major influence on N retention; in turn C balance is influenced by interaction with drivers of the SGS ecosystem (Fig 2.1), but especially by human landuse (Fig 2.23).*

Balancing the N budget: LT 51 WEB (NADP)

One of the most important indicators of ecosystem change is alteration of element inputs; indeed, N deposition is widely recognized to represent one of the most important facets of anthropogenic change (Vitousek et al. 1997). The SGS-LTER has long been a member of the National Atmospheric Deposition Program, and we have measured trace gas fluxes on many of our long-term plots, but several key aspects of element balance require better integration. We recently synthesized more than 30 years of work on the

N balance of the SGS (Burke et al. 2005), and found that we cannot close the N budget. Our key gaps are in understanding total N inputs, volatile NH_3 losses from plants, NO_2 and NH_3 absorption by plants.

Dry deposition is an important component of total atmospheric deposition (Lovett 1994). Current estimates of N deposition, based upon precipitation, underestimate the contribution of atmospheric N to the SGS, thus, we plan to develop a dry N deposition program. The mass flux of N to the plant/soil surface will be estimated using a modified Bowen-ratio method with measured changes in temperature and nitric acid concentration with altitude (Huebert and Robert 1985). In addition, we will estimate NH_3 absorption and volatilization from plants, as well as constructing an NO_2 budget.

***BGC 5**: Atmospheric deposition represents a major source of inorganic nutrients in SGS, but was previously underestimated because tools to estimate the balance between weathering and atmospheric inputs were lacking.*

NutNet: NEW LT, XSITE

The SGS-LTER is part of an international network (forty grassland sites including six LTER sites (AND, KNZ, JRN, SEV, SGS, NWT) conducting a new nutrient addition experiment. The purpose of this project is to assess top-down vs. bottom-up effects on community structure and function in herbaceous-dominated ecosystems globally. This new project will also assess multiple resource limitation via nutrient addition treatments that include N, P, K plus other nutrients in a factorial design (a total of 8 treatment combinations). In addition, there will be an herbivore exclosure treatment, in which entire 5 x 5 m plots will be fenced to exclude large herbivores. Plots have already been established at the SGS and nutrient additions (N, P, and K) are planned to begin in 2008, as are the grazing exclosures treatments.

2.B. Global Change and Biogeochemical Dynamics

Several long-term manipulative experiments, originally initiated during the 1970s and earlier during the IBP, evaluate the control of biogeochemical pools and processes by precipitation, temperature and nitrogen. In this section, we describe ongoing experiments and important new experiments to test our ideas (Figs. 2.21, 2.23, 2.24, 2.25).

Warming, wetting, drought, and N additions: LT14

Our conceptual framework predicts the importance of 2-way interactions between structure and function of SGS. A long-term study of ANPP suggested that ecosystem structure (plant community and soil pools) constrain ANPP (Lauenroth and Sala 1992). Production was greater in dry years and lower in wet years, compared to other sites where mean annual aboveground net productivity corresponded to the wet and dry conditions. This led us to the question: How does the relationship between ecosystem structure and function change under altered climate and resource availability?

We initiated a long-term experiment in 1995 to ask how increased temperature, increased and/or decreased H_2O availability and increased N availability influence the relationship between ecosystem structure and function. The experiment is replicated in the Patagonian steppe in Argentina by Osvaldo Sala. In each of two blocks, we implemented the four treatments (+ water, - water (at 2 levels of drought), + N, and heating using ITEX chambers) in a factorial design, and are measuring the responses of vegetation structure (species composition and numbers of tillers), ANPP, and decomposition (leaf and root litterbags). Intensive sampling will continue in SGS-LTER VI, and will continue at a lower intensity for 20 years or more. We occasionally measure trace gas fluxes from these treatments (Fig. 2.26). A surprising result is that temperature alone has a significant effect on methane uptake. Drought treatments indicate the resilience of *B. gracilis,* even to 10 years of 50% ambient rainfall. Our prediction is that:

***BGC6:** NPP and ecosystem respiration respond differently to precipitation, temperature and N availability changes in time and space. Heterotrophic respiration responds more rapidly to changes in temperature than autotrophic processes (NPP and autotrophic respiration; Fig 24.)*

Long-term studies of nutrient enrichment: LT42 and LT63 WEB and NEW LT.

Nutrient enrichment treatments established in 1971, sampled under SGS-LTER since 1982, show unexpected time lags in nitrogen availability and plant community responses (Vinton and Burke 1995, Milchunas and Lauenroth 1995). The long-term enrichment treatments consisted of two blocks, each with four 1-ha plots including a control, added H_2O, added N, and added H_2O plus N. Treatments were halted in the late 1970s, but increased N availability and increased invasive plant species persist into the present. In 1997, we initiated six new treatments (additional NSF funding) to reduce N availability and invasive species by adding various C sources (sugar, sawdust, lignin, sugar+sawdust, sugar+lignin, and control) to stimulate: *i)* microbial immobilization for short-term N sinks and: *ii)* humification for long-term sinks of N. We now see responses in many of the treatments (Fig. 2.27) and will continue to follow their long-term persistence. In 2003, we discontinued C supplements to evaluate how each of the new treatments responds over decades. Our prediction is that N availability will increase again on the sugar-only plots, but will remain low, with fewer invasive species, on the plots with recalcitrant C additions (sawdust and lignin) because turnover times differ among sources of C. Observations thus far support our hypothesis, with reversion to weed dominance on the old sugar treatments and dominance by native perennials on the more recalcitrant carbon treatments.

BGC7: *N availability has a smaller role in influencing biogeochemical pools than precipitation and temperature, but N availability generates critical inertia in ecosystem structure and function. N availability increases establishment of weedy, high N plants, which initially respond to high N, perpetuate N cycles, and persist. Thus, the SGS is vulnerable to changes in N availability, but C additions reduce N availability and may return SGS to native vegetation.*

Grasslands and terrestrial silica cycling NEW XSITE SYNTH

Available evidence suggests that grassland systems are a particularly large and active reservoir of biogenic silica (BSi; Blecker et al. 2006); global expansion of grasslands during the late Neogene (~23 mybp) likely increased both marine and terrestrial Si cycles, and thus the global C cycle. Paleoceanographic indicators changed during the Mio-Pliocene grassland expansion (5.5-23 mybp). Filippelli (1997) and Derry and France-Lanord (1997) note that the shift in geologic Si at that time correlates with increased weathering of the Himalayan foreland, close to the time of expansion of C4 grasslands in that region (Cerling and Quade 1990; France-Lanord and Derry 1994). Measurements on the SGS will further explore the role of grasslands in the Si cycle, especially because both N. American grasslands (Knapp et al. 1998, Kelly et al. 1993, 1998b; Melzer in prep) and S. African savanna grasslands (Knapp et al. 2004, 2006, Melzer, in prep) function to mobilize Si as BSi. First assessments for N. American grasslands suggest that dust export could be as high as 60 to 100 Tmol, a significant fraction of the 240 Tmol of BSi estimated to be stored in oceans (Conely 2002). Building on studies relating BSi to ANPP (Blecker et al. 2006), we will compile climatic and ANPP data from grass-dominated LTER sites (KNZ, SGS, SEV and JRN and other grassland ANPP data (Knapp and Smith 2001) to develop a model testing relative importance of grassland systems in the global Si cycle.

BGC8. *Grassland ecosystems play a major role in the storage and mobilization of silica relative to other terrestrial ecosystems.*

2.B.II New Experiments

We propose new experiments with the goal of determining sensitivity of ecosystem structure and function to changes in soil moisture (temporal pattern and amount) expected under changing seasonal patterns of precipitation, temperature increases (diurnal and nocturnal), elevated CO_2 and interactions (Fig. 2.20). We seek to understand the mechanisms controlling responses of: *i)* plant water relations and water sources; *ii)* C and N uptake and loss in key plant species; *iii)* N supply and C turnover in soils; and *iv)* ecosystem CO_2 exchange at annual, seasonal and daily scales. Our experiments follow the two criteria previously described: to manipulate factors most likely change and to examine most vulnerable and/or strongly linked ecological interactions.

Prairie heating,watering and CO_2 enrichment (PHACE) experiment: LT20 and NEW LT

Based on our previous research of the impacts of elevated CO_2 (Morgan et al. 2001, 2007, Parton et al. 2007), we established a new PHACE experiment in 2007 in a semi-arid grassland, 55 km north-west of the CPER at the USDA-ARS High Plains Grasslands Research Station, Cheyenne, WY. PHACE consists of thirty 3-m diameter circular plots: 20 plots are factorial combinations of two CO_2 (present ambient, and Free Air CO_2 Enrichment, or FACE-elevated [600 ppm] CO_2) and two temperatures (present ambient, and infra-red heater elevated temperature [1.5/3.0 ºC warmer day/night]) regimes, with five replications each.

The remaining 10 plots comprise two irrigation treatments. The goal of PHACE, led by USDA-ARS (Morgan, Blumenthal, F.A. Dijkstra) and University of Wyoming (Pendall, Williams), is to determine sensitivity of ecosystem structure and function to changes in soil moisture expected under increases in CO_2, temperature, precipitation, and interactions. We measure responses of *i*) plant/soil water relations; *ii*) carbon and nitrogen cycling; *iii*) key plant species abundances; *iv*) weed invasion; and *v*) trace gas fluxes. SGS-LTER VI will augment PHACE by exploring topics not presently covered in PHACE research **(**see above: *Plant demography and Prairie Heating, watering and CO_2 Enrichment*, and below: *Consequences of global changes on NPP and carbon and nitrogen cycling. Modeling/Analysis*).Our hypothesis for this experiment with respect to biogeochemistry is:

BGC9: *We hypothesize that ecosystem processes most affected by global change will be driven by net impacts on soil moisture. The effects will be modulated by high precipitation years, such that processes that respond negatively to the average, reduced soil moisture (N mineralization, soil respiration, and NPP), will increase in years of high precipitation. The primary impacts of elevated CO_2 will be driven by increases in soil moisture; increased atmospheric CO_2 levels reduce plant transpiration, thereby increasing soil water content, plant production, soil respiration, N mineralization and plant N uptake.*

Precipitation and pulse precipitation experiments LT71 and NEW ST

Semiarid and arid ecosystems are by the nature of their environments pulse driven (Noy-Meir 1973), with the SGS serving as an outstanding example. At the daily time scale, the SGS environment is most accurately described as a continuous background of dry soil intermittently broken by brief wet periods (Lauenroth and Bradford 2006). Duration of wet periods depends on the size of the precipitation event (Sala et al. 1992), and pulsed semiarid and arid environments are dominated by ≤5mm events (Sala and Lauenroth 1982, Loik et al. 2004). Precipitation pulses can influence biogeochemical dynamics (Austin et al. 2004, Sponseller 2007), but effects of pulses on C and N balance are not known in the SGS. We will experimentally manipulate timing and size of precipitation events inputs and evaluate responses including soil respiration, N availability and trace gas fluxes. Preliminary data from a July 2007 experiment suggest that single 5 mm precipitation events on dry soil can stimulate soil respiration for 30 hours at rates of more than 1 gC/m^2. A curious result was that soil moisture in the top 15 cm returned to baseline after 5 hours, so it is unclear why soil respiration did not return to baseline conditions as quickly. We hypothesize that:

BGC10: *Timing of precipitation events, in addition to total supply, is critical for the interactions of microbes, nutrient availability, plant species composition, and plant production (Figs. 2.19, 2.20).*

Warming study NEW LT, XSITE

We will initiate a new warming experiment because our current (***LT14***) design reduces precipitation and does not allow destructive sampling. Additionally, we will compare effects of warming at SGS-LTER to sites to the north (HPGRS in Wyoming) and south (SEV-LTER). We propose to experimentally increase T_{noct} at SGS-LTER and HPGRS using retractable aluminum curtains that reflect long-wave radiation emitted from the soil, a design currently in use at the SEV. Curtains unfurled at dusk and retracted at dawn have been used in shrublands to reduce energy loss by 64% and raise air temperatures by as much as 2.5ºC on clear nights and elevate soil temperature at 10 cm by an average of >1ºC. Curtains will be retracted during rain/snow events (detected by precipitation sensors) to allow H_2O inputs, and during high winds (sensed by anemometer) to minimize damage. Impacts on water balance are expected to be minimal (Beier et al. 2004). Materials lists, construction plans, and operational experience have been contributed by researchers carrying out a similar experiment at the SEV (see hypotheses above related to the effects of warming).

Recovery of shortgrass ecosystems from drought LT68 and NEW ST, XSITE.

We intend to explore the effects of severe and prolonged drought on native SGS grassland productivity and subsequent invasibility by exotic species, to determine whether similar responses to drought are observed in grasslands on broad geographic scales. We will use rainout shelters to impose a two-year summer drought at the SGS-LTER site as well as three sites along a north-south grassland gradient. To simulate drought, we will construct 20 rainout shelters at each site following Yahdjian and Sala (2002). At each site, there will be 10 shelters of each treatment: control, reduced precipitation by

50% and by 80%. These treatments are based on historical precipitation records for the region (NOAA 2007; Herbel et al. 1972).

BGC 1l: *Given short term drought, soil N will accumulate during years experiencing drought and this accumulation will affect plant species composition. Prolonged drought will provide a window of opportunities for the invasion of semi-arid grassland communities, where resources are increased after normal precipitation patterns return.*

2.C. Effects of Human Disturbance on Biogeochemistry

Our studies of human disturbance integrate across the entire LTER; projects evaluating the effects of grazing management and fire are described above under Plant Dynamics. Below, we describe our long-term experiment on cultivation management.

Long-term recovery following cultivation and cropland abandonment: LT43-46

Approximately 25-30% of the CPER and the PNG was plowed and abandoned by 1937. In 1990, we sampled vegetation and soil recovery on 13 fields selected to represent the precipitation and temperature gradients across the PNG, including one field at the CPER (Coffin et al. 1996, Burke et al. 1995). In 1994, we began sampling old fields at the CPER. We sampled vegetation and soil on six fields in 1994. We will repeat sampling at ~15-20 year intervals. We also initiated evaluations of recovering agricultural fields (Conservation Reserve Program, see above) and native fields to assess vegetation and soil recovery (Coffin et al. 1996, Burke et al. 1995, Ihori et al. 1995a,b).

BGC12: *The SGS is dominated by belowground C storage, because of the slow turnover of both plant biomass (long lifespan of roots) and of soil organic carbon (decomposition limited by low litter quality and soil moisture; Fig 2.28). Aboveground disturbances (grazing and fire) result in relatively small proportional changes in C and N cycling, but belowground disturbances (cultivation, mining, urbanization) result in dramatic changes in ecosystem C and N cycling because these pools are large and regenerate slowly (Fig.2.29).*

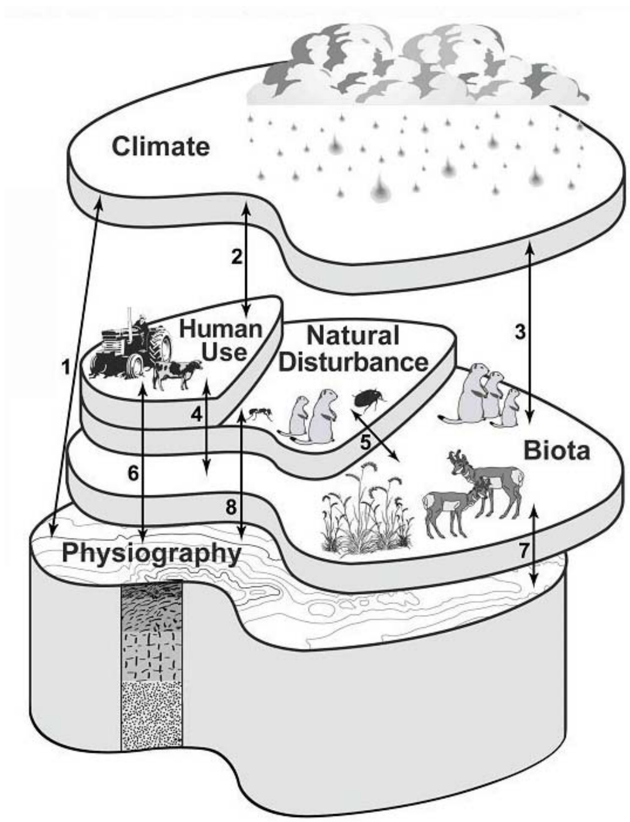
Management effects on H_2O, energy, and CO_2: LT55 and NEW LT

We propose to build upon our work from the previous proposal using Bowen ratio (BR) energy balance methodology to evaluate grazing effects on fluxes of H_2O, energy and CO_2. Because of biases between BR and eddy covariance techniques (Alfieri et al. in review), we will switch from flux tower methods to eddy covariance, the present standard for flux measurements of CO_2 and H_2O. Two towers will be placed in pastures with different grazing histories: moderately grazed and heavily grazed. A third tower will be placed in a pasture with an established prairie dog town, to evaluate the consequences of prairie dog colony dynamics (expansion and subsequent plague events). This research will help answer questions concerning how management and faunal dynamics impact carbon and energy exchanges of the SGS, and will be utilized with data from manipulative experiments in modeling exercises to predict future responses of the SGS to global changes (below).

Consequences of Global Changes on NPP and Carbon and Nitrogen Cycling: Modeling and Data Analysis: NEW SYNTH

We have now manipulated H_2O, temperature and N availability for more than 30 years, using long-term, short-term, and cross-site experiments, and for seven years conducted CO_2 enrichment studies. We plan to synthesize these data to evaluate our hypotheses (Figs. 2.21, 2.23). The SGS-LTER program has extensively used ecosystem models to represent our hypotheses and simulate impacts of climatic and land use changes on ecosystem dynamics, at regional, national and global scales (e.g. Parton et al. 2007). We propose to expand our modeling program to interpret and synthesize results from our long term and new experiments, and improve simulation models to address our new knowledge. Anticipated model improvements include: detailed photosynthesis and root growth sub-models, autotrophic plant respiration, effects of photo-degradation on surface litter decomposition and nutrient release; improving trace gas fluxes (N_2O, N_2, CH_4, and NO_x); and incorporating assumptions of plant community changes into model runs. A major focus will be to expand our capability to evaluate the interactive effects of rising CO_2 and temperature, altered precipitation patterns, UVB, and N deposition on key ecosystem processes

SGS-LTER CONCEPTUAL FRAMEWORK
Determinants of SGS Structure and Function



Important Interactions Within Research Areas:

Plant Dynamics
3,4,5,7,8

Faunal Dynamics
3,4,5,7,8

Soil Molecular Ecology
1,6,7,8

Biogeochemistry and Global Change Dynamics
1,2,3,6,7,8

Figure 2.1. Our conceptual model suggests that the current state and vulnerability of SGS ecosystems (structure and function) requires understanding of climate, natural disturbance, physiography, human use, and biotic interactions, and their interactions with the ecosystem. Each formal Research Area within the SGS-LTER project focuses on several of the interactions. One of the goals of SGS-LTER VI is to test the limits of function of the drivers, and particularly which interactions will be influenced directly or indirectly by global change.

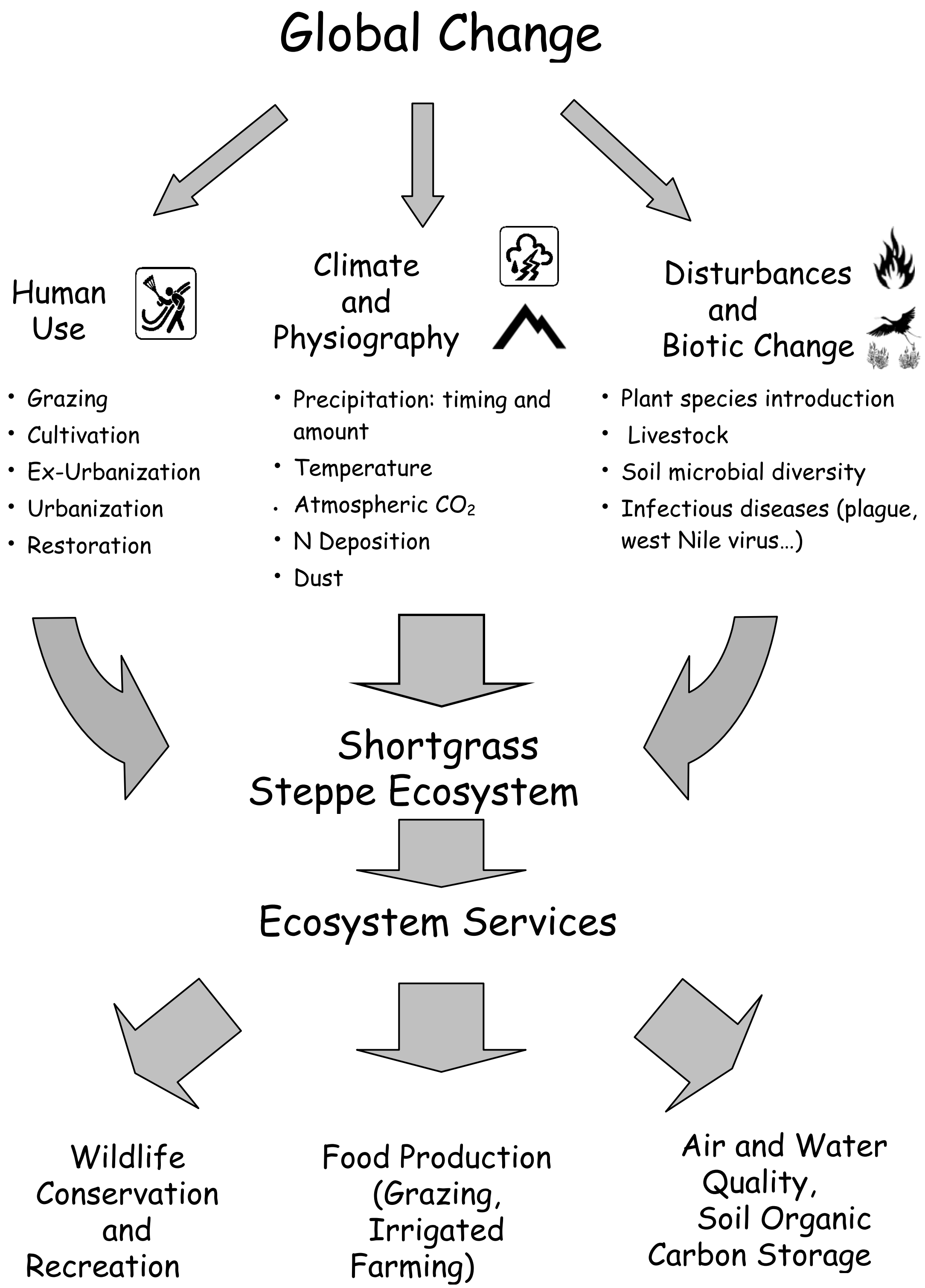


Figure 2.2. Specific factors within each of the large-scale ecosystem drivers with potential to alter the function and structure of the SGS ecosystem in response to global change. In turn, ecosystem services provided by SGS also have potential to change. Icons relate back to ecosystem drivers described in the text.

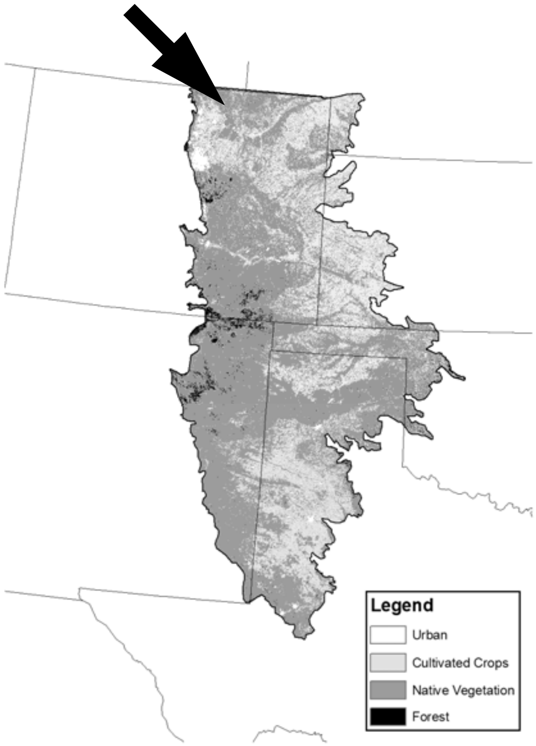


Figure 2.3. Extent and landuse of the SGS ecosystem in the Great Plains of the United States. Location of the SGS-LTER site is shown by the arrow (modified from Lauenroth and Burke, 2008).

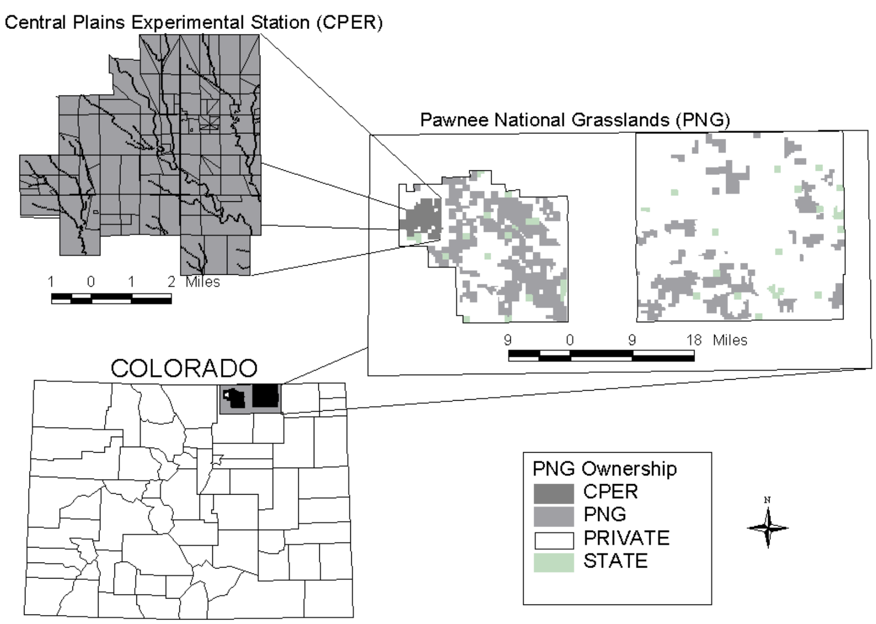


Figure 2.4. Map of the SGS-LTER site, composed of the Central Plains Experimental Range, administered by the USDA-Agricultural Research Service, and the Pawnee National Grassland, administered by the USDA-Forest Service. The map shows the mosaic of ownership and landuse that fragments the landscape.

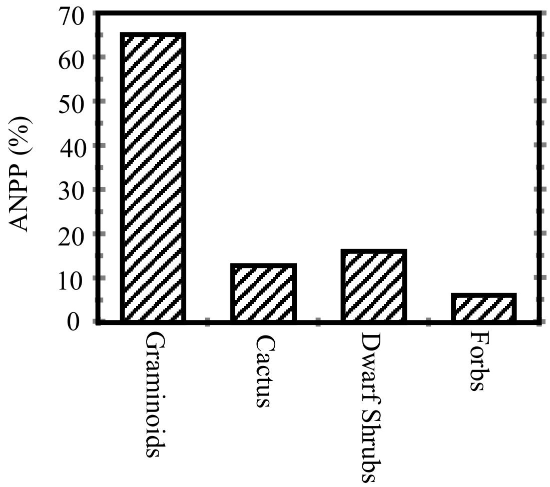


Figure 2.5. Aboveground net primary production as an indicator of plant group importance. The graminoid group is almost entirely dominated by blue grama (Lauenroth 2008).

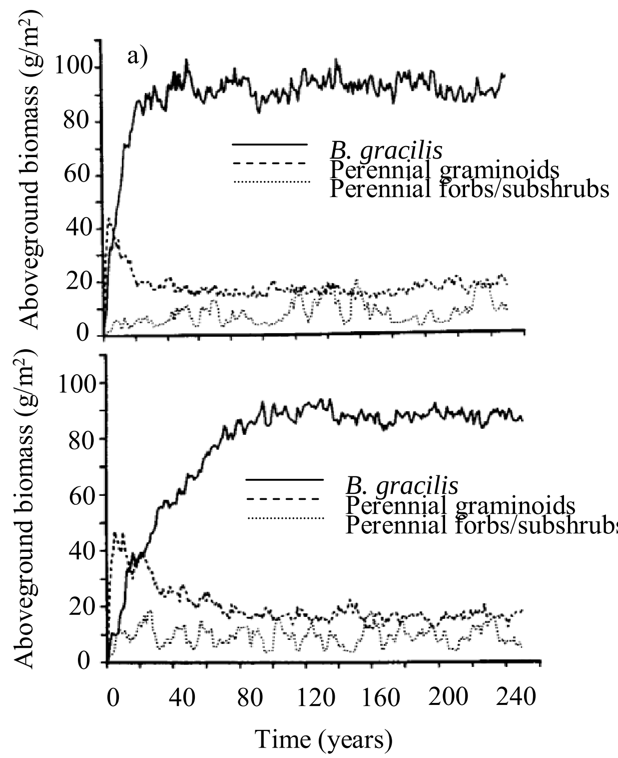


Figure 2.6. Influence of seed availability on the recovery of blue grama following disturbance (Peters and Lauenroth SGS 2008).

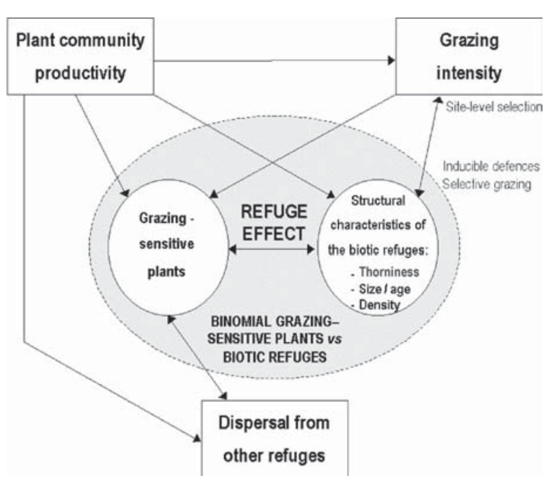


Figure 2.7. Conceptual model of factors influencing effects of biotic refuges at a local landscape scale in plant communities grazed by large herbivores (Rebollo et al. 2005).

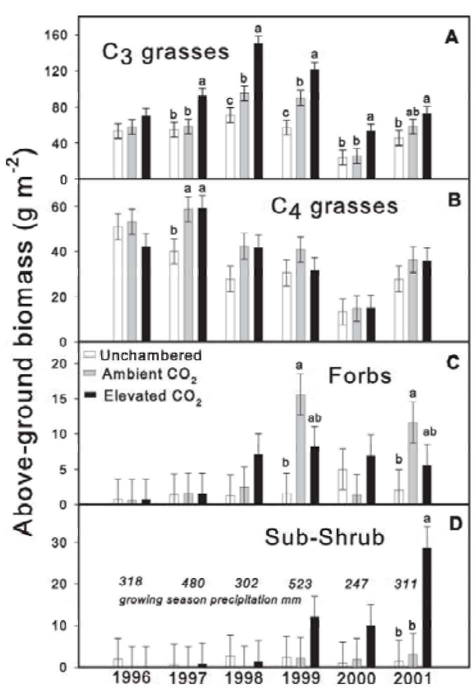


Figure 2.8. Aboveground plant biomass ambient (~365 ppm CO2), elevated (720 ppm CO2), and control plots. *A. frigida* (panel D) exhibited the greatest relative production increases (Morgan et al. 2007).

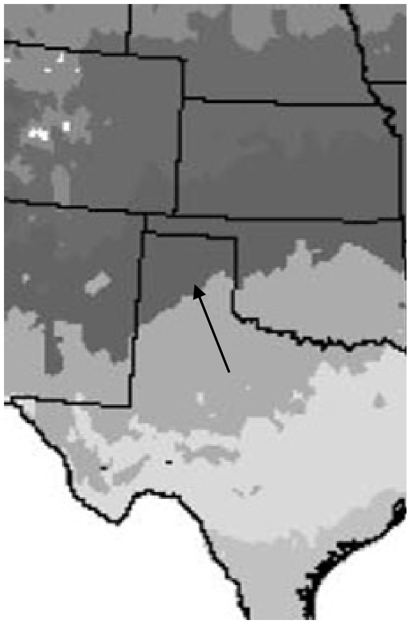


Figure 2.9. Minimum air temperatures in the southern shortgrass steppe (Adapted from NCDC 2002). Arrow points to the southern boundary of air temperature ≤ 0 F and the northern boundary of *Prosopis glandulosa*.

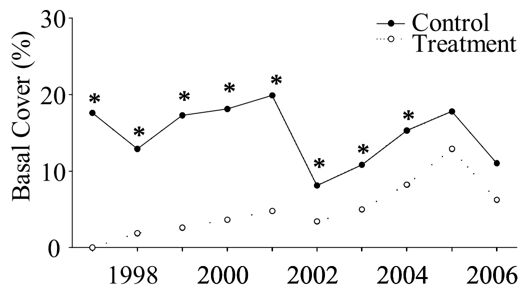


Figure 2.10. Recovery of blue grama following removal in 1997. (Munson and Lauenroth submitted)

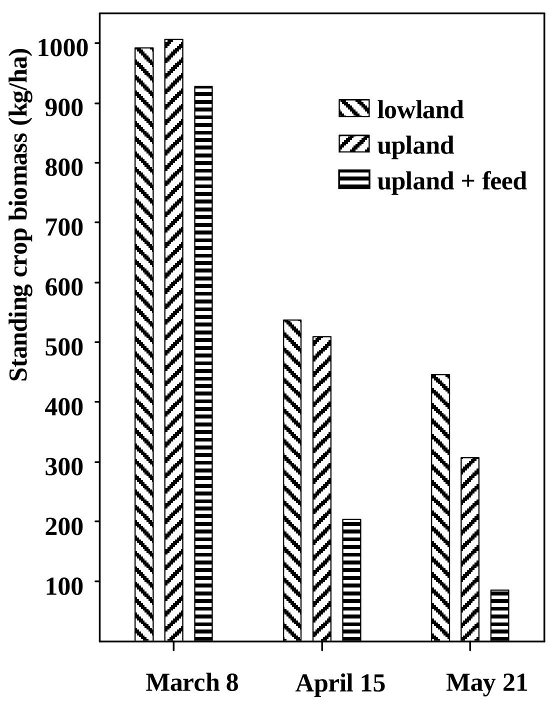


Figure 2.11. Aboveground biomass in spring grazed pastures with areas of supplemental feed for livestock.

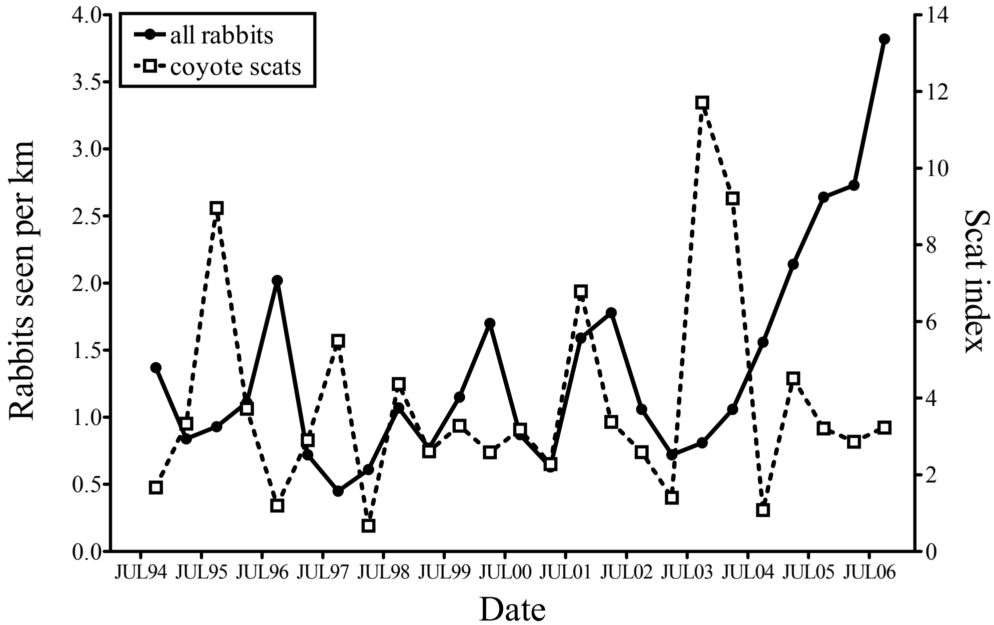


Figure 2.12. Numbers of rabbits, and especially black-tailed jackrabbits, the most arid-adapted of SGS lagomorphs, have increased dramatically following the 2000-2004 drought. Coyote abundance, as measured by scat counts, have failed to track the increase in rabbit numbers, suggesting some other factors besides prey may limit their numbers on SGS (Stapp et al. 2008).

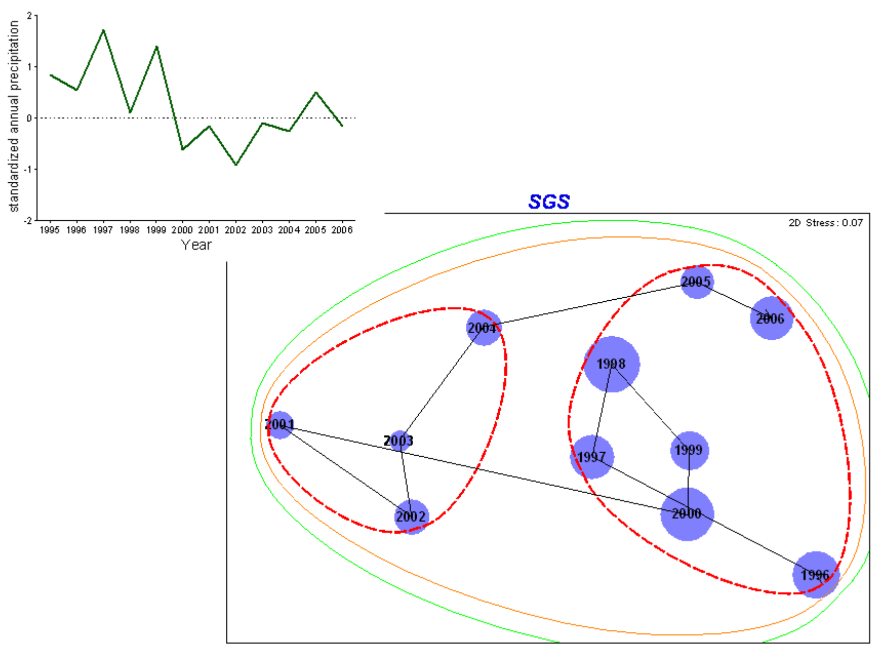


Figure 2.13. MDS ordination of SGS rodent communities from 1996-2006 shows that changes in rodent community structure closely track variation in precipitation (inset), and reveal dramatic effects of the 2000-2004 drought. Size of filled circles corresponds to relative amount of precipitation the previous year(Stapp et al. in prep).

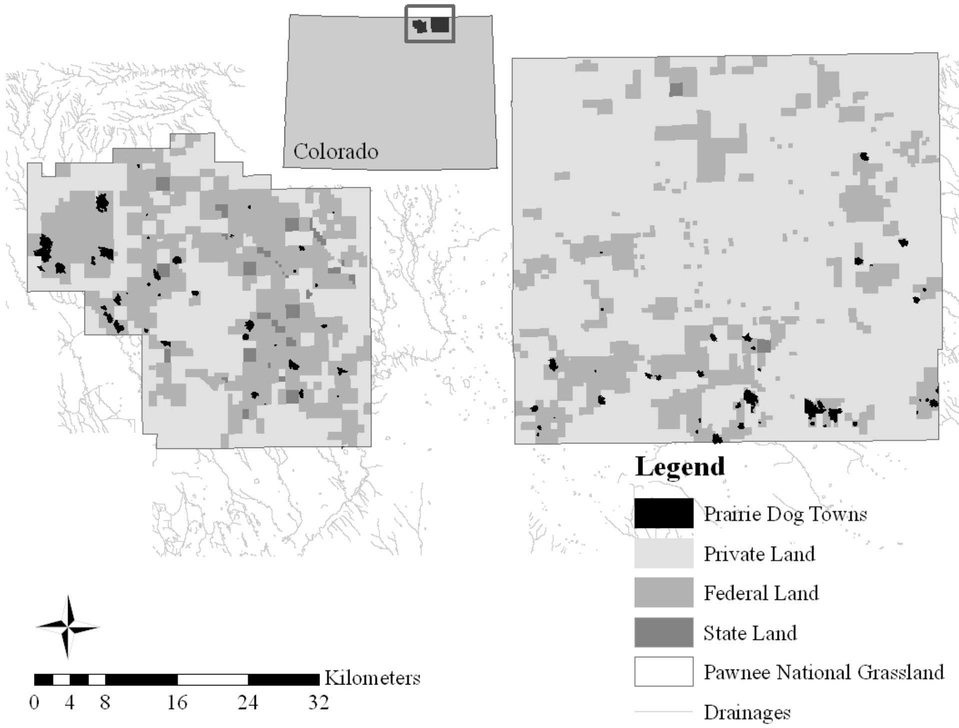


Figure 2.14. Location and largest recorded areas of black-tailed prairie dog towns on the SGS-LTER site (1981-2005).

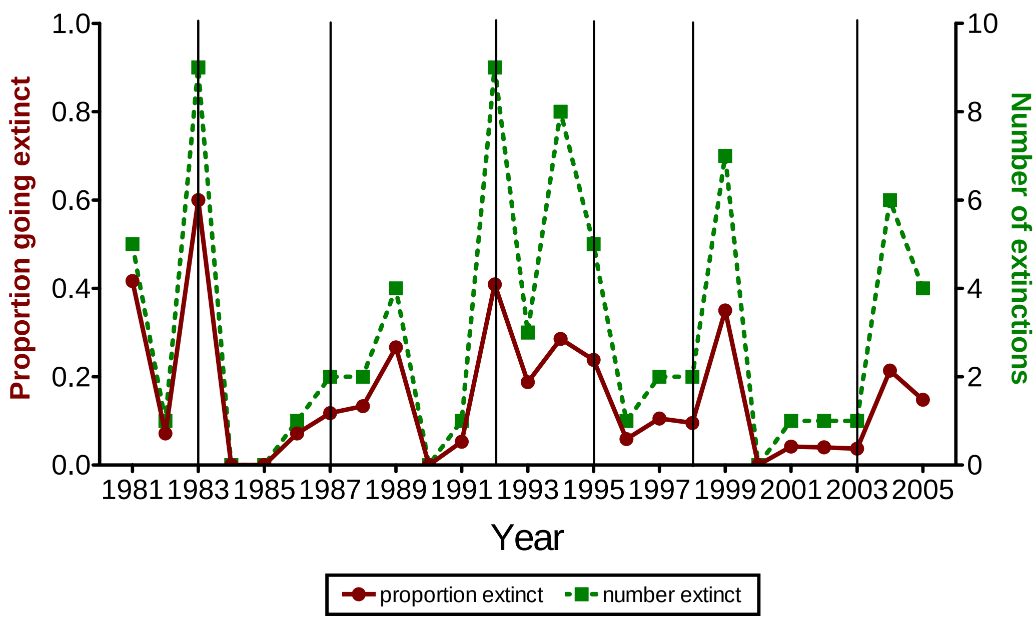


Figure 2.15. Plague-related extinctions of black-tailed prairie dog colonies tend to occur after El Nino Southern Oscillation events (vertical lines) (modified from Stapp et al. 2004).

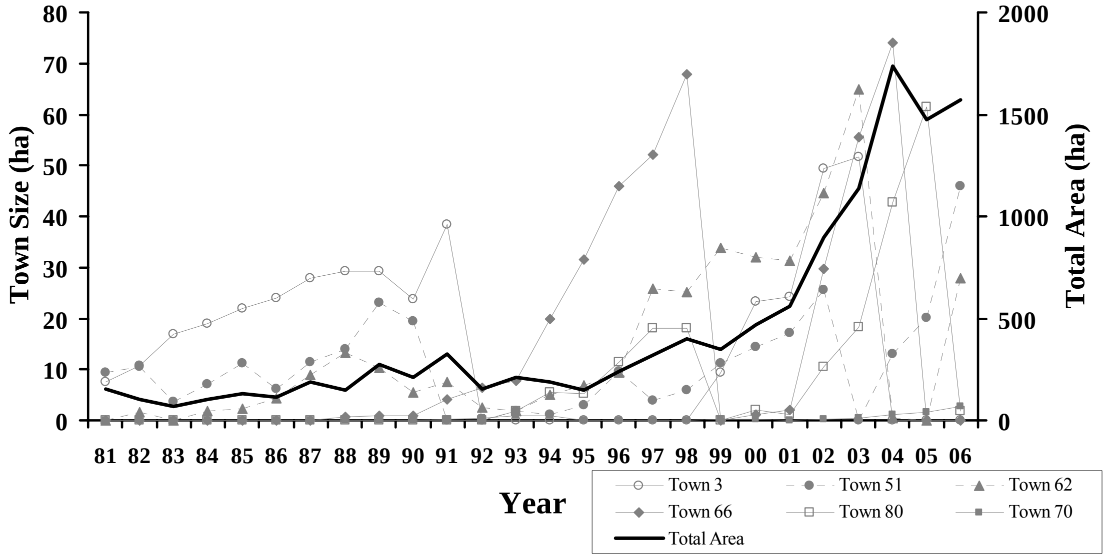


Figure 2.16. Total area occupied by black-tailed prairie dog towns on the SGS-LTER site during 1981-2006 (dark line). Trajectories of six representative towns are shown as lighter lines, showing the dynamics of extinction, re-colonization and exponential increase on individual towns within the metapopulation. Updated from Antolin et al. (2006).

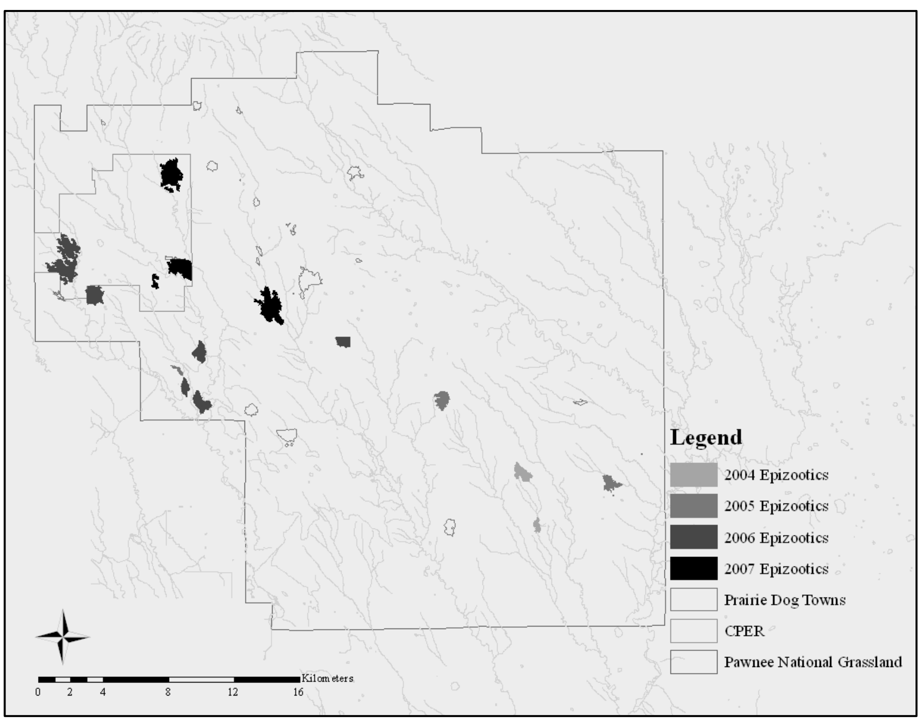


Figure 2.17. Black-tailed prairie dog towns on the western section of the SGS-LTER site during 2004-2007. All largest towns on the site experienced plague epizootics and became locally extinct during this time.

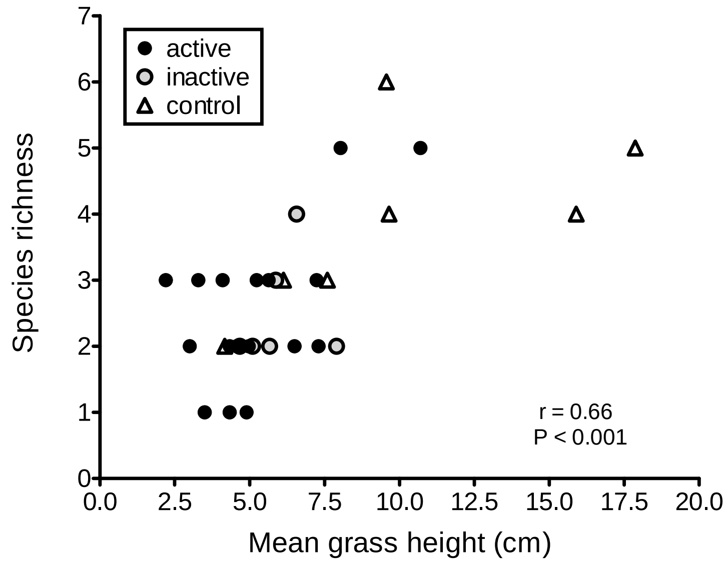


Figure 2.18. Rodent diversity both on active and inactive prairie dog colonies and in grasslands without prairie dogs is best explained by grass height. Closed circles are from trapping grids on active prairie dog towns, open circles are from inactive (plagued) towns, and triangles are from nearby control grids (Stapp 2007).

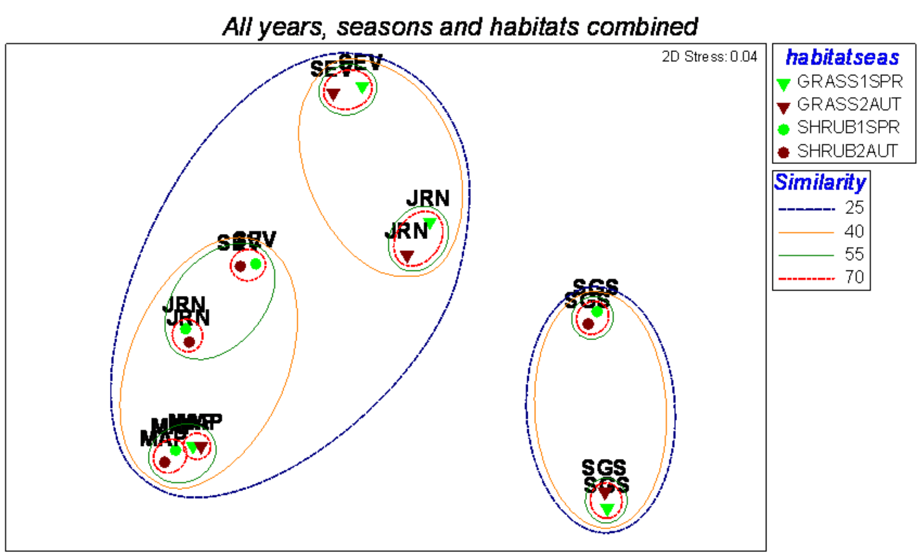


Figure 2.19. Rodent community structure on SGS is markedly different from that at other arid and semi-arid LTER sites, regardless of season and habitat type (shrub, grassland). Interestingly, grassland sites at Sevilleta (SEV) and Jornada (JRN) are more similar to one another than each other is to shrub habitats at the same site, a few km away. MDS ordination of 1996-2006 data from all sites as part of a cross-site analysis (Stapp et al. in prep).

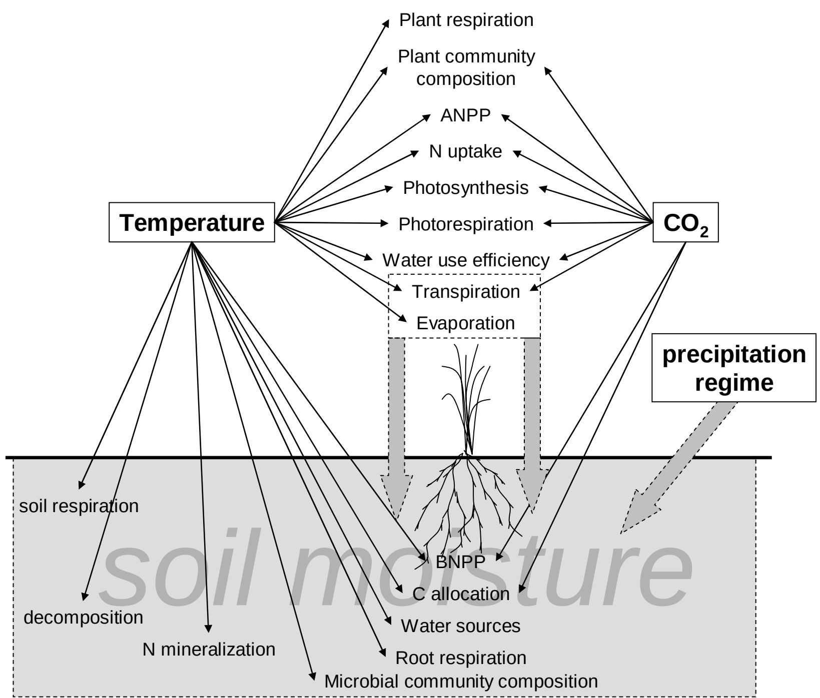


Figure 2.20. Soil moisture is the overriding determinant of all SGS ecosystem processes illustrated here. We hypothesize that direct impacts of global change factors on ecosystem processes (indicated by narrow arrows), although important, will be of secondary importance relative to alterations in soil moisture brought about by changes in precipitation regimes, temperature or atmospheric CO_2 (broad arrows).

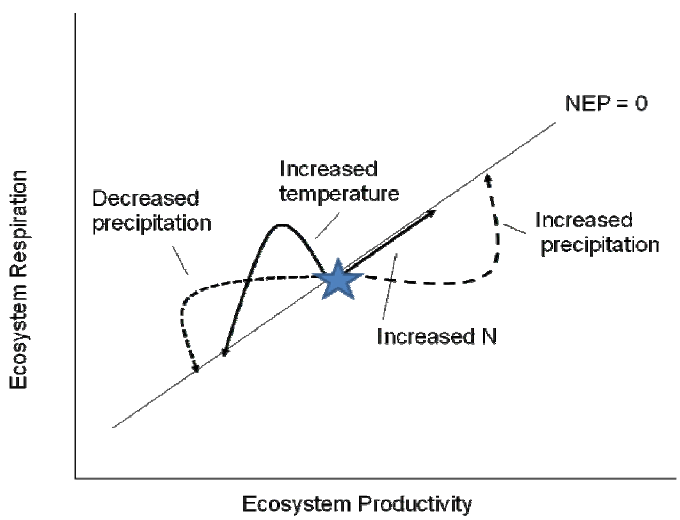
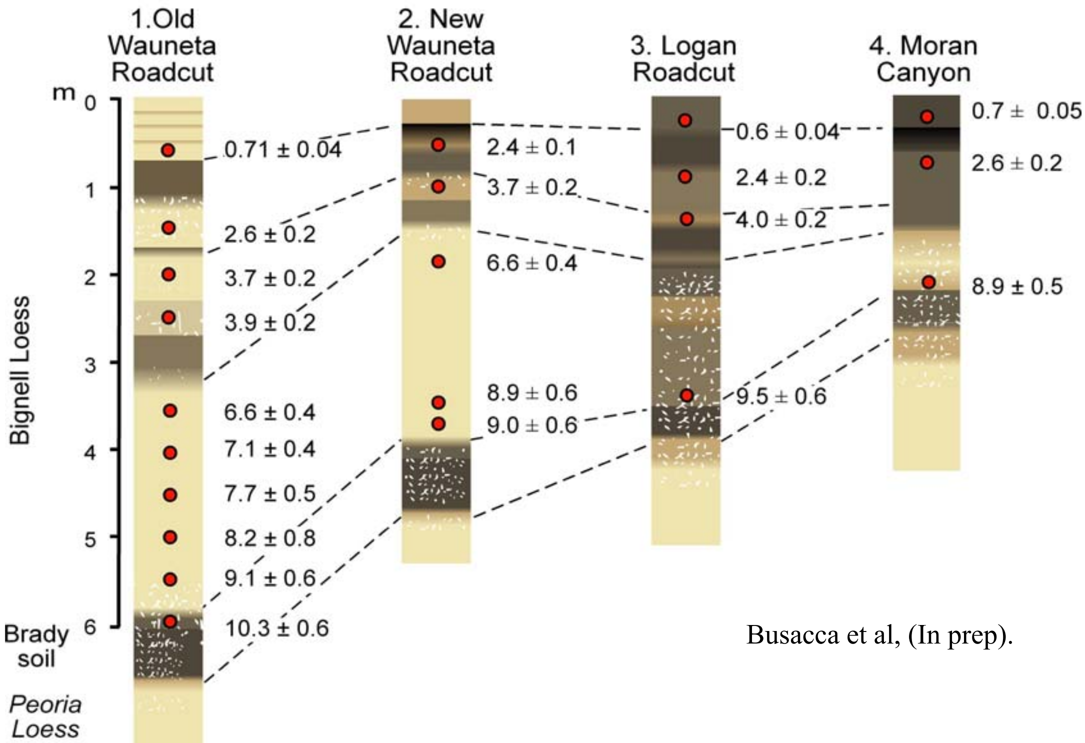


Figure 2.21. We hypothesize that NPP and respiration respond differently to precipitation, temperature and N availability changes in time and space. In particular, our initial results suggest that heterotrophic respiration responds more rapidly to temperature changes and NPP to precipitation changes, while both respond similarly to N increases. Our questions are: How long does it take for the perturbations to result in balanced respiration and productivity (NEP=0, or where the slope is 1:1). How do temperature, precipitation and N interact to influence carbon balance?



Busacca et al, (In prep).

Figure 2.22. Cross section of a western Nebraska loess deposit containing paleosols. The cross section extends from Old Wauneta to Moran Canyon in the direction of increasing MAP (left to right). The sequence of paleosols at Old Wauneta were sampled in 2003-2004 for paleoclimatic studies. Ages are in 1000s yr BP, courtesy of Joe Mason (Miao et al., 2005). Using these dates we determined rates of dust deposition at Old Wauneta between 9.1 - 6.6 ka averaged 0.07cm/yr; rates from 6.6 ka - present averaged 0.05 cm/yr. In contrast, Holocene deposition rates at Juniper Canyon in the Palouse region of the Pacific Northwest (Sweeney et al., 2005) averaged 0.02 cm/yr, or less than one-third the rate at Old Wauneta. Full glacial Peoria Loess deposition rates at Bignell Hill, NE (Roberts et al., 2003) averaged more than 1 cm/y from 18.9 - 16.6 ka, or about 14 times the early Holocene rate at Old Wauneta.

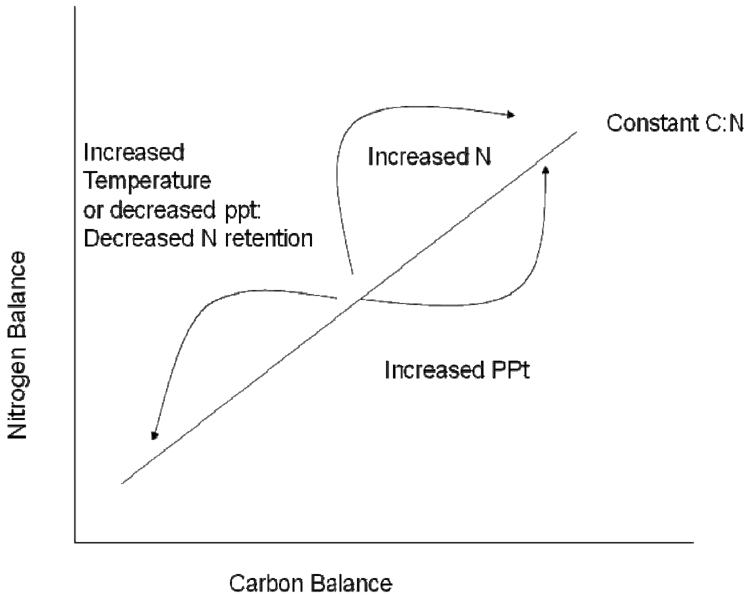


Figure 2.23. The effect of environmental change (temperature increase, precipitation increase or decrease, N availability addition or deletion) on C and N balance. Our hypothesis is that, in general, N is lost and gained more slowly than C, except in the case of anthropogenic additions. We propose to utilize our long-term temperature, precipitation, carbon, and nitrogen addition experiments, both on site and across environmental and management gradients using ^{15}N, to assess this effect and its temporal dynamics.

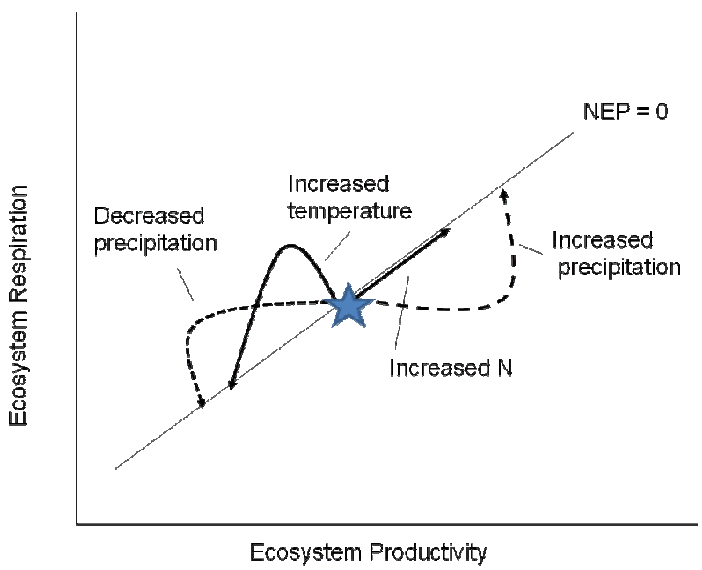


Figure 2.24. We hypothesize that increased numbers of small precipitation events, occurring as pulse precipitation, influence microbial dynamics (heterotrophic respiration, N mineralization, trace gas fluxes) more than plant dynamics such as net primary production. We propose to test this hypothesis in a series of experiments that will also evaluate plant-microbial competition for water and N.

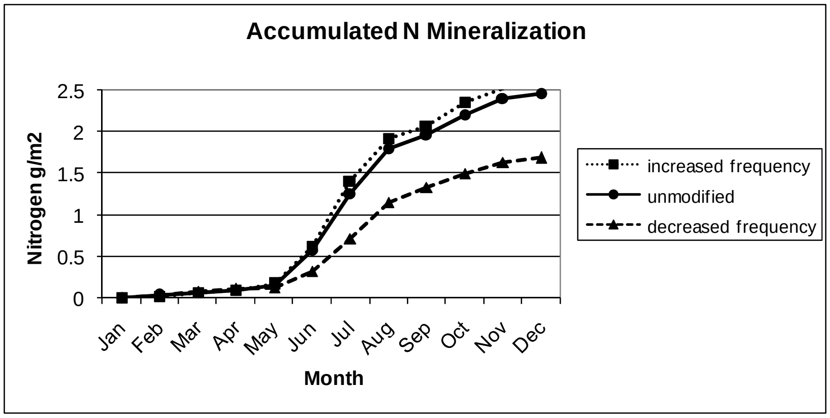


Figure 2.25. Results of DAYCENT simulations for the shortgrass steppe (Burke et al. 2002), in which we used the Konza (KNZ) LTER rainfall experiment scenario to model the effects of ambient precipitation, increased frequency but smaller events, and decreased frequency but larger events. All of the annual precipitation values were kept constant. The decreased frequency results in lower N mineralization (and all N fluxes and NPP) because, in the model, there are fewer days during which soil moisture is sufficient.

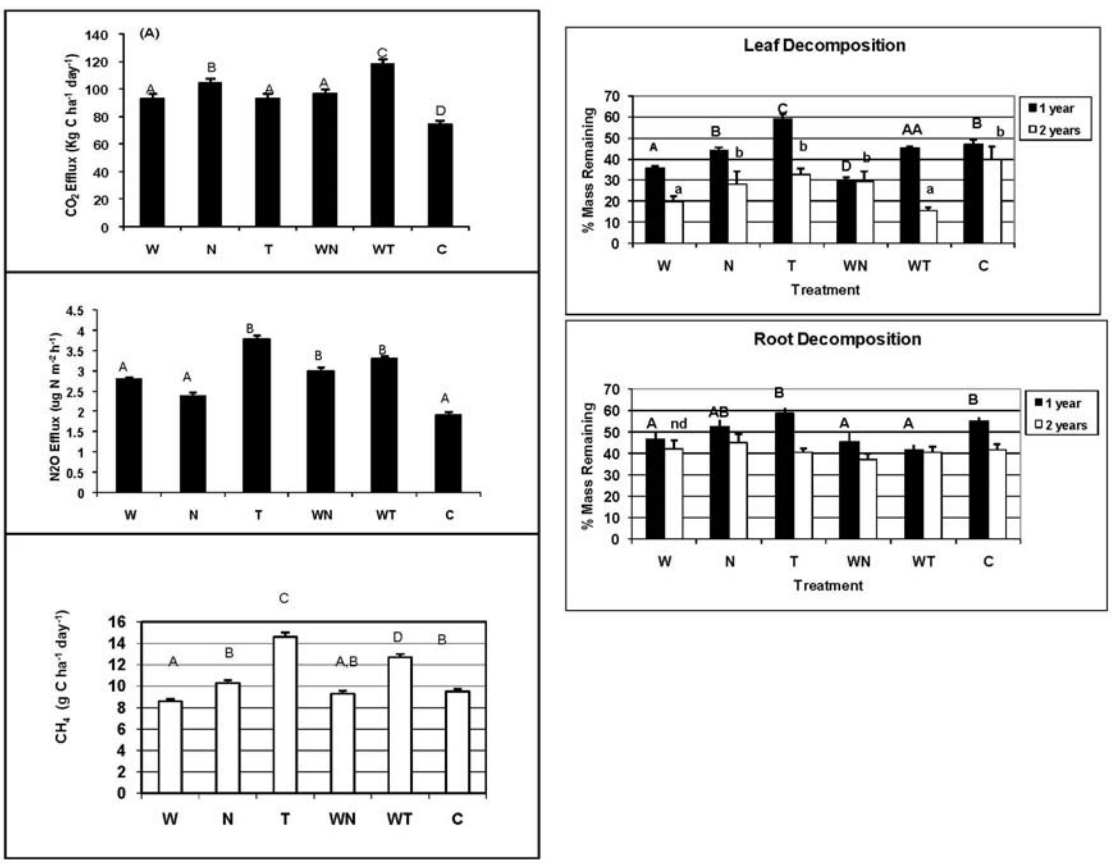


Figure 2.26. Effects of increased water (W), nitrogen (N), temperature (T) and their combined influences on soil respiration, CH_4 uptake, N_2O flux, and NO flux in our long-term environmental change study to date. The soil flux measurements were taken every two weeks, and averaged throughout the year. W = Water, N – Nitrogen fertilization, T = temperature increased using small passive chambers (between 3 and 5 degrees C during daytime), WN and WT are combined treatments, and C = control. Letters show significant differences, and error bars are standard error of the mean. Interestingly, CO_2 flux was increased by temperature, but decomposition was decreased.

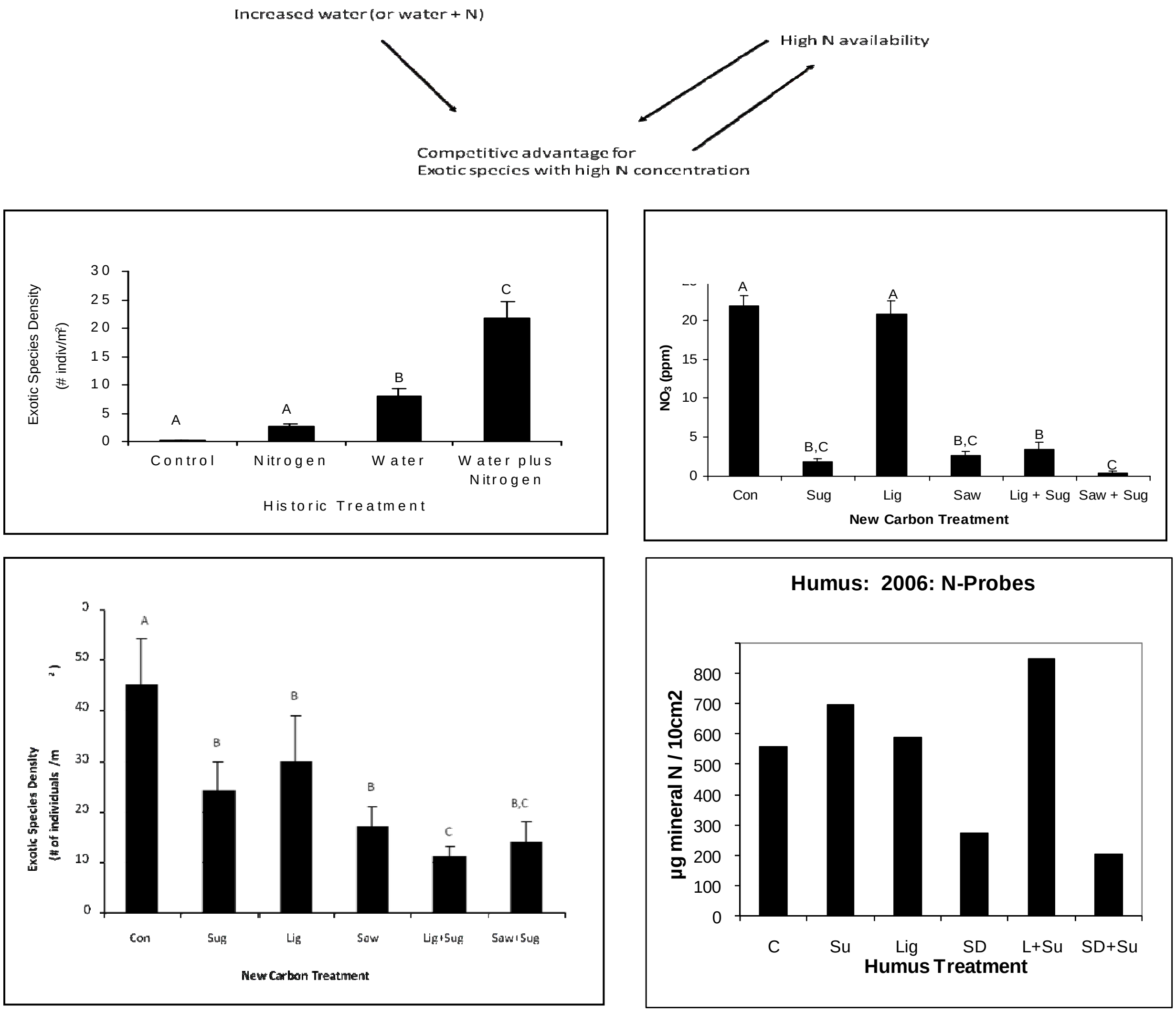


Figure 2.27. A) The relationship between anthropogenic N additions, N availability, and invasive species in shortgrass steppe ecosystems. B) Our long term (35 year) experiments indicate that without intervention, N additions lead to changes in plant communities that persist because of litter quality feedbacks (figures shows exotic species density across history Nitrogen (N), Water, (W), N+W, and Control (C) treatments. C) A more recent SGS-LTER carbon addition study has indicated that we can reduce N availability (sugar, lignin, sawdust, and combination treatments on the N+W plots in 2000), and D) without seeding, reduce exotic species cover (showing exotic species density on N + W plots in 2003). E) Finally, ceasing treatments has demonstrated that only sawdust maintains its ability to reduce N several years after treatment. (Burke et al. in prep)

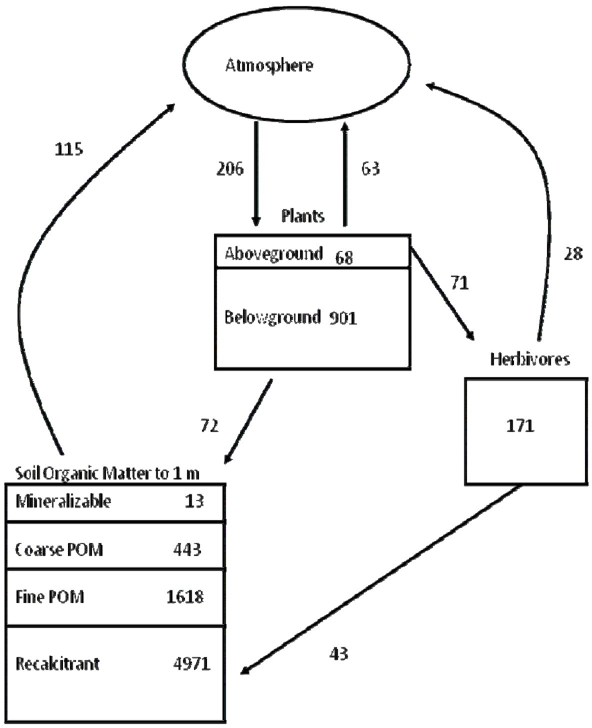


Figure 2.28. The distribution and fluxes of carbon in the shortgrass steppe ecosystem (from Burke et al. in press). We hypothesize that because of the very large dominance of soil organic matter, only disturbances that focus on soils have large consequences for biogeochemical cycling. Units of pools are g m^{-2} to a 1 m depth, and fluxes are in g m^{-2} d^{-1}.

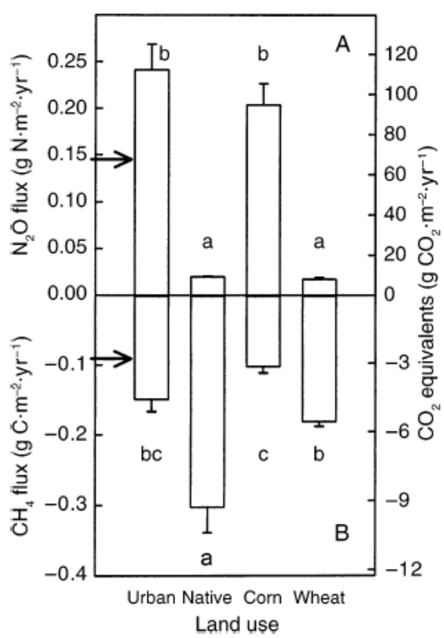


Figure 2.29. Data from a short-term study comparing trace gas fluxes (expressed as global warming potential) from native shortgrass steppe, urban areas, irrigated and fertilized corn, and dryland wheat-fallow (Kaye et al. 2004).

SECTION 3: PROJECT MANAGEMENT

One of the original goals of the architects of the LTER Program was that long-term, site-based research programs with a relatively stable funding base would be managed so that turnover of individual investigators and/or completion of scientific careers would not hinder the central goals or established experiments and data collection at the LTER sites (Callahan 1984). The SGS-LTER program remains committed to these principles and has flourished through carefully managing leadership to ensure both continuity and renewed vision, with slow but consistent turnover. We remain committed to rotating leadership as younger scientists rise in rank, prove their commitment to the long-term goals of the program, and feel comfortable assuming more responsibilities.

Our priorities for managing the SGS-LTER project are to ensure that we support a broad range of ecological scientists and stimulate new ideas and participation, all within the context of stability and continuity for the long-term studies we pursue. During SGS-LTER V (2002-2008) Dr. Eugene Kelly (EFK) became lead PI after serving as second PI for the last half of SGS-LTER IV. Former lead PI, Dr. Ingrid Burke (ICB), served as second for the first half of the term to ensure continuity. Dr. Michael Antolin (MFA) replaced ICB in year three in preparation for assuming the lead PI role for SGS-LTER VI. Midway through LTER VI, Dr. Jack Morgan (JAM) will replace EFK as second, in preparation for becoming lead PI in the future. We remain committed to the idea of gradual changes in leadership, and feel that this structure allows us to make smooth transitions to the future.

LTER researchers are organized into research groups, based on specific research interests, with a designated leader for each group (Fig. 3.1). Group leaders are consulted as needed, either individually or as a group, when major research decisions must be made or when specific requests for data, information, or collaboration are received. Willingness of group leaders to deal with these requests reduces workload of the administrative PI, and this distributed management facilitates greater coordination of this diverse research program.

Because we have a large group of participating senior scientists and collaborators, an executive committee (EC) is tasked with managing the progress of the project. The EC represents all of our research groups as well as the identified lead PI/Co-PI: MFA (Faunal Ecology), EFK (past lead PI, Global Change), ICB (Biogeochemistry), Dr. William Lauenroth (WKL, Plants and Grazing Dynamics), Dr. John Moore (JCM, Education and Outreach; Soil Molecular Ecology) and JAM (USDA ARS and Global Change). Membership within research groups is highly over lapping, many of our co-investigators belong to two or more of the groups. By including representatives or leaders from each research area in our executive committee, we maintain a management structure that mirrors our reporting to NSF, ensures balance across our sub-disciplines, and facilitates information dissemination among all researchers.

Comments from our mid-term site review team led us to add depth in areas that are crucial to understanding the SGS. During SGS-LTER V, we recruited six scientists to strengthen the project in needed areas: Drs. David Augustine (fire ecology), Dana Blumenthal (invasive species), Cynthia Brown (invasive species), Justin Derner (range ecology), Alan Knapp (plant ecology and ecopyhsiology), and Joseph Von Fisher (microbial ecosystem ecology). For SGS-LTER VI, we recruited eight new scientists to participate on the project: Drs. Richard Conant (biogeochemistry), Noah Fierer (microbial ecology), Niall Hanan (land-atmospshere), Julia Klein (range ecology), Patrick Martin (landscape ecology), Heidi Steltzer (plant ecology), Mary Stromberger (microbial ecology), and Matthew Wallenstein (microbial ecology). Resources allocated to each of these scientists' work is variable, but often include partial summer salary, logistical support for field work, travel to meetings to present results, participation in LTER Science Council meetings and workshops, and stipend/tuition support for co-advised graduate students, especially for summer field work at the SGS-LTER site. We are aware that, as a group, SGS-LTER scientists have low diversity, but we continue to focus on increasing gender diversity among this group through promotion and mentoring of researchers into greater leadership roles.

We initiated a collaboration with Dr. Peter Newman (recreation and tourism) to study impacts of recreational shooting on the Pawnee National Grassland. This study is the beginning of social sciences and economic research on the SGS-LTER. These studies will become more urgent as the SGS and ecosystem services are altered by 1) increasing exurban and suburban landuse on the SGS, 2) impacts of rapidly growing nearby urban populations, and 3) global change and its effects on both the SGS and surrounding ecosystems.

During SGS-LTER V we experienced some turnover. Dr. Arvin Mosier retired from the USDA ARS, Dr. Susan Stafford accepted a position at the University of Minnesota, and Dr. Roger Pielke, Sr., retired from CSU and joined the CIRES group at the University of Colorado in Boulder.

While the EC model described above works well, in practice MFA will serve as the responsible PI representing CSU to NSF and as the SGS Science Council representatives to the network. For day-to-day financial and other project decisions, MFA, EFK and JAM will share responsibility and coordinate activities with the three other EC members who represent leaders of the research areas. Interactions are at a daily level among PIs, the project manager, and the administrative assistant. Willingness of group leaders to deal with requests within the scope of their research areas allows for much better connection between the science in that group and the management, while still maintaining maximum connection to the entire project. A key in this distributed project management model is maximizing the involvement of other personnel in LTER activities. MFA and EFK will serve as SGS-LTER representatives on LTER Science Council (SC) and attend SC meetings. Additional site representatives will attend some meetings as appropriate. Minutes from these meetings are distributed to the entire group. Workshop participation is encouraged and supported when possible. Interactions among investigators are fostered, and scientific and programmatic information is disseminated in a variety of ways. All investigators (at CSU, UNC, California State U Fullerton, U Colorado-Boulder and at USDA-ARS) are on e-mail listserves that allow Dr. Sallie Sprague (Project Manager) to distribute information and request input. For example, LTER network office e-mail communications sent to "PI-list" are assessed by MFA and EFK for potential distribution to groups or the entire staff when appropriate.

The entire group of SGS-LTER participants (lead scientists, graduate students and staff) meets every other week during the school year for either a "brown bag" seminar or to discuss project business, and to provide general announcements. Research presentations are made by visiting scholars, graduate and undergraduate students, senior researchers from ARS and USGS, and our own SGS-LTER investigators. Our brown bag seminar series also serves to invite new researchers to meet our investigators and discuss new collaborations. Minutes are distributed group-wide and made available on our web site. Within our own research community, new ideas about interpreting data or setting up a next round of experiments by a research group often come from feedback provided by individuals from other groups. We are planning to initiate a local 'all scientists meeting', to be held at our new field station each fall to foster interactions among scientists within the project, to summarize our accomplishments from the summer field season, to prepare for the following year, and to plan proposals needed for the next year.

SGS-LTER employs a staff of 9-10 (Fig 3.1), supervised by the two lead PI's. Staff coordinate their efforts during weekly staff meetings with MFA and EFK. In the future, we will invite research group leaders to attend staff meetings each spring to help plan upcoming field research and each fall for comprehensive updates on the state of data collection for that year. In addition, staff increase the visibility of the SGS-LTER program at our biennial public symposium (see EDUCATION AND OUTREACH), and provide information to the public at events like Ag Day at CSU (football game) in the fall, and the Western Stock Show in Denver each January.

Finally, as our facilities require upgrades, other NSF funding allows us to update our field station and build parts of a larger and more comprehensive Grasslands Research and Education Center. Current funding is providing a new classroom building and housing. We continue to seek funding for a state-of-the-art laboratory for which architectural design is already in place (from previous and current NSF funding). It is our expectation that the new facilities will make the SGS-LTER site more attractive both to researchers from Colorado State, but also to new researchers from outside the current community.

In the first years of operation, the new field station will continue to be managed by the EC of the SGS-LTER. A new business model will be developed as the station is built out to capacity, in anticipation of broader use by outside researchers and classes from K-12 and Colorado State University. The Center will become a CSU facility with a separate income stream from classroom and laboratory fees, including those from the SGS-LTER (and possibly NEON) as principal clients. At that time, the station will hire its own director and staff.

Fig 3.1 . Organizational Structure of the SGS-LTER Project

Executive Committee
*Science Council Representative

Mike Antolin* (lead PI), Ingrid Burke, Eugene Kelly* (co-lead PI), William Lauenroth, John Moore, Jack Morgan (USDA-ARS), Sallie Sprague (ex-offico)

SGS-LTER Staff

Caroline Yonker (Soils), Mark Lindquist (Site Manager), Nicole Kaplan (IM leader), Judy Hendryx (Plants), Robert Flynn (IM), Sallie Sprague (Project Manager), Kim Melville-Smith (Education Coordinator), Becky Riggle (BGC), Dan Tripp (Faunal Ecology), TBA (Field, Monitoring, and Data Manager)

SGS-LTER Research Groups
**Group Leader

Global Change

David Augustine, Dana Blumenthal, Ingrid Burke, Cynthia Brown, Rich Conant, Niall Hanan, Gene Kelly, Julia Klein, Alan Knapp, Bill Lauenroth, Patrick Martin, Jack Morgan**
Bill Parton, Elise Pendall, Dave Williams

Biogeochemical Dynamics

Ingrid Burke**
Rich Conant, Gene Kelly, Julia Klein, Alan Knapp, Bill Lauenroth, Patrick Martin, Keith Paustian, Joe von Fischer

Plants and Grazing

David Augustine, Dana Blumenthal, Jim Detling, Justin Derner, Julia Klein, Bill Lauenroth**
Dan Milchunas, Jack Morgan, Heidi Steltzer

Faunal Ecology

Mike Antolin**
David Augustine,
Jim Detling, Paul Stapp

Soil Molecular Ecology

Noah Fierer, John Moore**
Mary Stromberger, Joe von Fischer, Matt Wallenstein

Social Science

Mike Antolin, Ingrid Burke, Peter Newman

Synthesis/Modeling

Mike Antolin**, Ingrid Burke, Jim Detling, Alan Knapp, Bill Lauenroth, Jack Morgan, Bill Parton, Keith Paustian

Cross Site Studies

Ingrid Burke, Gene Kelly**, Alan Knapp, Bill Lauenroth, Patrick Martin, Jack Morgan, Heidi Steltzer, Paul Stapp

SGS LTER
Education, Outreach and Information Management Groups

Education and Outreach

Ingrid Burke, Gene Kelly, John Moore**, Kim Melville-Smith
Mark Lindquist, Sallie Sprague

Information Management

Nicole Kaplan**
Bob Flynn

SECTION 4: INFORMATION MANAGEMENT

Goals

The goals SGS-LTER IMS are to support SGS research and the Network research plan. A functional information management system must be well organized, and nimble enough to support ecological research efforts that change with advances in technology (Stafford et al. 1986a, b). The SGS Information Management (IM) team reaches these goals by managing and designing a system to:

- Facilitate discovery, dissemination and integration of useful data and standardized metadata by LTER scientists, the scientific and educational communities, and the public;
- Create a robust cyber-infrastructure that connects people with relevant expertise, data, and information technology (IT) equipment to enable scientific endeavors (Atkins et al. 2003);
- Support collaboration, and participate in outreach and synthesis activities;
- Contribute to Network-wide databases and NIS (Network Information System) initiatives.

Scope of the SGS Data

The SGS IMS encompasses over two hundred non-spatial data sets and metadata from as early as 1943, spatial data contained in a Geographic Information System (GIS), and specimen information for the reference collection at the SGS field station. We have transformed legacy data sets from hard-copies of datasheets, Fortran card decks, and 7-track tapes produced by United States Forest Service working at the Central Plains Experimental Range in the late 1930s and grassland researchers funded by the International Biological Program in the late 1960s into digital copies with metadata that now encompass fifteen percent of our SGS system (Stafford et al. 2002).

Data tables for ongoing long term datasets are updated annually. All metadata and most data are accessible on-line in accordance with the SGS and LTER Data Acquisition Policy (http://sgslter.colostate.edu/Data/AcquisitionPlcy.htm). Since 2002, an average of ninety-one datasets were requested each year from the SGS website or through e-mails to the IM team. Most of these data requestors were not associated with SGS, but rather represented a worldwide distribution of users. These data provided information for research projects, writing proposals or synthesis publications, developing or completing coursework for GK-16, inquiring about imformation management practices, and designing resource management and conservation plans (**Figure 4.1**).

Publications, including technical reports, theses, dissertations, journal aritcles, book chapters and abstracts are updately quarterly and searchable on-line by querying on date, author(s), keyword(s) and/or publication type (http://sgslter.colostate.edu/Publications/searchpblctns.htm). Data and metadata tables and GIS data are related in a data dictionary and are accessible on-line through a download page or through a map viewing tool (ArcIMS) on the SGS-LTER website (http://sgslter.colostate.edu/website/).

A few of our on-going, current datasets that contain information regarding species of concern are stored off-line. These data are accessed and distibuted by request with permission from the Principal Investigator (PI).

Design of SGS IMS

A windows-based server with RAID technology (Redundant Array of Inexpensive Disks) centralizes the management of data, metadata and other information. LTER users store their LTER data and other files on the centralized server so as to take advantage of the backup system, facilitate real-time capture of their LTER products, and to share data with other designated users. Researchers and students working off campus can still access the LTER IT infrastructure by launching the Colorado State University (CSU) Virtual Private Network, used to authenticate their access to the system. Personnel data and other sensitive data are protected against misappropriation and misuse by controlling permissions based on user login accounts. Guidelines are distributed to our users annually.

This hardware architecture has flexibility to migrate the system to other locations within CSU, as the project leadership and administration change over time. Back-up media were enhanced by doing away with 8mm tape and implementing more accessible and economical external hard-drives off-site. Incremental back-ups are performed nightly and full back-ups semi-monthly.

We are addressing the need to manage increasing amounts of data from sensors and new types of data from new research endeavors by expanding data storage capacity, upgrading to faster servers and developing community-wide methods and minimum standards for data collection and publication. In addition, new field station facilties are planned with increased bandwidth and dedicated space for sample archives.

SGS Database and Web Site

The SGS IM Team currently uses a Windows 2003 Server platform and Access Relational Database Management System (RDBMS) to serve metadata, data, citations for publications, and tools for project management. We are implementing a new RDBMS on a windows-based dynamic server, which is maintained, backed-up, and logged for web hits monthly by CSU at no cost to the project. SGS metadata are currently accessed by navigating the data webpages to an ASCII format for downloading (http://sgslter.colostate.edu/Data/DataLibrary.htm). The new database and website are built on improved information architecture that enhances navigation, data discovery and access by relating information about metadata and datasets more broadly within the database (http://wsprod.colostate.edu/cwis532/). The new database design has been included in a community model of managing metadata in an RDBMS, which is available to other LTER sites and partner agencies. Metadata content in EML (Ecological Metadata Language) generated from the database, will support new approaches to data integration, synthetic research, and scientific workflows (Michener 2006). EML best practices have been followed as metadata have been added or updated in the database and LTER recommendations for websites have been implemented in our next generation SGS web site (Kaplan 2005).

Involvement of SGS IM Team in Site Research

The SGS IM team attends research team meetings regularly, and establishes and communicates IM priorities and strategies annually. The IM team stays involved during data collection, verification, entry, QA/QC, archiving, and publication (Brunt 2000) **(Figure 4.2).** IM team roles and responsibilities are updated regularly to plan and delegate how our system is maintained, projects are completed, and new cyberinfrastructure investments are focused **(Table 4.1).** Protocols for research projects are available on-line and documented annually in the Field Crew Manual (http://sgslter.colostate.edu/Research/ResearchTopics.htm). SGS-LTER IMS users have access to most data and metadata on our centralized server, as data are collected and entered following each field season. We engage directly with PIs, students and technicians in planning and implementing information management standards as research is planned and implemented. We have useful IT tools to manage SGS resources and are now designing web tools for SGS-LTER PIs and staff to publish exciting research news, interesting images of the prairie, and upcoming events on-line.

LTER Network Data Policies

The LTER Network Data Access Policy has been adopted by the SGS-LTER community (http://sgslter.colostate.edu/Data/LTERNetworkDataPolicyRevisionReport.pdf). PIs have requested that graduate students and new researchers be informed of the policy and are instructed on guidelines to organize and submit their data and metadata files prior to graduation.

Metadata

SGS-LTER has generated attribute level EML from the new database for thirty-percent of our long-term studies, and harvests new EML to the LTER Network Metadata Catalog monthly. The SGS-LTER is committed to producing high quality metadata as the success of future cross-site and synthesis research may rely on applications built on EML. SGS-LTER researchers can submit metadata for new studies directly into the RDBMS via web-based forms. We also are testing and developing tools to generate EML from our GIS.

Data QAQC and Usage

A suite of QAQC programs, called the Matrix, currently checks and formats meteorological data and floral dynamics datasets, which make up over sixty percent of our datasets. The IM team will continue to work with researchers to develop tools to more efficiently process, quality check, publish, and synthesize data with high integrity.

SGS Contributions to LTER Network and Community Activities

The IM team contributes data to the NIS quarterly. We participate in annual meetings, cross site projects, and other community-driven IM activities, such as the Canopy Databank Project (http://canopy.evergreen.edu/bcd/home.asp) at The Evergreen State College, US Geological Survey, National Biological Information Infrastructure "data cooperative" (Kaplan 2003), Science Environment for Ecological Knowledge (http://seek.ecoinformatics.org/) and EcoTRENDS (http://www.ecotrends.info/EcoTrends/). SGS-LTER remains closely connected to the LTER IM and EcoInformatics communities as Nicole Kaplan, SGS-LTER IM Team Leader is co-chairperson of the LTER IM Committee.

Summary

SGS-LTER has a rich legacy of data sets that serve as a resource for future generations. This includes a strong flow of data and metadata from the field to the IMS along with extensive communication with PIs and students along the way. The SGS-LTER RDBMS serves as a good foundation to build IM tools that create greater access to information, support local science, and contribute to community driven efforts based on EML. The SGS-LTER cyber-infrastructure is challenged by increasing quantities of data, samples, and specimens, and new expertise needed to manage new types of data from sensors and genomic analysis. Investments in personnel, equipment and distributed bandwidth will expand our capabilities to support site and network science.

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Figure 4.1 Data Set Requests by Purpose by SGS and Other Users from 2002 - 2007

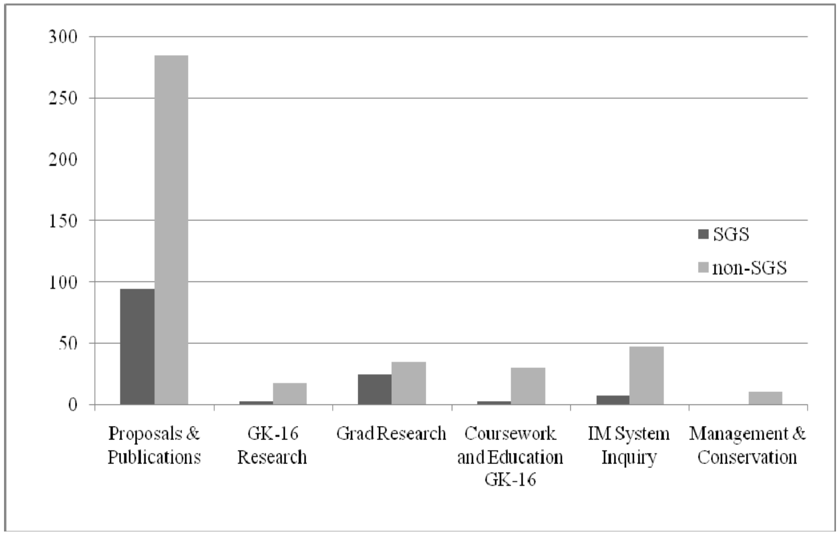
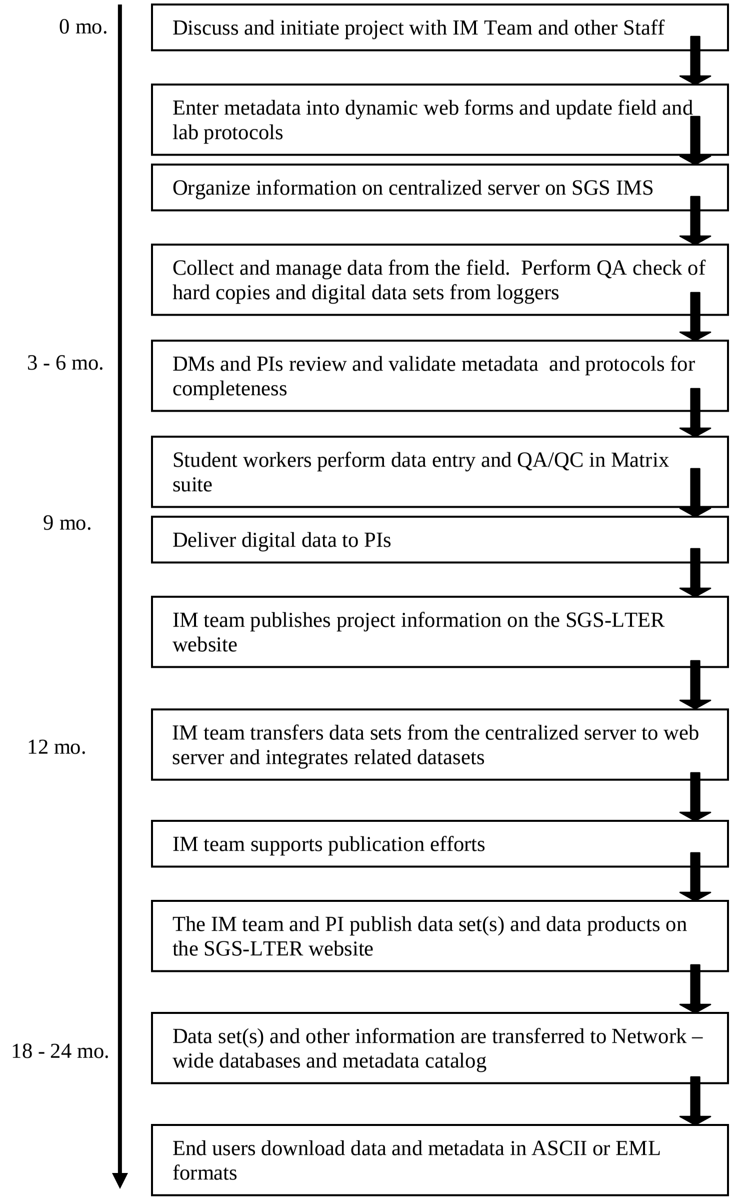


Table 4.1 Roles and delegation of critical tasks for SGS IM team personnel.

Roles	Leadership	IM	GIS	IT	Database/ Web	Total FTEs
Nicole Kaplan (IM)	.10	.75		.05	.10	1.0
Bob Flynn (IT/GIS)		.05	.10	.25	.10	.50
Programmer					.25	.25
Data-Entry Students		.40	.10			.50
Total	**.10**	**1.2**	**.20**	**.30**	**.45**	**2.25**

Figure 4.2 Time line of collecting, verifying, archiving, and publishing data



SECTION 5: EDUCATION AND OUTREACH

Education Plan

We propose to build upon goals established in our previous grant cycle, paying particular attention to fostering cross-site collaborations. Our education plan targets K-12 students, teachers, undergraduate and graduate students.

Goal 1: Provide interdisciplinary instruction, research experiences and professional development opportunities.

Goal 2: Promote interactions between higher education and K-12 through instruction, research experiences and professional development

Goal 2: Increase the participation of groups under-represented in STEM disciplines by working with under-served schools, providing research experiences for minority high school students, and by actively recruiting minority undergraduate and graduate students.

Undergraduate Education: We promote undergraduate research opportunities within research clusters through REU opportunities, direct funding from the LTER and related grants, and through university-wide initiatives designed to increase undergraduate involvement in STEM (e.g., current NSF UBM grant, and pending NSF URM grant). To meet this goal the LTER leadership will coordinate undergraduate initiatives, will work with the CSU Key Academic Community (a freshman and sophomore cluster program), the CSU Summer Ecology Research Program (Sophomores-Seniors) and the CSU NSF-funded Undergraduates in Mathematics and Biology program (Sophomores-Seniors: www.fescue.colostate.edu) to recruit students. These programs promote research experiences, provide professional development training, and actively work with the CSU student affairs programs to recruit and retain students from under-represented groups. Undergraduates will be integrated team members, participating in project meetings and conducting student-led research projects culminating in a symposium presentation.

Graduate Education: Each SGS-LTER research group allocates funding to support graduate students during the summer session. Additionally, the SGS-LTER scientists will continue to secure additional graduate assistantships through research grants, training grants (NSF IGERT: www.primes.colostate.edu), and outreach grants (NSF GK-12, CDE MSP).

K-12 Outreach and Training: We provide high quality research experiences, workshops and courses for university credit leading to recertification, endorsements, and/or graduate degrees, and increase the participation of K-12 students from groups under-represented in STEM disciplines. Our K-12 efforts build on existing partnerships with CSU, the University of Northern Colorado, and regional school districts (Table 5.1). Our activities include follow-up activities, assessment and evaluation. Our efforts will be funded using the Schoolyard LTER supplemental funds, as well as Federal, State and private foundation funds. Examples include the CSU Mathematics and Science Partnership funded by the Colorado Department of Education ($409,819; three years), the NSF funded GK-12 ($1,399,087; five years) and Teacher Professional Continuum ($135,000; four years) programs (see Current and Pending – Moore), and the Pharos Foundation – Bohemian funds ($22,129; one year). Key elements of the SGS-LTER K-12 education plan include the following:

Professional Development (PD) Workshops: SGS-LTER scientists and graduate students will continue their leadership in the development and delivery of PD workshops for teachers designed to increase content knowledge, prepare teachers for field experiences, and transfer knowledge and experiences to the classroom. Current efforts include a partnership with AND, CAP, JRN, LUQ through an NSF TPC grant, and a collaborative with KBS and MCR for IPY with funds from the Smithsonian Institute. Participants are provided funds to pay for twp graduate credits through continuing education. Teachers may also enroll in a graduate degree program at CSU, including on-line courses, web-based activities and field experiences.

K-12 Professional Development (RET, Graduate Programs at CSU): The SGS-LTER provides research opportunities, graduate credit, fellowships, and funds for school resources for K-12 teachers. For example, we provide a $2,500 summer research stipend for teachers that have completed or are enrolled in the PD Workshops. Funding to support this effort will continue to come from the SLTER supplements, direct costs on other grants, and NSF Research Experience for Teachers supplements. Apart from opportunities at the SGS-LTER site we will continue to promote cross-site opportunities for our teachers as we did in 2006 and 2007 with the ARC LTER. Expectations include participation on a project, data collection, analysis, report writing, presentation and transference of these experiences to the K-12 classroom. Teachers will work with senior personnel and graduate students to develop standards-based education modules for local and national dissemination.

Graduate-K-12 Partnership: To promote greater interaction between higher education and K-12, and to provide continuity in the proposed K-12 PD activities, we encourage graduate student involvement in K-12 classrooms with participating teachers. We are piloting a modified NSF GK-12 model wherein LTER graduate students are offered an augmentation to their research stipend ($2000 per semester to two students) on a rotational basis to work in the K-12 classroom for one afternoon per week during the AY (~120 hrs). Graduate students will assist teachers with instruction, in implementation of the modules that they jointly developed, and share their joint field experiences. We currently support eight graduate students with augmentation awards funded by the Colorado Department of Education through 2010. Requests for funds on regular research grants are pending.

Research Experience for Minority High School Students (RAMHSS): We provide summer research opportunities at CSU for high school students under-represented in STEM disciplines. The SGS-LTER leadership has a long history of working with under-represented high school students through their partnerships with regional TRIO programs (Upward Bound, Upward Bound- Math and Science) and the NSF RAMHSS program. We will seek funding to support the students through NSF RAMHSS supplemental funding and work with programs at CSU that provide career counseling and college preparatory courses. Students will be selected from schools close to CSU with high numbers of minority students (primarily Hispanic in Colorado) that participate in either on-campus resident programs (e.g., the CSU Upward Bound Program) or non-residential programs. Students will participate on a project, work with data, write a report and give a presentation. We provide career advising and assistance in completing college entrance and scholarship applications in partnership with the CSU student support services.

Outreach Plan

SGS-LTER has a significant presence at CSU and the surrounding community, especially through the biennial Shortgrass Steppe Symposium (last hosted Jan. 2007, previously in Jan. 2003 and Jan. 2005). At this venue we present our research to our colleagues, but also involve others who use and manage the SGS. Our most recent SGS Symposium was themed as "A Town Hall Meeting: Where is the Prairie Growing?" Presentations, discussions, and posters focused on changing land use on the grasslands and the impacts of shifting urban/rural boundaries, with presentations by SGS-LTER scientists, officers from the CO Division of Wildlife, and the Nature Conservancy. Approximately 180 persons attended, including staffers for several of our federal and state elected officials, workers from county, state and federal agencies, members of local and state conservation groups, and ranchers from the area surrounding the SGS-LTER site. We anticipate continuing this symposium, and for the future (2009) have tentative plans to sponsor a similar outreach symposium to a broader audience across the Great Plains, in coordination with the other grassland sites (CDR, JRN, KNZ, SEV).

Besides the public outreach we gain from our K-12 education, we have established a presence with the agricultural and ranching communities in Colorado, by staffing booths each year at large events like Ag Day at a Colorado State football game each fall, and the Western Stock Show in Denver each January.

In our work we have also developed partnerships with the USDA-NRCS, USFWS, the Nature Conservancy, Rocky Mountain Bird Observatory, CO Division of Wildlife, the Crow Valley Grazing Association, and especially with the Pawnee National Grassland (PNG), with whom we have a Memorandum of Understanding extending the SGS-LTER site to include all of the PNG (see Fig. 2.4 in section 2). Examples of management consulting to the PNG included *i)* analyses of prairie dog town sizes and plague outbreaks (SGS-LTER predicted plague, and PNG delayed poisoning for control: plague naturally removed the prairie dogs in 2004-2007); *ii)* participation in a multi-user group to develop a recreation shooting management plan in 2006; *iii)* consultation on grazing management in 2007.

Table 5.1: List of SGS-LTER Partner School and Teachers	
Rocky Mountain High School	Carol Seemueller, Tom Creegan, Dave Swartz Marion Annis
Irish Elementary	Paul Ashby, Marion Wells
Riffenburgh Elementary	Bob Faris, Merin Lewis
Cache La Poudre Junior High	Barb Groves, Mary Richmond
Fossil Ridge High School	Dana Jensen
Union Colony Prep School	Ron Lamb, Cathy Hoyt
Heath Middle School	Alex Melendez
John Evans Middle School	Ana Tuska, Bob Frederick
Meeker Elementary	Caroline Street, Peggy Hoerner
McAuliffe Elementary	Becky Ramirez, Chuck Call, Theresa Rupp
Poudre Learning Center	Ray Tschillard
Brentwood Middle School	Steve Swenson, Jennifer Parrish, Mark Bruemmer Mike Chandler
Chappelow K-8 Arts & Literacy Magnet	Laura Grissom
Werner Elementary	Mitzi Johnson, Mary Laszlo

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FACILITIES AT COLORADO STATE UNIVERSITY

Shortgrass Steppe Long Term Ecological Research Field Station

The SGS-LTER Field Station is located on the Central plains Experimental Range (CPER) in northeastern Colorado, approximately 61 km northeast of Fort Collins. Experiments have been conducted on the CPER since 1938, and from the SGS Field Station since the 1960's. The SGS Field Station provides logistical support for research on the 6280 CPER and the 78,100 ha Pawnee National Grassland that constitute the research area for the SGS-LTER project.

The CSU SGS Field Station consists of the headquarters area located on a 1.6 ha plot, a residence for the site manager, and a corral and pasture area of 53 ha. Three buildings are located in the headquarters area: a dormitory, a storage/worskshed building, and an office/laboratory building.

The main SGS LTER headquarters building (214 m2) has offices, laboratories, a dining/meeting room, and a kitchen. This multi-purpose building serves as the focal point for all activities at the site including conferences, meetings and classes. The common space is equipped with general access computers and a high speed internet connection. The laboratory has workbenches, a digital balance, a pH meter, a conductivity meter, and two grieve drying ovens which enable an investigator to process field samples to a finished or nearly-finished state. This laboratory space is used by researchers for weighing and sorting soil and vegetation samples, national atmospheric deposition program sample processing, and preparing mammal traps. Adjacent to the headquarters is a storage/sample processing building (134 m2) with facilities for washing, drying, and storing samples. This building also serves as the workshop/garage for field station heavy equipment. The dormitory has six rooms, five capable of double occupancy and one with four beds.

The site manager's house is located directly across from the headquarters. This 102 m2 building is fully furnished and serves as the year round residence for the site manager and his family. The corral facilities adjacent to the house are constructed of heavy timber and are capable of holding up to 40 head of livestock. Four pens (10.4 m x 14.6 m), a working chute and scales (1400 kg capacity), a head catch, and an adjustable loading ramp are available in the corral area. These facilities adjoin a 22 ha lightly grazed pasture, an 11 ha heavily grazed pasture, and a 22 ha 'holding' pasture.

In 2005, plans for expanding and modernizing the SGS Field Station began with initial funding from NSF, under cooperative agreements with the USDA ARS and CSU. Architectural plans for a new laboratory, classroom, storage and housing facilities are complete. Ground was broken in the fall of 2007 for the classroom building. Construction has proceeded well and the classroom is expected to be opening in the spring of 2008. The plans call for addition of housing units within the year. Using existing funds, site work and infrastructure are being completed during this first phase of development, and funding for the new laboratory building is being sought.

On-campus offices for the SGS-LTER

During SGS-LTER V we were able to secure permanent on-campus office space for the project. Assigned space is three offices of approximately 120 sq ft for the Project Manager, IM Manager, and Administrative Assistant. SGS-LTER has use of nearby conference rooms for brown-bag lunches, staff meetings, and other events. We have additional office, laboratory and computer space for staff, graduate and undergraduate students.

Department of Biology

Several PI's and senior participants (Antolin, Von Fsicher, Knapp) are housed in the Biology Department (offices average 120 sq. ft.). This description of the Antolin lab is typical: 1,000 sq. ft. and centrally air conditioned. The wet laboratory is equipped with sinks, distilled water, fume hoods, freezers, refrigerators, -80C deg ultracold freezer, and standard glassware. Observational equipment includes 2 Wild stereo microscopes w/ camera tubes for photography, and 2 Sartorius balances, 1 lab and 1 analytical. Equipment for genetic research includes heating blocks and microcentrifuges for DNA extractions, MJ Research themocyclers, power packs and gel boxes for agarose and acrylamide electrophoresis of DNA samples, an imaging system for recording results and standard glassware.

Department of Soil and Crop Sciences

Co-PI Kelly operates a complete analytical laboratory for soil, plant and water samples. Senior participant Stromberger operates a complete laboratory for soil microbial investigation. CSU's Soil Testing Laboratory and laboratories in the plant science building collectively have the necessary fume hoods, distilled water, vacuum lines, and supplies of laboratory glassware and reagents. Basic and advanced equipment is available. This includes an ICP, ion chromatograph, atomic absorption and emission spectrometers, visible and UV range spectrometers, soil moisture pressure equipment, centrifuge, pH and conductivity meters, constant temperature bath for particle size measurements, vacuum pumps, combustion furnaces, ovens, automatic titration, soils grinding and sample preparation room, petrographic microscopes, X-ray diffractometer, analytical balances, auto-analyzer and microcomputers with direct access to the mainframe.

Table 1.1: SGS-LTER Bibliography 2002-2008

Below, we list the publications supported by funding from NSF for the Shortgrass Steppe Long Term Ecological Research Project. . Publications in italics resulted from long-term data sets (3 years or more), an asterix (*) marks publications that represent important synthesis (cross-site synthesis, including modeling, literature review, or regional analysis), publications marked † represent part of graduate students' dissertations or these, and †† show undergraduate theses.

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<u>Journal Articles</u>

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Lauenroth, W.K. and D. Betz. 2002. Exotic plants and propagules on roadsides and adjacent shortgrass steppe. Abstracts of the 87th ESA Annual Meeting, Tucson, AZ.188.

†Lehmer, E.M.. 2003. A rare incident of hibernation in free-ranging black-tailed prairie dogs. Colorado Prairie Dog Technical Conference, February 25-27, Fort Collins, CO.

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†Lehmer, E. M. 2003. The relationship between torpor, environment, and body condition in free-ranging black-tailed prairie dogs. 6th Shortgrass Steppe Symposium, January 10, Fort Collins, CO.

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†Lowe, P.N., W.K. Lauenroth, and I.C. Burke. 2003. Effect of humus precursors and sucrose on exotic species in a disturbed shortgrass steppe site. 6th Shortgrass Steppe Symposium, January 10, Fort Collins, CO.

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†Melzer, S.E., E.F. Kelly, C.M. Yonker, A.K. Knapp, O. Chadwick, M.D. Smith, R.W.S. Fynn and K.P. Kirkman. 2007. Quantifying the Primary Controls on Silica Storage and Mobilization in Grass Dominated Ecosystems. Shortgrass Steppe Symposium. January 11, CSU, Fort Collins, CO.

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Moore, J.C. 2002. Effects of NPP on food web structure and dynamics. Meeting of the ESF InterACT working group, Interaction Strength in Food Web, University of the Aegean, October 2002, Lesvos, Greece.

Moore, J.C.. 2002. When top-down effects become bottom-up effects. Programme ESF Exploratory Workshop: Trophic interactions in a changing world, April 2002, Texel, Nederlands.

Moore, J.C.. 2003. The living soil. Keynote address. Graduate workshop on soil biodiversity and ecosystem function. June 2003, Wageningen, Netherlands.

Moore, J.C.. 2003. Do belowground interactions affect aboveground herbivory? 6th Shortgrass Steppe Symposium, January 10, Fort Collins, CO.

Moore, J.C.. 2003. Changes in nutrient flow influence dynamic stability: Or do nutrients matter? McGill University, Montreal, Canada. February 2003.

Moore, J.C., J.K. Detling, L.M. Hartley, H. Horton, and M. Quirk. 2003. The Colorado Front Range GK-12 Project: linking academic research and K-12 education. 6th Shortgrass Steppe Symposium, January 10, Fort Collins, CO.

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Morgan, J.A., E. Kandeler, D.G. Milchunas, D.R. LeCain, A.R. Mosier, J.Y. King, W.J. Parton, S. Rudolph, and D. Tscherko. 2007. Elevated CO2 Alters Plant & Microbial Communities in the Shortgrass Steppe. Shortgrass Steppe Symposium. January 11, CSU, Fort Collins, CO.

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Morgan, J.A., D.G. Milchunas, E. Pendall, W.J. Parton, and J.D. Derner. 2007. Enhanced forage production resulting from rising atmospheric carbon dioxide may not be good news for rangelands. Fourth USDA Greenhouse GAS conference. Baltimore, MD.

Morgan, J., S. Yamanoto, R. Oren, M. Ebinger, J. Smith, A. Miyata, N. Saigus, M. Okano, and Y. Hayashi. 2002. Working group 6 report: Flux-net of terrestrial carbon. Proceedings of the 9th US-Japan workshop on global change. Tokyo, Japan. 23-24.

Morgan, J.A.. 2005. Influence of CO2 enrichment on plant community and soils systems in semi-arid rangelands. Society for Range Management Annual Meeting, Fort Worth, TX.

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Morgan, J.A., F. Milglietta, B.A. Kimball, W.J. Parton, D.R. LeCain, A. Zaldei, J.D. Reeder, E. Pendall, D.G. Williams, and D.M. Blumenthal. 2006. The High Plains Global Change Experiment: Semi-arid grassland responses to combined elevated CO2 and warming. Abstracts of the 91st ESA Annual Meeting, Aug 6-11, Memphis, TN.

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Morgan, J.A., D.E. Pataki, J.M. Gruenzweig, C. Korner, P.A. Niklaus, H.W. Polley, R.S. Nowak, and P. Newton. 2003. Grassland productivity responses to rising atmospheric carbon dioxide are driven primarily by water relations. Abstracts of the 88th ESA Annual Meeting, August 3-8, Savannah, GA. 243.

Morgan, J.A., E. Pendall, A.R. Mosier, D.G. Milchunas, J.Y. King, W.J. Parton, and C. Kroner. 2005. The role of water relations in driving grassland ecosystem responses to rising atmospheric CO2. Seventh International CO2 Conference, September 26-30, Boulder, CO, extended abstract.

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Mosier, A.R., J.A. Morgan, J.Y. King, D. LeCain, and D.L. Milchunas. 2002. Soil-atmosphere exchange of CH4, CO2, NOx, and N2O in the Colorado shortgrass steppe under elevated CO2. 7th annual scientific conference of the international global atmospheric chemistry project, September 18-25, Heraklion, Crete, Greece.

Mosier, A.R., J.A. Morgan, J.Y. King, D. LeCain, and D.L. Milchunas. 2002. Soil-atmosphere exchange of CH4, CO2, NOx, and N2O in the Colorado shortgrass steppe under elevated CO2 after five years. American Society of Agronomy Annual Meeting, November.

†Munson, S.M. and W.K. Lauenroth. 2007. Plant Community and Ecosystem Change on Conservation Reserve Program Lands in Northeastern Colorado. Shortgrass Steppe Symposium. January 11, CSU, Fort Collins, CO.

†Munson, S.M. and W.K. Lauenroth. 2006. Plant community and exosystem change on Conservation Reserve Program lands in northeaster Colorado. Abstracts of the 91st ESA Annual Meeting, Aug 6-11, Memphis, TN.

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†Munson, S.M., and W.K. Lauenroth. 2007. Plant Community and Ecosystem Properties in a Semiarid Grassland Chronosequence. 13th Annual Front Range Student Ecology Symposium, Fort Collins, CO.

†Munson, S.M. and W.K. Lauenroth. 2005. Long-term response of shortgrass steppe vegetation to removal of Bouteloua gracilis. 7th Shortgrass Steppe Symposium, January 14, Fort Collins, CO.

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Newbold, T.A.S., P. Stapp, J.D. Derner & W.L. Lauenroth. 2007. Using livestock grazing to improve habitat for Mountain Plovers. Ecological Society of America, San Jose, CA.

Newbold, T.A.S., P. Stapp, K.E. Levensailor, J.D. Derner and W.K. Lauenroth. 2007. Using livestock grazing to improve habitat for Mountain Plovers: A summary of responses after 3 years of treatments. Shortgrass Steppe Symposium. January 11, CSU, Fort Collins, CO.

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Niyogi, D., C. Crabbe, V.K. Saxena, S. Raman, K. Wilson, K. Alapaty, R.A. Pielke, Sr., J. Eastman, AND Y. Xue. 2002. Does regional aerosol loading affect terrestrial carbon exchange? AGU Spring Meeting, Washington Convention Center, 28-31 May, Washington DC.

†O’Mara, M.S., W.K. Lauenroth, R.A. Hufbauer. 2003. Ecology of Linaria Dalamatica on the Central Plains Experimental Range. 6th Shortgrass Steppe Symposium, January 10, Fort Collins, CO.

Parton, W.J., S. DelGrosso, D.S. Ojima, A.R. Mosier, and J.A. Morgan. 2003. Simulated nitrogen constraints on elevated CO2 responses for grassland and forests. Abstracts of the 88th ESA Annual Meeting, August 3-8, Savannah, GA.262.

Pendall, E., J.D. Reeder, A.R. Mosier, and J.A. Morgan. 2006. Changes in soil organic matter fractions and inorganic C after five years of doubled CO2 in a semi-arid grassland. Soil Science Society of America Annual Meeting, Indianapolis, Indiana (invited talk).

Peters, D., R.A. Pielke Sr., B. Bestelmeyer, and C. Allen. 2003. Spatial nonlinearities and cascading effects across landscapes in the Earth system. Land Open Science Meeting, "Global Change and the Terrestrial Human Environment System", December 2 - 5, Morelia, Mexico.

Peterson, T., N. Hanan, J. Morgan, J. Reeder, I. Burke, and K. Paustian. 2003. Carbon, water and land-use in Conservation Reserve Program Lands of the Shortgrass Steppe. 6th Shortgrass Steppe Symposium, January 10, Fort Collins, CO.

Pielke Sr., R.A. 2006. Land cover changes - A major perturbation to the earth's climate system. Global Change Open Science Conference, July 10-13.

Pielke Sr., R.A., and T.N. Chase. 2003. A proposed new metric for quantifying the climatic effects of human-caused alterations to the global water cycle. Observing and Understanding the Variability of Water in Weather and Climate. 6th Shortgrass Steppe Symposium, January 10, Fort Collins, CO.

Pielke, R.A., Sr. 2002. Land use change and impact on weather and climate. Dean Advisory Panel Meeting, April 12, CIRA, CSU, Fort Collins, CO.

Pielke, R.A., Sr. 2002. Land surface processes and analyses in weather and climate. Keynote presentation, August 12, GIS in Climate, Weather and Impacts Workshop, NCAR, Boulder, CO.

Pielke, R.A., Sr. 2002. Understanding Colorado's climate changes. Who's running the Ecosystem? The 13th Annual South Platte Forum, October 23-25, Longmont, CO.

Pielke, R.A., Sr. 2002. The coupling of water with other components of the earth's climate system: The role of vegetation. Featured presentation. AGU Spring Meeting, 28-31 May, Washington DC.

Pielke, R.A., Sr.2002. Atmosphere-land surface interactions in semi-arid regions. The American Geophysical Union Chapman Conference on Eco-Hydrology of Semiarid Landscapes: Interactions and Processes, 9-13 September, Taos, NM.

Pielke, R.A., Sr. 2002. Ecosystem processes as a component of global climate variability and change. Natural Resource Ecology Lab Fall Seminar series "Future Directions of Global Ecosystem Science", CSU, October 4, Fort Collins, CO.

Pielke, R.A., Sr. 2002. Planning for drought in Colorado. The City Club of Denver, Brown Palace Hotel, December 10, Denver, CO.

Pielke, R.A., Sr. 2002. Update on water resources and forecasts. President's Community Relations Committee, Ammons Hall, CSU Oval, December 6, Fort Collins, CO.

Pielke, R.A., Sr. 2002. A new currency to assess climate change based on heat. College of Natural Resources Brown Bag Seminar, April 4, CSU, Fort Collins, CO.

Pielke, R.A., Sr. 2003. The Colorado drought 2001-2003: A growing concern. CSU College of Engineering Alumni Reception, March 6, Denver, CO.

Pielke, R.A., Sr. 2003. Preparing for a changing climate: The potential consequences of climate variability and change. 15th Annual Ag Conference, April 17, Colorado Springs, CO.

Pielke, R.A., Sr. 2003. Drought in Colorado: Where are we in 2003? AGU Hydrology Days 2003, March 31-April 2, Fort Collins, CO.

Pielke, R.A., Sr. 2003. The Colorado drought in the SGS LTER region: 2002 - 2003. SGS-LTER Brown Bag Seminar, March 5, CSU, Fort Collins, CO.

Pielke, R.A., Sr. 2003. Drought in the future. National Western Stock Show, A Can Do Landscape Drought Conference on "Dealing with Drought: Saving Water Now, Planning for Its Future", April 15 CSU, Fort Collins, CO.

Pielke, R.A., Sr. 2003. Drought update, presented at The Northern Colorado Business Report's Northern Colorado Summit Session entitled " High and Dry: Surviving the Current Drought, Planning for the Next One". April 22, Fort Collins, CO.

Pielke, R.A., Sr. 2003. Drought history and predictions. National Grasslands Managers Meeting, May 13-15, Greeley, CO.

Pielke, R.A., Sr. 2004. Drought update. Water Availability Task Force Meeting, January 21, Boulder, CO.

Pielke, R.A., Sr., and C.L. Castro. 2003. Diagnosing the effect of ENSO and PDO summer teleconnections on the North American monsoon with RAMS. Poster presentation at the DoD/ARL Forums on Modeling the Atmospheric Boundary Layer, May 19-23, Fort Collins, CO.

Pielke, R.A., Sr., T.N. Chase, J.L. Eastman, and M. Coughenour. 2002. Human influences on the global climate system-The first order effect of landuse change and the landscape dynamics. (Invited presentation.) Joint AMS Session with the 16th Conference on hydrology and the 13th Symposium on Global Change and Climate Variations, January 13-17, Orlando, FL.

Pielke, R.A., Sr., and N. Doesken. 2002. Climate history leading up to 2002 drought. Colorado Drought Conference: Managing water supply and demand in the time of drought. Lory Student Center, CSU, December 4, Fort Collins, CO.

Pielke, R.A., Sr., and N. Doesken.. 2003. The drought. Agricultural Experiment Station Research Center Conference, January 16, Lory Student Center Senate Chambers, CSU, Fort Collins, CO.

Pielke, R.A., Sr., and N. Doesken.. 2003. Drought in Colorado - Past, present, future. Workshop on Assessing the Impacts of Prolonged Severe Drought on Aquatic Ecosystems and Water Quality of The South Platte River Basin, Colorado April 3-4, CSU, Fort Collins, CO.

Quirk, M.H. and J.C. Moore. 2006. Effects of Black Tailed Prairie Dog (Cynomys ludovicianus) Activity on Belowground Community Structure in the Shortgrass Steppe. LTER All Scientists Meeting, September, Estes Park, CO.

Quirk, M.H., and J.C. Moore. 2007. Effects of Black-Tailed Prairie Dog (Cynomys ludoviciamus) Activity on Soil Foodweb Structure in the Shortgrass Steppe. Shortgrass Steppe Symposium. January 11, CSU, Fort Collins, CO.

Quirk, M.H., J. King, D. Milchunas, A. Mosier, J. Morgan and J. Moore. 2005. Impacts of altered UV raditation on below ground food webs in the shortgrass steppe. Soil Ecology Society Annual Meeting, Argonne, IL

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Quirk, M.H., L. Fox-Parrish, R. Ramirez, M. Hiller, and J.C. Moore. 2005. Prospectus for elementary educational book: My Home, Your Home: The shortgrass steppe. National Science Foundation, Shortgrass Steppe LTER Site Review, July 13-15, CSU, Fort Collins, CO.

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Reeder, J.D., G.E. Schuman, J.A. Morgan, and D.R. LeCain. 2003. Response of organic and inorganic carbon and nitrogen stocks to historic grazing management of the Shortgrass Steppe. 6th Shortgrass Steppe Symposium, January 10, Fort Collins, CO.

Ross, B. and B. Wunder. 2006. The effects of habitat shape on home range sixe of Ord's kangaroo rat (Dipodomys ordii). LTER All Scientists Meeting, September, Estes Park, CO.

Rutledge, S.A.,W. Petersen, W.R. Cotton, R.A. Pielke, G.E. Liston, S. Saleeby, and C.L. Castro. 2002. RAMS investigations of the North American monsoon. Fifth VAMOS panel meeting, March, University of Costa Rica, San Jose, Costa Rica.

Salas, J.D., and R.A. Pielke, Sr. 2002. Drought analysis and properties by stochastic method. AUG Hydrology Days 2002, April 1-4 CSU, Fort Collins, CO.

Salkeld, D.J., and P. Stapp. 2007. Community ecology of plague in prairie dogs. Ecological Society of America, San Jose, CA.

Salkeld, D.J., P. Stapp, R.J. Eisen, D.W. Tripp, K.L. Gage, and M.F. Antolin. 2006. Ecology of infectious disease workshop, State College, PA.

Salkeld, D.J., P.Stapp, R.J. Eisen, D.W. Tripp, K.L. Gage, and M.F. Antolin. 2005. National Science Foundation Ecology of Infectious Disease Investigators Meeting, Washington, DC.

†Savage. L.T. and M.F. Antolin. 2004. Gene Flow in Metapopulations of Black-tailed Prairie Dogs. Society for the Study of Evolution, Fort Collins, CO.

†Savage, L. and M. Antolin. 2005. Gene flow in metapopulations of black-tailed prairie dogs. National Science Foundation, Shortgrass Steppe LTER Site Review, July 13-15, CSU, Fort Collins, CO.

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Table 1.2 SGS-LTER existing and new long-term and short-term studies and associated electronically available metadata and datasets.

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
Long-Term Studies:					
LT 1. *Bouteloua gracilis* seed production-Evaluate temporal and spatial variability of seed production of *B. gracilis*	1989	yearly	5 sites x 2 grazing x 3 blocks x 3 transects x 11 plants	Coffin and Lauenroth 1992 / Lauenroth	Metadata link Dataset title: Bogr Seed Harvest *Data set id: 1991-2000 falsp*
LT 2. Plant Phenology-Monitor major events in the life cycle of plants	1996	weekly April - October	31 species and 7 phenological stages	Dickinson and Dodd 1976 / Lauenroth	Metadata link Dataset title: Phenology Study *Dataset id: PhenologyStudy*
LT 3. Small Mammals-Monitor small mammal populations in Atriplex-grassland	1987	yearly (late summer)	3 5.0 ha reps x 256 traps spaced 15m apart	McEwen	Dataset title: Long-term capture/recapture small mammal data *Dataset ids: Ltpopdyn, herbgran, trapuse*
LT 4. Small Mammals II-Assess spatial and temporal patterns of abundance and community composition of small mammals among representative shortgrass steppe vegetation types	1994	twice yearly (mid spring, late summer)	6 webs (3 in shrub areas, 3 in upland prairie) x 124 traps x 4 nights SPTRs trapped 2 x year vegetation monitored annually	Stapp 1996 (dissertation) Lindquist et al. 1995 / Stapp	Metadata link Dataset title: SGS-LTER long-term monitoring project: small mammal populations *Dataset ids: LTMntrSmlMamPop, sptrproj, MntrVegSmlMamWeb*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 5. Lagomorphs-Assess spatial and temporal patterns of abundance and community composition of lagomorphs among representative shortgrass steppe vegetation types	1994	quarterly (January, April, July, October)	32-km route driven one night per 4 seasons to spotlight rabbits	Stapp 1996 (dissertation) Lindquist et al. 1995 / Stapp	Metadata link Dataset title: SGS-LTER long-term monitoring project: Spotlight Rabbit Count *Dataset ids: LTMntrSpotlightRabbitCnt,*
LT 6. Canids-Assess spatial and temporal patterns of abundance and community composition of canids among representative shortgrass steppe vegetation types	1994	quarterly (January, April, July, October)	32-km route driven once to remove scats; driven 1-2 wks. Later to count/collect scats	Stapp 1996 (dissertation) / Stapp	Metadata link Dataset title: SGS-LTER long-term monitoring project: Carnivore Scat Count *Dataset id: LTMntrCarnivoreScatCnt*
LT 7. Christmas Bird Count-Monitor winter bird populations	1972	annually	15 mile diameter circle	Braun 1994 / Ryder	Metadata and data link
LT 8. Breeding Birds-Monitor breeding birds in accordance with continent-wide scheme	1968	five times per year	50 stops, one every ½ mile on established route	Porter and Ryder 1974 / Ryder	Dataset title: Pawnee avian road count field data *Dataset id (and metadata link): avrd9402*
LT 10. Arthropods-Monitor arthropod densities and community diversity	1998	five times per year (May – September)	One 30x40 m grid (20 traps) x 6 sites, where LT 4 is conducted	Stapp / Stapp	Metadata link Dataset title: SGS-LTER long-term monitoring project: Arthropod abundance on trapping webs *Dataset id: LTMntrArthroAbndTrapWebs*

Table 1.2.2

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 11. ANPP-Monitoring	1983	yearly	6 sites x 3 transects x 5 quadr. (0.25 m2) (3 topographic positions, 1 ungrazed, fine & coarse texture (shrubland) soil sites) in conjunction with soil water, plant-N dynamics data sets	Lauenroth et al. 1986 / Milchunas	Metadata link Dataset title: Aboveground biomass (grams) per species *Dataset id: ltnpps*
LT 12. Plant-N Dynamics-seasonal and long-term tissue N concentrations	1984	6 times per year	4 sites x 3 sample reps x 3 species	Milchunas / Milchunas	Metadata link Dataset title: Long-term Nitrogen study *Dataset id: ltn*
LT 13. Vegetation N-yield-Nitrogen concentration and yield from ANPP plots for Bogr, Spco, and others	1987	yearly	6 sites x 15 clip quadrats x 3 vegetation ypes	Milchunas / Milchunas	Metadata link Dataset title: Long-term Nitrogen study – long-term NPP *Dataset id: ltnppn*
LT 14. Increased Temperature, Water, and N-Effects on species composition, ANPP, & above-/belowground decomposition	1995	yearly	2 blocks x 4 trts. (control, water, N, W+N)+60 warming chambers in control,W	Lauenroth and Burke / Lauenroth	Metadata link Dataset title: Cross-site study *Dataset id: x-site*

Table 1.2.3

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 15. Patterns and Controls of N_2O and CH_4 fluxes- Determine impact of land use and management on trace gas fluxes through long-term measurement of gas fluxes and controlling parameters	1990	weekly	20 sites x 6 locations (measured soil-atmosphere exchange of N_2O, CH_4, CO_2, and NO)	Mosier et al. 1991 / Mosier	Metadata link Dataset title: CPER Trace Gas Data *Dataset id: gasflux*
LT 16. BNPP (root biomass) - Root biomass dynamics in conjunction with long-term ^{14}C turn-over experiment	1985	monthly through growing season	8 locations x 5 plots	Milchunas and Lauenroth 2001; Milchunas and Lauenroth 1992 / Milchunas	Metadata link Dataset title: Belowground root harvest *Dataset id: rootharv*
LT 17. ^{14}C Dynamics/Turnover - Short and long-term carbon dynamics in aboveground, crown, root, and soil on pulse-labeled plots	1985	biannually	8 locations x 5 plots x 2 depths	Milchunas and Lauenroth 1992 / Milchunas	Metadata link Dataset title: 14C Study – Soil and Veg C14 long and short term *Dataset ids: ltsoil, stsoil, Lt10c14*
LT 18. ^{15}N Studies - Determine the long-term dynamics of added N at the landscape scale	1981	1/10yr	2 locations (midslope & swale) x 4 cylinders (10cm diam. x 40cm height) per sampling period	Delgado et al. 1995 / Mosier	Metadata and data link
LT 19. ^{15}N retention/grazing-topography - Evaluate N retention in plant (leaf, crown, root) & soil (fast, slow, recalcitrant pools)	1988	1/5 yr, now decadal	2 grazing treatments X 2 topopositions X 3 plots	Hook	Metadata link *Dataset in progress*

Table 1.2.4

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 20. Elevated CO_2 - Evaluate shortgrass steppe ecosystem dynamics and trace gas exchange under elevated CO_2	1996	weekly	6 large open-top chambers at 1 site	Morgan et al. 2001, Nelson et al. 2004/ Morgan	Metadata link Dataset title: Open Top CO2 Chambers *Dataset ids: otc_annbiomass, otc_cover , otc_sppharvest*
LT 21. Individual Plants + Grazing – Topography Interactions on SOM – Evaluate accumulation of SOM under plants	1995	1/5 yr	3 locations each with 3 landscape positions (summit, midslope, swale)	Burke et al. 1999	Dataset title: Effects of grazing and exclosure on soil organic matter *Dataset id (and metadata link): gzsom*
LT 22. Automated Micromet - Monitor microclimatic variables.	1970	Hourly, 15-minute	Precip., wind dir., wind spd., air temp., surface temp., dew pt. Temp., vapor pr., total radiation, soil water, soil heat flux, soil temp.	Lapitan and Parton 1996 /Lauenroth	Metadata link Dataset title: Cr21x Meteorological Data *Dataset ids: cr21xm2, cr21xm, cr21xh,*
LT 23. Manual Micromet - Monitor microclimatic variables	1970	daily	Air temp, relative himidity, precip., open pan evap., soil temp, snow cover	Lapitan and Parton 1996 / Lauenroth	Metadata link Dataset title: Standard daily weather field values and historical weather data (above and belowground) *Data available in ClimDB*
LT 24. Lysimeter - Monitor water balance of intact steppe soils and vegetation	1986	hourly	3m diameter native steppe inputs and losses of water	Parton et al. 1981 / Lauenroth	Metatdata link Dataset title: Soil water lysimeter field data *Dataset ids: lyscd, nplys*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 25. Precipitation - Recording rain gauges	1939	daily	3 locations year round, 11 locations for growing season	Lauenroth	Metadata link Dataset title: Network of precipitation gauges *Dataset ids: pptn4x6, pptn3x11*
LT 26. Soil Water Dynamics - Monitor soil water along 3 catenas and Ecosystem Stress Area site with neutron probe	1983	biweekly May - Sept., then monthly	5 sites x 5 to 12 tubes x 5 depths	Singh et. al 1998 / Lauenroth	Metadata link Dataset title: Soil water: Neutron probe *Dataset ids: npsand, npshl, npowl, npesa, nptopo*
LT 27. Small-Scale Disturbance - Evaluate the long-term recovery of shortgrass plant communities after small scale disturbances	1984	yearly 1984-1994: 1/2yr 1996	2 sites x 4 dates x 3 sizes x 8 blocks.	Coffin and Lauenroth 1989	Metadata link Dataset title: Effects of small-scale disturbances on plant community structure at the CPER. *Dataset is: erodata*
LT 30. White-Grub Recovery X Grazing - Evaluate the long-term recovery of shortgrass plan communities after mortality by white grubs (june beetle larvae) and grazing)	1977	'77, '78, '80, '82, '90, '95, then 1/5yr	4 sites x 2 grazing x 2 patches x 2 microsites	Coffin et al. 1998	Metadata link Dataset title: Grubkill data – cover, biomass, density and plant recovery *Dataset ids: gkyrcov, gkyrbio, gkyrden, grubr*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 31. Grazing-Topography - Assess response of vegetation communities (density and basal cover) to long-term heavy and ungrazed treatments (est. 1939) across landscape topography	1984	variable - 3 times (yrs) thus far	3 sites x 2 trts. x 2 topo positions x 50 quadrants (density) or 50 10-point frames (cover)	Milchunas et. al 1989 / Milchunas	Metadata link Dataset title: Grazing Strip Study *Dataset ids: sdgznpps, gzsoilcn*
LT 32. Grazing Old/New Exclosures Vegetation Density and Basal Cover - Plant community dynamics of old and newly-grazed and ungrazed treatments	1992	biannually	6 sites x 4 trts. x 20 quadrats (density) or 20 10-point frames (cover)	Milchunas / Milchunas	Metadata link Dataset title: Exclosure study density and cover, and production *Dataset id: ExclosureSty*
LT 33. Grazing Old/New Exclosures 1992 Soil Nutrients	1992	1/5yr	6 sites x 4 trts. x 10 cores	Burke / Burke	Metadata link Dataset title: Effects of Grazing and Exclosure on Soil Organic Matter *Dataset id: gzsom*
LT 34. Grazing Old/New Exclosures Root Biomass - Biomass to a depth of 100 cm	1993	1/5yr	6 sites	Lauenroth / Milchunas	Metdata link Dataset title: Minirhizotron videography *Dataset in progress*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 35. Grazing Old/New Exclosures Belowground Food Web -	1992	1/5yr	6 sites	Moore / Moore	Metadata link Dataset title: Fungal counts, soil bacteria, protozoan, mycorrhiza, nematodes, and arthropods *Dataset in progress*
LT 36. Grazing Old/New Exclosures Minirhizotron - Root growth phenology and turnover	1997	1/d, 1/wk, 1/mo depending on time of yr	6 sites	Lauenroth / Milchunas	Metdata link Dataset title: Minirhizotron videography *Dataset in progress*
LT 37. Grazing Old/New Exclosures ANPP - Productivity and consumption 9caged, uncaged) of old and newly-grazed and ungrazed treatments	1992	biannually	6 sites x 4 trts. x 5 quadrats	Milchunas / Milchunas	Metadata link Dataset title: Grazing/soil texture aboveground biomass, basal cover and utilization *Dataset ids: zx92npps, zx92ds, zx92bcs*
LT 38. Grazing Old/New Exclosures N-yield - N concentrations and yields from ANPP plots of old and newly-grazed and ungrazed treatments	1992	biannually	6 sites x 4 trts. x 5 quadrats	Milchunas / Milchunas	Metadata link Dataset title: GZTX exclosure study Nitrogen content of NPP samples *Dataset id: gztxnppn*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 39. Grazing Old/New Exclosures Diet Selection - Bite counts by species for old and newly-grazed treatments	1992	biannually	6 sites x 4 trts. x 5 50m transects	Milchunas / Milchunas	Metadata link Dataset title: GZTX exclosure study utilization *Dataset id: exclsrStyBitCntUtil*
LT 40. Grazing Old/New Exclosures Trace Gas Flux - Estimate of N_2O, NO, and CH_4 fluxes for old and newly-grazed treatments	1994	weekly	3 sites 9 grazed/ungrazed) x 6 locations, N_2O, CH_4, CO_2, NO	Mosier and Morgan / Mosier	Metadata link Dataset title: CPER Trace Gas Data *Dataset id: gasflux*
LT 41. Grazing Old/New Small-Scale Disturbances by Mammals - Recovery of vegetation on mammal mounds	1992	1/5yr	6 sites x 4 trts., evaluation of whole plot	Coffin and Lauenroth	Metadata link Dataset title: Effects of small-scale disturbances on plant community structure at the CPER. *Data set in progress*
LT 42. Nutrient Enrichment Treatments (Ecosystem Stress Area) Plant Density and Basal Cover - Successional trajectories following water, N, W+N treatments applied from 1971-75	1982	annually thru 1991; then biannually	2 reps x 4 trts. x 5 trans. x 10 quadrats (density) or 10 10-point frames (cover)	Milchunas and Lauenroth 1995 / Milchunas	Metadata link Dataset title: ESA Study – density, canopy cover and basal cover *Dataset ids: esayrdb8291, esayrdbs, esayrccs, esayrbcs*

Table 1.2.9

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 43. Abandoned fields (A) Vegetation - Evaluate effects of soil texture and climate on recovery of shortgrass plant communities on abandoned agricultural fields in the Pawnee National Grasslands	1990	1/10yr	13 sites x 2 trts. (native & abandoned) x 6 90m trans. X 33 plots ($1m^2$)	Coffin et al. 1995 / Peters	Metadata link Dataset title: Earthwatch vegetation data – cover, density *Dataset ids: ewtchcov, ewtchden*
LT 44. Abandoned fields (A) Soils - Evaluate effects of soil texture and climate on recovery of soils on abandoned agricultural fields in the Pawnee National Grasslands	1990	1/10yr	13 sites x 2 trts. x 2 90m trans. x 3 locations	Burke et al. 1995, Ihori et al. 1995a, Ihori et al. 1995b / Ihori	Metadata link Dataset title: Earthwatch – organic matter in abandoned fields, In situ Nmin on Native, Abandoned and Cultivated Fields, and total C and N *Dataset ids: deepsoil, abfnmin, cntext*
LT 45. Abandoned Fields (B) Vegetation - Evaluate effects of soil texture and climate on recovery of shortgrass plant communities on abandoned agricultural fields in the CPER	1994	1/10yr	15 sites x 2 trts. (native & abandoned) x 6 90m trans. x 33 plots ($1m^2$)	Coffin et al. / Burke	Metadata link Dataset title: Earthwatch vegetation data – cover, density *Dataset ids: ewtchcov, ewtchden*
LT 46. Abandoned Fields (B) Soils - Evaluate effects of soil texture and climate on recovery of soils on abandoned agricultural fields in the CPER	1994	1/10yr	15 sites x 2 trts. x 2 90m trans. X 3 locations	Burke et al. 1995 / Burke	Metadata link Dataset title: Earthwatch organic matter in abandoned fields and lab incubation of soils and microbial biomass *m, d* *Dataset ids: abfcn, abfnmin, abfldsum,*

Table 1.2.10

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 47. Regional modeling of ecosystem processes in the Central Grasslands Region	1988	continuous modeling program	soils, climate, and land use information for the plains region of Colorado, Nebraska, and Kansas	Burke, Lauenroth Coffin, and Parton	Metadata link *Dataset in progress*
LT 48. Monitoring Birds of Prey	1992	yearly during breeding season	Check nests from roads using spotting scope and band young	Ryder	Metadata link *Dataset in progress*
LT 49. Monitoring plant community change through time and or space using permanent quads	1997	once a year in June	6 sites, 2 treatments at each site, 2 1x1 m^2 plots per treatment (plot without cactus sampled intensively with pantograph, plot with cactus photographed)	Lauenroth	Metadata link Dataset title: chart project *Dataset in progress*
LT 50. Paleoecology and Geomorphology of the CPER	1992	annually	Drilling rig is mounted to 1-ton pickup, and can negotiate existing roads.	Kelly and Yonker	Link to metadata *Dataset in progress*
LT 51. National Atmospheric Deposition Program long-term monitoring site	1985	daily	please see NADP web site	Van Bowersox	Link to NADP metadata and data Link to N-deposition metadata
LT 52. UV-B Radiation – Long-term trends	1994	daily	please see UVB web site	Gibson	Metadata and data link
LT 53. Arthropod inventory across a catena	1995	monthly April-September	900 m transect of 182 pitfall traps open for 4 nights	Lindquist, Stapp and Crist	Metadata link Dataset title: Live arthropod pitfall trapping across a double catena *Dataset is: LT_arth_catena*

Table 1.2.11

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 54. Effects of different-sized herbivores on grasslands: across site studies	1997	3 sites annually	3 x 50 quadrats (cover and density) 3 x 15 NPP samples	Milchunas	Metadata link *Dataset in progress*
LT 55. Bowen Ratio CO2 Exchange of Shortgrass Steppe	1998	every 20 minutes	3 adjacent sites (non-grazed, moderately and heavily grazed)	Morgan	Metadata link *Dataset in progress*
LT 56. Amphibian Monitoring	2001	through the growing season	4 sites x 144 coverboards	Lindquist, Lauenroth, Horger	*Metadata and data set in progress*
LT 57. Ecosystem response to the removal of the dominant species *Bouteloua gracilis*	1997	annually	6 sites X 4 trts.	Lauenroth, Burke, and Coffin	Metadata Link Dataset title: BOGR Removal Experiment Density Data: Point of Intercept and Density *Dataset ids: BOGRRmvlDnsty, BOGRRmvlPntIntrcpt*
LT 58. The effect of drought on ecosystem functioning	1998	annually	2 sites x 3 trts.	Burke, Lowe, and Murphy	Metadata link Dataset title: Rainout Shelter Experiment Data: density and basal cover *Dataset in progress*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 59. Forest Service and CPER Burn Studies	1998	monthly for N annually for NPP, oppo and shrub mortality	4 sites x 2 trts x 5 .5 m^2 plots	Milchunas	Metadata link Dataset title: Fire ecology studies *Dataset in progress*
LT 60. P-Dog Vegetation Studies	1998	annually	5 sites x 2 trts. x 15 .5 m^2 plots	Detling	Metadata link *Dataset in progress*
LT 61. The effects of fragmentation on the genetics of black-tailed prairie dogs	2000	annually	Prairie dog town in Southwestern south Dakota and eastern Colorado	Antolin and Savage	Metadata link *Dataset id: cylupop*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 62. P-dog habitat studies	2001	annually	Prairie dog towns across Pawnee National Grasslands	Antolin, Van Horne, and Woodard	Metadata link (map) *Dataset in progress*
LT 63. Ecosystem significance of soil as a long-term sink for anthropogenic addition of nitrogen	1998	annually	8 blocks x 3 transects x 6 trts	Burke, Lauenroth, and Lowe	Metadata link *Dataset in progress*
LT 64. US Climate Reference Network Long Term Site	2002	hourly	temp/precip/Solar/Surface IR/and wind instruments transmit data hourly	Lindquist	Metadata and data link
LT 65. Estimation of composition and relative density of carnivore species on the Pawnee National Grassland	2005	seasonally	Each scent station survey will take four days to complete (6 surveys in all).	Uresk et al, 2003, Linhart and Knowlton 1975/Antolin	Metadata link *Dataset in progress*
LT 66. Grazing Strategies to manage shortgrass steppe for species-specific habitat	2005	April-September	10 sites managed for mountain plover	Lauenroth/Derner/Stapp	Metadata link *Dataset in progress*
LT 67. Survey of trace gas fluxes and associated microbial communities	2005	5 dates per year	10 sites, 6 points are each site, 10-15 soil cores 2 inches in diameter, flux of CO_2, N_2O and CH_4 measured	Mosier/Von Fischer	Metadata link *Dataset in progress*
LT 68. Temporal Effects of Drought on Semi-arid grassland ecosystems	2007	April - September	30 plots (2.5m x 2m), 20 of which will have rainout shelters and 10 of which will be controls	Yahdjian and Sala (2002/ Knapp, Kelly, and Cherwin	Metadata link *Dataset in progress*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
LT 69. Patch burn and small plot fire frequency and seasonality	2006	April - September	Full factorial plot layout (3 frequencies X 2 seasons X 4 reps). Fire frequency of 0, 1, and 3 years. Fire seasonality of spring and fall and burn 25% of pasture once every 4 years, burning to occur summer	Derner/Knapp, Kelly, Lauenroth, Burke	Metadata link *Dataset in progress*
LT 71. Temporal variability in aboveground net primary productivity, plant species distribution, and climate in grasslands	2005	May - October	15 rainout shelters in 2005 with an additional 10 rainout shelters in 2006 (n=25 total shelters or plots).	Heisler/Kelly, Knapp	Metadata link *Dataset in progress*
Current and Terminated (t) Short-Term Studies:					
ST 1t. Transect Study - Organic Carbon in Soils across Toposequences	1983	short-term	8 km transect oriented normal to the major drainages total of 140 pedons representing 23 toposequences and 7 plains segments were characterized	Yonker et al. 1988 / Yonker	Metadata link Dataset title: Transect Study - Elevation and Distance EDM, Hillslope Study - Soil Characterization by Horizon *Dataset ids: transect, hillslop*
ST 2t. Transect Study - Elevation and Distance EDM	1983	short-term	Reference points were established baseed on locations of USGS benchmarks on or near the CPER. Location coordinates are distances to those reference points.	Yonker et al. 1988 / Yonker	Metadata link Dataset title: Transect Study - Elevation and Distance EDM *Dataset id: tranedm*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 3t. Hillslope Study - Elevation and Distance EDM	1983	short-term	Reference points were established based on locations of USGS benchmarks on or near the CPER. Location coordinates are distances to those reference points. For this data set, the reference point is 11.	Paroussis 1984 / Yonker	Metadata link Dataset title: Hillslope Study - Elevation and Distance EDM *Dataset id: hilledm*
ST 4t. ESA - Plant Tissue Belowground Chemistry and Biomass	1991	short-term	2 shrubs, 4 grasses and 2 forbs located on the "ESA" plots. small soil cores (2cm diameter, 10cm depth) sample 3 individuals of each of the 8 species on both the control and nitrogen-enriched ESA plots, resulting in 48 total plants sampled.	Vinton and Burke 1995	Dataset title: ESA Plant tissue lignin, carbon, nitrogen, and biomass, soil carbon and nitrogen *Dataset ids (and metadata links): etisslig, etisscn, esoil, ebelbio*
ST 5t. Nitrogen mineralization methods study	1992	monthly (June-Oct.)	10 Locations: 10 paired uplands and lowlands	Hook and Burke 1995	*Dataset id: Nminmeth*
ST 6t. Landscape/Seasonal nitrogen mineralization methods study	1992	monthly (June-Oct.)	10 Locations: 10 paired uplands and lowlands	Hook and Burke 2000	*Dataset id: Nminseas*
ST 7t. Regional Study	1992	short-term		Vinton and Burke 1997	Dataset title: Belowground Biomass, Belowground Plant Tissue Chemistry, Soil Carbon and Nitrogen, Aboveground Plant Tissue Chemistry *Dataset ids: nmsoil, nmrocn, nmrobio, nmplcn*

Table 1.2.16

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 8t. Paleopedology Study - soil particle size and grain size	1992	short-term	For granulometric comparison with the pedons, samples of modal fluvial and eolian origin were taken. The seven fluvial sites were located along Owl and Eastman Creeks. The three eolian sites were located on the nearest undisputed dune fields.	Blecker et al. 1997 / Yonker	Dataset title: Paleopedology Study - soil particle size and grain size *Dataset id (and metadata link):* partsize
ST 9t. Paleopedology Study - pedon descriptions	1992	short-term	Forty-one pedons were selected for study. Pedons 1-12 occur on North Owl Creek terraces, pedons 13-21 occur on upland ridges, pedons 22, 23, 34-36, and 40 occur on dissected uplands, pedons 24-26, 37-39, and 41 occur on upland plains, pedons 30-33 occur S	Kelly et al. 1998 / Yonker	Dataset title: Paleopedology Study - pedon descriptions *Dataset id (and metadata link):* paleoped

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 10t. Captures of tenebrionid beetles from three shrubland sites, 1992-95	1992	two trapping sessions per year	Pitfall trapping of arthropods in spring (May/June) and summer (July/August) from summer 1992 to spring 1995. Pitfall traps (64) placed in systematic random design in shrub, cactus, grass, and bare ground microhabitats on each of three sites (3.24 ha) rep	Stapp 1997 / Stapp	Dataset title: Captures of tenebrionid beetles from three shrubland sites, 1992-95 *Dataset id (and metadata link): teneb*
ST 11t. Captures of arthropods from 3 shrubland sites, 1992-95	1992	two trapping sessions per year	Pitfall trapping of arthropods in spring (May/June) and summer (July/August) from summer 1992 to spring 1995. Pitfall traps (64) placed in systematic random design in shrub, cactus, grass, and bare ground microhabitats on each of three sites (3.24 ha) rep	Stapp / Stapp	Dataset title: Captures of arthropods from 3 shrubland sites, 1992-95 *Dataset id (and metadata link): arth*

Table 1.2.18

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 12t. Summary of small mammal species in pellets of great-horned owls	1992	opportunistic collection of owl pellets	We collected regurgitated pellets of great horned owls from known roost sites on the CPER between summer 1992 and summer 1994. We identified small mammal remains using reference collections at Colorado State University and Denver Museum of Natural History.	Zimmerman et al. 1996 / Stapp	Dataset title: Summary of small mammal species in pellets of great-horned owls *Dataset id (and metadata link): owldiet*
ST 13t. Captures of rodents from 3 shrubland sites, 1992-94	1992	two to three trapping sessions per year	Live trapped rodents for 3-5 consecutive nights on each of three sites during spring (May/June), summer (July/August), and winter (Dec/Jan) periods between 1992 and 1994. Rectangular trapping grids consisted of 100-144 large Sherman live traps	Stapp 1997 / Stapp	Dataset title: Captures of rodents from 3 shrubland sites, 1992-94 *Dataset id (and metadata link): alltrap*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 14t. Defoliation effects on western wheatgrass plants in long-term protected and long-term grazed pastures	1992	once per month for 3 months	please refer to methods in dissertation	Atsedu / Atsedu	Dataset title: Biomass and Tissue Nitrogen, morphology, biomass - Blue Grama and Western Wheatgrass-Greenhouse and Field Data *Dataset ids (and metadata links):* *bogrgrhb*, *bogrfldm*, *bogrfldb*, *pasmgrhb*, *pasmfldm*, *bogrgrhm*, *pasmgrhm*, *postbogr*, *postpasm*
ST 15t. Idaho-Utah Study	1992	once	soil samples: 5cm depth from under the plant and between vegetation samples:	Aguiar / Aguiar	Dataset title: Biogeochemistry Data, Carbon & Nitrogen Mineralization, Soil ph/electrical Conductivity Data *Dataset ids: fgx_sum, fgx_min, fgx_ph*
ST 16t. Phenology of grasses, forbs, and shrubs at CPER	1993	once per week for 20 weeks	please refer to methods in dissertation	Atsedu / Atsedu	Dataset title: Phenological data grasses, forbs and shrubs -CPER *Dataset ids (and metadata links):* *grasses*, *forbs*, *shrubs*

Table 1.2.20

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 17t. Microhabitat selection, movement patterns and interactions between *Onychomys leucogaster* and *Peromyscus maniculatus* in a short-grass steppe landscape	1993	3 trapping periods	Free ranging deer mice given a choice between Sherman traps containing odors of grasshopper mice, harvest mice, and traps with no rodent odors to evaluate the response of deer mice to grasshopper mice, a suspected predator or competitor.	Stapp and Van Horne 1996 / Stapp	Dataset title: Captures of *Peromyscus maniculatus* form odor response experiment, 1994 *Dataset id (and metadata link): odor*
ST 18t. Natural Abundance N15 Study – Plants and Soils	1993	once	We sample sites on two continents (N. and S. America), in areas that have ecosystems that are grass dominated and shrub dominated. Soils were sampled immediately beneath shrubs and beneath grasses, at 4 depths to 1 m.	Burke / Burke	Dataset title: Natural abundance *Dataset id (and metadata link): natabund*
ST 19t. Regional Study	1994	once	Five 15cm soil cores were taken at each site from bare ground spaces between plants at randomly spaced intervals along a transect. Field cores were left in situ for 30 days. Lab estimates of N and C mineralization were preformed.	Barrett, J.E., I.C. Burke, and W. K. Lauenroth/Barrett	Dataset title: Percent Cover - Fine-textured sites, Regional N min patterns *m* *Dataset ids (and metadata link): covf, nmin*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 20t. Habitat use of and interactions between rodents of shortgrass prairie	1994	once during each four seasons	Live-trapping rodents for 3 consecutive nights on a rectangular grid (3.8-4.1 ha) on a shrub grassland site in pasture 10SW during winter (Jan), spring (May), summer (July), and fall (Oct) 1994. Grid consisted of 144-156 large Sherman live traps.I collected fecal pellets.	Stapp 1997, Stapp and Van Horne 1997 / Stapp	Dataset title: Captures of rodents from shrub grassland site, 1994 Vegetation at random trap stations on removal trapping webs, 1994, Percentage of animal matter in rodent diets *Dataset ids (and metadata links): oltrap94, rantrap, diet*
ST 21t. Effects of a methamidophos application on *Pasimachus elongatus* LeConte (Coleoptera: Carabidae): an update after six years.	1994	six times from May-Aug 94	This study was conducted at the 6,280 ha Central Plains Experimental Range (CPER).	McIntyre / McIntrye	Dataset title: Population densities of *P. elongatus* beetles in areas with various methamidephos exposures *Dataset id (and metadata link): meth*
ST 22t. Microhabitat selection, movement patterns and interactions between *Onychomys leucogaster* and *Peromyscus maniculatus* in a short-grass steppe landscape	1994	3 trapping sessions of 4 consecutive days	144-156 Sherman live traps	Stapp, P 1997 / Stapp	Dataset title: Captures of rodents from species removal experiment, June-Aug 1994. Movement and microhabitat use of *Peromyscus maniculatus* in removal experiment, 1994 *Dataset ids (and metadata link): remdens, bothsumm*

Table 1.2.22

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 23t. Soil Organic Matter Data Summary	1994	once	We sampled four different som manipulations: higher litter inputs (beneath living plants); lower litter inputs (between plants); lack of litter inputs (ant induced bare area); and high erosion, high decomposition, low litter inputs (wheat fallow)	Bisbee / Burke	Dataset title: Soil Organic Matter Data Summary *Dataset ids (and metadata link): somcn, somcnin, somcnout*
ST 24t. The effects of vegetational architecture on beetle movements on the shortgrass prairie	1994	24 samples taken in 4-month period	Treatments: GG= grazed since 1939, GU= grazed during 1939-1989, and ungrazed since 1990 UU= ungrazed since 1939 UG= ungrazed during 1939-1989, and grazed since 1990	McIntyre / McIntrye	Dataset title: Movement patterns of *Eleodes hispilabris* and *Pasimachus elongatus* beetles - different trophic levels, Movement patterns of *Eleodes extricata* and *E. hispilabris* Beetles - hunger and food distribution *Dataset ids (and metadata link): trophic, hunger*
ST 25t. Effects of plant mortality of the dominant species and other important species on the dynamics of a shortgrass plant community	1994	during the growing season of 1994	Bogr's recovery will be evaluated using several abandoned agricultural fields with different soil texture characteristics (from coarse to fine) and with a west edge bordering unplowed vegetation at the PNG and CPER	Martinez / Martinez	Dataset title: Recovery of Blue Grama *Dataset id (and metadata link): recovery*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 26t. Assessing nematode biodiversity in Colorado shortgrass steppe natural and managed ecosystems	1994	once	Treatments: GG= grazed since 1939, GU= grazed during 1939-1989, and ungrazed since 1990 UU= ungrazed since 1939UG= ungrazed during 1939-1989, and grazed since 1990	Huang Freckman Coffin	Metadata link Dataset title: Nematode Counts to Taxonomic Group, Nematode Counts to Genera Group, Nematode Counts Taxonomic Reference Codes, Nematode Counts Metadata/Sample Data, Nematode Counts to Family Group, Nematode Counts to Trophic Group *Dataset ids: taxa, genera, taxaref, counts, family, nemtroph*
ST 27t. Effect of shrub density on soil water patterns	1995	one sample date for each site	50 meter transects were set up at a site with an abrupt change from grass-dominated vegetation to shrub dominated vegetation. At 5 meter intervals along the transects (stations), vegetation analyses were performed.	Lauenroth Dodd	Metadata link Dataset title: Shrub allometrics of *Atriplex canescens*, Plant cover analysis of vegetation transects, Soil water data from a soil profile *Dataset ids: remallo, pitwater, vegcover, shrubsiz*
ST 28t. Soil texture and decomposition on vegetation transects	1995	short-term	A 2 m wide x 5 m lond x 2 m deep dug soil to expose shrub roots	Lauenroth Dodd	Metadata link Dataset title: Resin Bag Study, Carbon and nitrogen data from a soil profile *Dataset ids: soils, pitresin, pitcnoct*

Table 1.2.24

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 29t. Vectors of seed dispersal for <u>*Bouteloua gracilis*</u> and <u>*Buchloe dactyloides*</u>	1995	short-term	Pats deposited last fall throughout 27NE (Met station), 15NE & SE, 23E, 25SW & SE.	Fraleigh Coffin / Fraleigh	Metadata link Dataset title: Seed dispersal of blue grama and buffalograss *Datset ids: winddisp, cowdung, cowfur*
ST 30t. Seed Variation Under Prickly Pear Cactus – This study produced 2 data sets: percent cover and species variation.	1995	short-term	Site - ungrazed strip and adjacent heavily grazed pasture A random compass direction from each random fence post location was used.	Bayless / Lauenroth	Dataset title: Percent cover of cactus *m* And Species variation under cactus *Dataset ids (and metadata links): cactarea, sppvar1, sppvar2,*
ST 31t. Ecophysiology Western Wheatgrass and Blue Grama	1995	8 sample dates	Plants were entirely defoliated except for four mature, non-senescent leaves, two which were left intact.	Fahnstock	Dataset title: Clipped and unclipped, grazed and ungrazed sites, water potential, gas exchange *Dataset ids: elsmclip, elsmgug, bogrug, xppelsm, leafloc*
ST 32t. ARS Common Gardens Clone Height		short-term		Kotanen	Dataset title: Common garden *Datset id: comgard*
ST 33t. Cross Site Study -		short-term		Vinton and Burke 1997	Dataset title: Plant Tissue *Dataset id: cplant*

Table 1.2.25

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 34t. Plant Species List for the CPER (Don Hazlett - collaborator)		short-term		Kotanen, Bergelson, and Hazlett (in review)	Data Query Link Dataset title: Plant List
ST 35t. Torpor patterns, diet and lipid composition of free-ranging prairie dogs	2001	annually	animals were captured and anesthetized ; Temperature-sensitive data loggers (18.2 g, 3-cm diameter; Stow Away TM TidbiT, Onset, Pocasset, Massachusetts) were surgically implanted into the abdominal cavity; loggers recorded Tb (abdominal) every 24 min	Van Horne Lehmer	Metadata link *Dataset in progress*
ST 36t. Black-tailed Prairie Dog Mounds: Do they contribute to plant species diversity and nitrogen cycling?	2000	summer	measured plant cover and biomass by species from mound, inter-mound, and off-town plots on three active prairie dog towns at a site in Texas, Colorado, and Montana	Farrar	Metadata link *Dataset in progress*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 37t. UV, abiotic and biotic components of production and decomposition on SGS: interactions with CO2 enrichment	2000	annually	total of 106 tents, each 4 X 4 ft, constructed of both UV block material (lexan) and UV pass material (Aclar film)	Milchunas King	Metadata link *Dataset in progress*
ST 38. Scaling properties of species along the transition from SGS to tall grass prairie	2000	annually	along each 2 km transect on the CPER, survey birds, butterflies, beetles and plants	Weins VanHorne	Metadata link data set in progress
ST 39. Var. in decomp, N mineralization and soil resp. rates x precip. Gradient in central great plains	1999	monthly	16 exclosures - measure porductivity (above- and belowground), decomposition rates, nitrogen mineralization, soil respiration, soil organic matter, litter quality, and mineralizable C and N pools	McCulley Burke Lauenroth	Metadata link *Dataset in progress*
ST 40. Burrowing owl nesting patterns in NE Colorado.	1999	annually		VanHorne Woodward	Metadata link *Dataset in progress*
ST 41. Biogeochemical controls on CO^2 and N^2O exchange at different spatial scales under elevated CO^2	1998	annually		Mosier and Morgan	Metadata link *Dataset in progress*
ST 42t. Cattle use of prairie dog towns	1999	short-term	walking and/or driving surveys to assess the location of the cattle and vegetataion sampling on and off prairie dog towns	Guenther Detling / Guenther	Metadata link *Dataset ids: pdogforage, pdogveghgt*

Table 1.2.27

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 43. The genetic structure of recolonized black-tailed prairie dogs	1997	short-term	DNA will be obtained from tissue samples taken from live-trapped prairie dogs (n = 10-25 individuals per colony)	Roach Van Horne Antloin	Metadata link *Dataset in progress*
ST 44t. Grazing refugia and biodiversity	1997	short-term	8 sites x 4 60 m transects inside and outside exclosures Danbenmire quadrats and 10 1" diameter soil cores to 15 cm taken from each site	Milchunas Salva, Rebollo	Metadata link *Dataset in progress*
ST 45t. Effects of soil heterogeneity evaporation and transpiration	1995	short-term		Wythers Lauenroth	Metadata link *Dataset in progress*

Table 1.2.28

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 46t. How will asymmetric temperature increases influence shortgrass steppe plant communities?	1995	short-term	8 paired 4 x 4m plots One plot of each pair will be warmed using a cover that opens and closes automatically. Grasshopper manipulations will be in 30-40 cased patches 10cm in diameter per 4 x 4m plot. Sampling will include non-destructive (cover, phenology, albedo, mortality, photosynthetic rates) and destructive techniques (biomass, leaf chemistry, root production, soil chemistry).	Alward Detling	Metadata link *Dataset in progress*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 47t. Alterations in species composition of grassland communities resulting from climate changes and increased temperature	1994	short-term	3 4 x 4m plots manipulate grasshopper herbivory levels using temporary cages on 0.5 X 0.5m sub-plots. 1 plot will be warmed using a cover that opens and closes automatically. Sampling will include non-destructive (basal cover, tiller and inflorescence production, cladode number, albedo, mortality) and destructive techniques (biomass, NPP, leaf chemistry, root production, soil chemistry).	Alward Detling	Metadata link *Dataset in progress*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 48t. Isotopic variation of water in shortgrass prairie: influence of cover and lifeform on the 18O signatures of soils and plants	1994	short-term	2 cm diameter soil cores (0-50cm) will be taken from all sites (swale, mid-slope, ridge) in spring when we expect some soil water input from melting snow (Ehleringer et al. 1991). Soil water will be removed in-situ using extraction techniques described by Hsieh et al. 1993.	Welker Kelly Hook	Metadata link *Dataset in progress*
ST 49t. The role of roots in soil organic matter formation and maintenance	1993	short-term		Kelly Burke	Metadata link Dataset title: Soil organic matter of bare ground between ant mounds *Dataset ids: baregrnd, mndage, mnddist, deadplnt*
ST 50t. The influence of soil texture on plant productivity in the central grasslands	1993	short-term	open current grazing exclosures for grazing, and new areas will be excluded (approximately 1-2 hectares	Lane Coffin	Metadata link Dataset title: Density and percent cover coarse and fine textured sites *Dataset ids: densc, covc, covf, densf, npp94*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 51t. Effects of landscape factors, precipitation and individual plants on nitrogen mineralization	1992	monthly (late June, collect in July, August, September, and October).	10 Locations x 20 plots: 10 paired uplands and lowlands Total of 400 soil cores (including initial sample) and 320 resin bags;	Hook Burke	Metadata link Dataset title: Individual plant organic matter and soil water dynamics, Individual plant horizontal root patterns *Dataset ids: ompattrn, soilh2O, rootpatt*
ST 52t. Plant species effects on soil properties in shortgrass steppe	1992	short-term	Collect above and belowground parts of eight different plant species (2 shrubs, 4 grasses and 2 forbs) located on the "ESA" plots. Also collect small soil cores (2cm diameter, 10cm depth) from beneath the canopy and adjacent to each of the species.	Vinton Burke	Metadata link *Dataset in progress*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 53t. Mortality of individual Bogr plants in SGS plant community as influenced by small disturbances	1991	2 growing seasons	6 sites at the CPER to represent three soil texture classes: clay loam, silt loam, and sandy loam 100 plants per site were chosen as follows. Five plants were randomly assigned to each treatment (5 plants x 2 grazing (U & G) x 5 mortality treatments x 2 forms of death = 100 total plants per site) shading or removing.	Lauenroth Coffin Fan	Metadata link *Dataset in progress*
ST 54t. The Understory Vegetation Associated with *P. flexilis* Stands of Northeastern Colorado The Demography and Age Structure of the *P. flexilis* Stands on the Shortgrass Steppe A 60 Year Analysis of the Spatial Distribution of *Pinus flexilis* on the Shortgrass Steppe Using Archival Aerial Photography	1999	once	determine the understory composition and overstory canopy cores taken from the *P. flexilis* stands aerial photography from the 1937, 1941, 1957, 1969, 1993 and 1998 the distribution of the mixed *P. flexilis* / *J. scopulorum* stands	Dreyfuss	Metadata link *Dataset in progress*

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 55t. The effect of grazing, water, nitrogen and disturbance on the establishment of two exotic species	1999	short-term	plant 30 seeds per .25 meter squared plot and apply 12 treatments with 3 replications plant 2 exotic species seperately: downy brome and dalmation toadflax and apply a matrix of treatments: grazing, irrigation, nitrogen application, and disturbance look at emergence, growth rate, maximum height, number of inflorescences, biomass (after flowering, before dispersal) and phenology	Lauenroth / Betz	Metadata link *Dataset in progress*
ST 56. Habitat use, survivorship, and mortality causes of Ord's Kangaroo rats in disturbed and fragmented habitats	2005	May 2005 – August 2006	Kangaroo rats (n = 30) trapped and radio collared	Harker et al. (1999)./Antolin	Metadata link *Dataset in progress*
ST 57. The role of photodegradation in surface litter decomposition across a UV gradient in the Great Plains, USA	2005	2006 - 2008	3x2 factorial design, nested within three sites at SGS, SEV, and CDR	Milchunas/King	Metadata link *Dataset in progress*
ST 58. Prairie dogs and ants as disturbance agents on the shortgrass steppe: Implications for habitat heterogeneity	2005	End of growing season	Measure mound and vegetation characteristics on 50x50 m grid on 6 p-dog town and 6 control plots	Detling/Alba	Metadata link *Dataset in progress*

Table 1.2.34

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 59. Parasite-mediated selection of the major histocompatibility complex (MHC) and parasite community dynamics in black-tailed prairie dogs (Cynomys ludovicianus)	2006	2006-2008	For each animal record weight, sex, number and diversity of endo- and ectoparasites, allelic diversity at the MHC DRB-1 locus, and genotypes of up to 20 microsatellite loci and the control region of the mitochondrial DNA.	Antolin	Metdata link *Dataset in progress*
ST 60. Granivore influence of plant population and community dynamics	2007	1 June 2007 to 30 September 2010	evaluate how seed production, seed rain, granivore predation, and seed- and site limitation of plant recruitment shape plant community dynamics	Detling/Alba	Metadata link *Dataset in progress*
ST 61. A survey of herpetofauna of the Shortgrass Steppe	2007	April - October	General Census	Moore/Mackessy	Metadata link *Dataset in progress*
ST 62. Mediation of spatial organization in the swift fox (Vulpes velox)	2003	September-April	20 foxes from 10 neighboring pairs will be radio-collared and tracked to quantify space use, movement patterns, and intra-specific association.	Roell 1999, Withey et al. 2001, Kitchen et al. 1999, Schauster et al. 2002/Darden	Metadata link *Dataset in progress*
ST 63. Interactions between Northern Grasshopper Mice (Onychomys leucogaster) and Fleas in Prairie Dog Colonies: Implications for the Spread of Fleas	2006	May - August	5-8 2.25 ha grids, trapped with 100 Sherman live traps for 4-5 nights,	Stapp/Kraft	Metadata link *Dataset in progress*

Table 1.2.35

LONG-TERM (LT 1-71) AND CURRENT OR TERMINATED (t) SHORT-TERM STUDIES (ST 1-64)	YEAR INITIATED	SAMPLING FREQUENCY	EXPERIMENTAL DESIGN or METHODS	REFERENCE FOR DETAILS/DATA SET AUTHOR	METADATA, DATA, and HYPERLINKS TO ON-LINE INFORMATION
ST 64. Ecosystem change on conservation reserve program lands	2005	April - September	restoration chronosequences that consist of three field ages: 2 years (n=3), 8 years (n=3), 16 years (n=3) and an additional uncultivated (n=3) field	Munson/Lauenroth	Metadata link *Dataset in progress*

Table 1.3 Electronically available spatial data sets.

Central Plains Experiment Range (CPER) GIS Datasets

Dataset Name	**Description**	**Source**
cper-bdy	Boundary of CPER	USGS quads
cper-building	Buildings within the CPER	Aerial Photos and USGS quads
cper-elev_contours	Elevation Contours of CPER	based on 10M DEM
cper-exclosures	Exclosures in CPER	GPS
cper-fences	Fence lines in CPER	USGS PLSS and other sources
cper-lakes	Lake boundaries in CPER	USGS 1:24000
cper-landforms	Landform in CPER	USGS 1:24000
cper-landmark	Landmarks in CPER (tanks, corrals, windmills)	GPS
cper-pastures	Pasture boundaries in CPER	USGS PLSS and other sources
cper-pipelines	Pipelines in CPER	Various sources
cper-pls	Public Land Survey boundaries in CPER	USGS PLSS 1:24000
cper-roads	Roads in CPER	USGS, GPS and other sources
cper-soils	Soil boundaries in CPER	Special NRCS soils survey
cper-streams	Stream lines within CPER	USGS 1:250000
cper-vegibp	IBP Vegetation within CPER	IBP Species Composition
cper_metstations	Meteorological Station s in CPER (recorded weather data can be joined and mapped)	GPS
cper_studysites	Study sites within CPER	GPS
cper_dem	Digital Elevation Model (raster)	USGS 10M DEM
cper_pdog (97 to 07)	Prairie Dog Town Boundaries (1997 to 2007)	GPS by CSU
cper_chart (97-06)	Permanent square meter plots	Pantograph
cper_PhotoIndex	Aerial Photo Indices of CPER – 1937, 1941, 1977, 1982	
cper_wildfire_june06	June 2006 Wildfire boundary	GPS by CSU

Pawnee National Grassland (PNG) GIS Datasets

Dataset Name	Description	Source
png_boundary	Boundary of PNG	USGS and USFS
png_exclosures	Exclosure boundaries in PNG	GPS
png_geology	Geology boundaries in PNG	USGS
png_landuse_weld	Landuse in PNG	Weld County
png_ownership	Land Ownership in PNG	Weld County
png_pls	Public Land Survey Boundaries in PNG	USGS
png_roads	Road lines with PNG	USGS 1:250000
png_soils	Soil boundaries with PNG	NRCS Weld County Soil Survey
png_streams	Stream lines in PNG	USGS 1:250000
png_dem	Digital Elevation Model (raster)	USGS 10M DEM
png_pdog (81 to 06)	Prairie Dog Town Boundaries (1981 to 2007)	GPS by USFS
png_watersheds	Major watershed boundaries in PNG	USGS 10M DEM

CPER Miscellaneous Map Imagery

Dataset Name	Description	Comments
Photos	Aerial Photos and Indices - 1937, 1941, 1977, 1982	Indices are digital. Photos are hard copy images (1977 has been scanned to digital images)
Root Diagrams	Root Diagrams - scanned images in CPER	scanned and vectorized by CSU for analysis of root distribution by depth.
Burn Areas	Burned areas 1960 - 1999	From aerial photos and GPS
Cultivated Fields	Cultivated Fields 1954 - 1999	
Management Methods	Fields with Management Methodologies 1937 – 1999 of CPER	
Grazing Intensity	Grazing Intensity by Field	
Protected Areas	Protected Areas of CPER/SGS	
Power Lines	Power Lines of CPER	
Trails	Trails of CPER	

Table 1.3.2

Central Grasslands Miscellaneous Map Imagery

Dataset Name	**Description**	**Comments**
Absolute Production of C3 and C4 Grasses	Absolute Production of C3 and C4 Grasses derived from NRCS Range Site Data	
Absolute Production Grasses by Species	Absolute Production Grasses by Species (24) derived from NRCS Range Site Data	
Duration of Greenness	Duration of Greenness - NDVI derived	
Grain Carbon Change	Grain Carbon Change (1995-1950-1900)	
Onset of Greenness	Onset of Greenness - NDVI derived	
Peak of Greenness	Peak of Greenness - NDVI derived	
Relative Production of C3 and C4 Grasses	Relative Production of C3 and C4 Grasses derived from NRCS Range Site Data	
Relative Production of Grasses by Species	Relative Production of Grasses by Species (24) derived from NRCS Range Site Data	
Soil Carbon Change	Soil Carbon Change (1995-1950-1900)	
Steady State Soil Carbon	Steady State Soil Carbon (1900)	
Precipitation	Precipitation - 20-year mean annual contours	
Temperature	Temperature - 20-year mean annual contours	
Weather Stations - 20-year mean	Weather Stations - 20-year mean-monthly and mean-annual data (points)	

Table 1.3.3

Table 1.4 Electronically available IBP Legacy Data Sets Category/Title
Aboveground Herbage
1978 aboveground herbage (epa)
aboveground herbage summary output
Biomass
Ecological Stress Experiment: Nutrient Stress
1970 aboveground herbage (pawnee) biomass esa field data
1970 aboveground herbage (pawnee) biomass esa summary data
1971 aboveground herbage (pawnee) biomass esa field data-6 dates 4 dbl sampled
1972 aboveground herbage (pawnee) biomass esa field data-9 dates
1973 aboveground herbage (pawnee) biomass esa field data-8 dates 6 dbl sampled
1974 aboveground herbage (pawnee) biomass esa field data-8 dates 3 dbl sampled
1975 aboveground herbage (pawnee) biomass esa field data-5 dates 2 dbl sampled
1976 aboveground herbage (pawnee) biomass esa field data-4 dates on 1st 3
1977 aboveground herbage (pawnee) biomass esa field data-4 dates dbl sampled
1978 aboveground herbage (pawnee) biomass esa field data
Grazing intensity
1969 aboveground herbage (pawnee) biomass grazing intensity field data-10 dates
1969 aboveground herbage (pawnee) biomass grazing intensity summary data-10 dates
1970 aboveground herbage (pawnee) biomass grazing intensity field data-11 dates
1970 aboveground herbage (pawnee) biomass grazing intensity summary data-11 dates
1971 aboveground herbage (pawnee) biomass grazing intensity field data-5 dates
1971 aboveground herbage (pawnee) biomass grazing intensity summary data-5 dates
1972 aboveground herbage (pawnee) biomass grazing intensity field data-6 dates 1st dt no trt1
1972 aboveground herbage (pawnee) biomass grazing intensity summary data-6 dates 1st dt no trt1
Network comparison
1971 aboveground herbage (pawnee) biomass network comparison field data-12 dates
1971 aboveground herbage (pawnee) biomass network comparison summary data-12 dates
1972 aboveground herbage (pawnee) biomass network comparison field data-8 dates 1st dt no trt1
1972 aboveground herbage (pawnee) biomass network comparison summary data-8 dates 1st dt no trt1
Bridge set
1972 aboveground herbage (pawnee) bridge set field data
1972 aboveground herbage (pawnee) bridge set summary data

	Bug damaged plot		

			1978 aboveground herbage (pawnee) bug damaged plot field data

	C14		
		Photosynthesis	
			1977 aboveground herbage (epa) carbon 14 photosynthesis data
			1978 aboveground herbage (epa) carbon 14 photosynthesis data
	Exclosure		
		Grazing by soil texture	
			1991 aboveground herbage - exclosure study grazing by soil texture (raw data)
	Plant growth		
			1977 aboveground herbage (epa) plant growth-only trt L & M
			1978 aboveground herbage (epa) AGSM plant growth-9 dates trts A-D
Aboveground invertebrates			
			1971 aboveground invertebrate (pawnee) insect-range plant association data
			1971 aboveground invertebrate (pawnee) pit trap invertebrate collection data
			1971 aboveground invertebrate (pawnee) sweep net invertebrate collection data
			1972 aboveground invertebrate (pawnee) bureau of sport fisheries
			1972 aboveground invertebrate (pawnee) bureau of sport fisheries
			1972 aboveground invertebrate (pawnee) insect-plant host data (v. yount)
			1972-3 aboveground invertebrate (pawnee) grasshopper plot data and programs
			1977 aboveground invertebrate (epa) grasshopper census data
			aboveground invertebrate (pawnee)
			aboveground invertebrate (pawnee) species code list
	Density & biomass		
		Esa field data	
			1971-1974 aboveground invertebrate (pawnee) density & biomass esa field data
		Esa summary data	
			1972-1974 aboveground invertebrate (pawnee) density & biomass esa summary data
		Grazing intensity	
			1970-1972 aboveground invertebrate (pawnee) density & biomass grazing intensity field data
			1970 aboveground invertebrate (pawnee) density & biomass grazing intensity summary data
			1972 aboveground invertebrate (pawnee) density & biomass grazing intensity summary data
		Network comparison field data	
			1971-1972 aboveground invertebrate (pawnee) density & biomass network comparison

			field data
			1972 aboveground invertebrate (pawnee) density & biomass network comparison summary data
	Dung insects		
		Field data	
			1971-1972 aboveground invertebrate (pawnee) dung insects field data
		Summary data	
			1971-1972 aboveground invertebrate (pawnee) dung insects summary data-# & mg per g of pat
			1971-1972 aboveground invertebrate (pawnee) dung insects summary data-# & mg per pat
	Dung mites		
		Field data	
			1971-1972 aboveground invertebrate (pawnee) dung mites field data
		Summary data	
			1971-1972 aboveground invertebrate (pawnee) dung mites summary data-# & mg per g of pat
			1971-1972 aboveground invertebrate (pawnee) dung mites summary data-# & mg per pat
	Field data		
			1970-1972 aboveground invertebrate (cottonwood) field data
			1970-1972 aboveground invertebrate (jornada) field data
			1970-1972 aboveground invertebrate (osage) field data
			1970-1972 aboveground invertebrate (pantex) field data
			1971-1972 aboveground invertebrate (pawnee) field data
			1972-1973 aboveground invertebrate (ale) field data
			1972 aboveground invertebrate (bridger) field data
			1973-1974 aboveground invertebrate (san joaquin) field data
			1974-1976 aboveground invertebrate (epa) montana field data
	Summary data		
			1970-1972 aboveground invertebrate (cottonwood) summary data
			1970-1972 aboveground invertebrate (jornada) summary data
			1970-1972 aboveground invertebrate (osage) summary data
			1971 aboveground invertebrate (pawnee) summary data
			1972-1973 aboveground invertebrate (ale) summary data
			1972-1973 aboveground invertebrate (pantex) summary data
			1973-1974 aboveground invertebrate (san joaquin) summary data
			1974-1976 aboveground invertebrate (epa) montana summary data

Table 1.4.3

Belowground Herbage			
			1975 belowground herbage
			1978 belowground herbage
	Field data		
			1970 belowground herbage (pawnee) field data
			1971 belowground herbage (pawnee) field data-all dates trts
			1972 belowground herbage (pawnee) field data
			1973-1976 belowground herbage (pawnee) field data-all dates trts sample date codes
			1975 belowground herbage (pawnee) site 13-field data-3 dates trts H-K
			1976 belowground herbage (pawnee) site 13-field data-2 dates trts H-K
			1977 belowground herbage (pawnee) field data
			1978 belowground herbage (epa) field data-5 dates trts A-D
	Summary data		
			1970 belowground herbage (pawnee) cores avg within quadrats summary data
			1971 belowground herbage (pawnee) summary data-all dates trts
			1972 belowground herbage (pawnee) summary data
			1973-1974 belowground herbage (pawnee) summary data-cores avg within quadrat
			1975 belowground herbage (pawnee) site 11-all cores avg within quadrats summary data
			1975-1977 belowground herbage (pawnee) summary data
			1976 belowground herbage (pawnee) site 13-summary data-2 dates trts H-K
Belowground Temperature			
	Combined field data		
			1971-82 belowground temperature (pawnee) combined field data
	Field data		
			1971-1994 belowground temperature (pawnee) field data
	Output summary table		
			1971-1994 belowground temperature (pawnee) output summary table
	Summary data		
			1971-1994 belowground temperature (pawnee) summary data
Birds			
			1968-72 avian (pawnee) ryders' permanent plot pawnee data
			1970-73 avian (ale cottonwood)
			1973 avian (pawnee) ryder's permanent plot pawnee data
			1974-75 avian boyd's bird field data
			avian
			avian owl prey field data (marti robinson)
	Diet data		
			1968-72 avian (pawnee) baldwin bird diet data

Table 1.4.4

			1968-72 avian (pawnee) baldwin bird diet data
			1970-71 avian (pawnee) lark bunting reformatted data diet data (baldwin
	Hawk data		
			1970-71 avian (pawnee) hawk data (ollendorf)
			1971-73 avian (pawnee) hawk growth data
	Int. - ext. collection		
			1970-71 avian (jornada) avian int. - ext. collection
			1970-72 avian (cottonwood) avian int. - ext. collection
			1970-72 avian (osage) avian int. - ext. collection
			1970-72 avian (pantex) avian int. - ext. collection
			1971-72 avian (ale) avian int. - ext. collection
	Nesting field data		
			1970-1972 avian (pawnee) avian nesting field data
	Road count		
		Field data	
			1968-90 avian (pawnee) avian road count field data
			1970-72 avian (pantex) avian road count field data
			1971 avian (ale) avian road count field data
			1972 avian (jornada) avian road count field data
			1972-74 avian (cottonwood) avian road count field data
			1972-75 avian (osage) avian road count field data
		Summary data	
			1968-73 avian (pawnee) avian road count summary data
Decomposition			
	Field data		
			1974 decomposition (epa) field data
			1975 decomposition (epa) field data-cellulose
			1975 decomposition (epa) field data-native litter
			1976 decomposition (epa) field data
	Summary data		
			1971-1972 decomposition (pawnee) summary data
Grubkill			
			1977-1980 plant recovery on grubkills (raw data)
			1982 plant recovery on grubkills (raw data)
			1990 plant recovery on grubkills (raw data)
Hygrothermograph			
	4hr intervals		

Table 1.4.5

			1984 hygrothermograph (pawnee) data-4hr intervals (1- 6-84 to 16- 9-84)
			1984 hygrothermograph (pawnee) data-4hr intervals (11-12-84 to 5- 2-85)
			1984 hygrothermograph (pawnee) data-4hr intervals (17- 9-84 to 10-12-84)
			1984 hygrothermograph (pawnee) data-4hr intervals (20- 2-84 to 1- 6-84)
			1984 hygrothermograph (pawnee) data-4hr intervals (30-10-84 to 19- 2-84)
			1985 hygrothermograph (pawnee) data-4hr intervals (2- 9-85 to 31-12-85)
			1985 hygrothermograph (pawnee) data-4hr intervals (5- 2-85 to 7- 5-85)
			1985 hygrothermograph (pawnee) data-4hr intervals (7- 5-85 to 2- 9-85)
	Daily max and min		
			1983-85 hygrothermograph (pawnee) daily max and min (16-10-83 to 4- 2-85)
			1985 hygrothermograph (pawnee) daily max and and min (5- 2-85 to 31-12-85)
	Field data		
			1971 hygrothermograph (ale) field data
			1971 hygrothermograph (osage) field data
			1972 hygrothermograph (ale) field data
			1972 hygrothermograph (bridger) field data
			1973 hygrothermograph (ale) field data
			1976-1981 hygrothermograph (pawnee) field data format as on form #150
	Processed with program HYTHER		
			1975 hygrothermograph (pawnee) data processed with program HYTHER
			1971 hygrothermograph (pawnee) data processed with program TWOHR
			1973-1974 hygrothermograph (pawnee) data processed with program TWOHR
	Uncorrected data (process with HYTHER or TWOHR)		
			1970 hygrothermograph (pawnee) uncorrected data (process with HYTHER or TWOHR)
Litter			
	Bridge set		
		Field data	
			1972 litter (pawnee) bridge set type 1 field data
		Summary data	
			1972 litter (pawnee) bridge set type 1 summary data
	Esa		
		Field data	
			1970-1976 litter (pawnee) esa type 1 field data
			1973 litter (pawnee) esa type 3 field data
		Summary data	
			1970-1976 litter (pawnee) esa type 1 summary data
			1973 litter (pawnee) esa type 3 summary data

Table 1.4.6

	Field data		
			1977 litter (epa) field data
			1978 litter (epa) field data
	Grazing intensity		
			1971-1972 litter (pawnee) grazing intensity type 1 field data
			1971-1972 litter (pawnee) grazing intensity type 1 summary data
	Herbicide		
			1972 litter (pawnee) klm (herbicide) type 1 field data
			1972 litter (pawnee) klm (herbicide) type 1 summary data
	Insecticide		
			1972-1973 litter (pawnee) xyz (insecticide) type 1 field data
			1972-1973 litter (pawnee) xyz (insecticide) type 1 summary data
	Litter component data		
			1969-1970 litter (pawnee) litter component data
	Network comparison		
		Field data	
			1971-1972 litter (pawnee) network comparison type 1 field data
			1972 litter (pawnee) network comparison type 3 field data
		Summary data	
			1971-1972 litter (pawnee) network comparison type 1 summary data
			1972 litter (pawnee) network comparison type 3 summary data
Lysimeter			
	Field data		
			1972-1978 soil water - lysimeter (pawnee) field data
	Neutron probe		
		Field data	
			1983-1992 soil water - neutron probe (pawnee) lysimeter field data
	Summary data		
			1972-1976 soil water - lysimeter (pawnee) summary data
Mammals			
			1975 small mammal
			small mammal (pawnee)
	Large herbivore activity		
			1972 small mammal (pawnee) large herbivore activity data
			1973 small mammal (pawnee) swartz large herbivore activity data
	Autopsy data		

Table 1.4.7

			1972 small mammal (pantex) autopsy data
		Esa	
			1972 small mammal (pawnee) esa autopsy data
		Off-grid	
			1973-1974 small mammal (san joaquin) off-grid autopsy data
	Diet data		
			1969-70 small mammal les flake - diet data & program
	Field data		
			1971 small mammal (pawnee) field data
	Live trap		
		Field data	
			1970 small mammal (bridger) live trap field data
			1970 small mammal (cottonwood) live trap field data
			1970 small mammal (dickson) live trap field data
			1970 small mammal (jornada) live trap field data
			1970 small mammal (osage) live trap field data
			1970 small mammal (pantex) live trap field data
			1971-1975 small mammal (pawnee) live trap field data
		Zippin analysis	
			1973 small mammal (pawnee) live trap zippin analysis
	Off-grid snap trap data		
			1971-1972 small mammal (pawnee) misc. off-grid snap trap data
	Pronghorn interaction		
			small mammal (pawnee) rob deblinger's pronghorn interaction data
	Reproductive data		
			1969-70 small mammal les flake - reproductive data
	Snap trap		
			1970 small mammal (bison) snap trap field data
			1970 small mammal (bridger) snap trap field data
			1970 small mammal (cottonwood) snap trap field data
			1970 small mammal (dickson) snap trap field data
			1970 small mammal (jornada) snap trap field data
			1970 small mammal (nevada) snap trap field data
	Summary data		
			1971 small mammal (pawnee) summary data
	Weight & reproduction		

Table 1.4.8

			1970 small mammal (bridger) mammal wt & reproduction analysis
			1970 small mammal (cottonwood) mammal wt & reproduction analysis
			1970 small mammal (dickson) mammal wt & reproduction analysis
			1970 small mammal (jornada) mammal wt & reproduction analysis
			1970 small mammal (osage) mammal wt & reproduction analysis
Microarthropods			
			1971 soil microarthropods (pawnee) field data
			1971 soil microarthropods (pawnee) summary data
			1972 soil microarthropods (pawnee) deep sample (16 30 aug) field data
			1972 soil microarthropods (pawnee) deep sample (16 30 aug) summary data
			1972 soil microarthropods (pawnee) deep sample (23 26 may) field data
			1972 soil microarthropods (pawnee) deep sample (23 26 may) summary data
			1972 soil microarthropods (pawnee) deep sample (29 jun 6 july) field data
			1972 soil microarthropods (pawnee) deep sample (29 jun 6 july) summary data
			1972 soil microarthropods (pawnee) deep sample (5 14 apr) field data
			1972 soil microarthropods (pawnee) deep sample (5 14 apr) summary data
			1972 soil microarthropods (pawnee) esa nc
			1972 soil microarthropods (pawnee) esa nc
			1973 soil microarthropods (pawnee) deep sample (may) field data
			1973 soil microarthropods (pawnee) deep sample (may) summary data
			1973 soil microarthropods (pawnee) deep sample (winter) summary data
			1973 soil microarthropods (pawnee) esa field data
			1973 soil microarthropods (pawnee) esa summary data
			1973 soil microarthropods (pawnee0 deep sample (winter) field data
			1974 soil microarthropods (pawnee) esa field data
			1974 soil microarthropods (pawnee) esa summary data
			1975 soil microarthropods (pawnee) nematicide study analysis (0-5 5-10
			1975 soil microarthropods (pawnee) nematicide study analysis trt H I (10-15
			1975 soil microarthropods (pawnee) nematicide study analysis-combine trts H-J I
			1975 soil microarthropods (pawnee) nematicide study data
			1975 soil microarthropods (pawnee) nematicide study data with wts and trophics
			1975 soil microarthropods (pawnee) nematicide study trophic summary by host (0-10cm)
			soil microarthropods (pawnee)
Nematodes			
			1975 aboveground herbage (pawnee) nematode study-1 date trts H-K
			1976 aboveground herbage (pawnee) nematode study-1 date trts H-K
Phenology			
	Field data		
			1970 phenology (cottonwood) field data - 12 dates condensed

Table 1.4.9

			1972 phenology (cottonwood) field data
			1972-1977phenology (pawnee) field data
	Montana field data		
			1975-1977 phenology (epa) montana field data
Soil macroarthropods			
			soil macroarthropods
			soil macroarthropods
	Esa		
		Field data	
			1971-1972 soil macroarthropods (pawnee) esa field data
	Field data		
			1970-1974 soil macroarthropods (pawnee) field data
	Grazing intensity		
		Field data	
			1971-1972 soil macroarthropods (pawnee) grazing intensity field data
	Nematicide study		
			1975 soil macroarthropods (pawnee) analysis of stanton ARFR data (nematicide study)
			1975 soil macroarthropods (pawnee) analysis of stanton BOER data (nematicide study)
			1975 soil macroarthropods (pawnee) analysis of stanton nematicide study-special trophics-ARFR & BOGR data
			1975 soil macroarthropods (pawnee) data from stanton nematicide study-special trophics
	Network comparison		
		Field data	
			1971-1972 soil macroarthropods (pawnee) network comparison field data
	Summary data		
			1970-1974 soil macroarthropods (pawnee) summary data
Soil Water, Gravimetric			
			1977 soil water - gravimetric (epa) different depths for frost block comparisons
			1978 soil water - gravimetric (epa)

	Esa		
			1976 soil water - gravimetric (pawnee) environmental stress area field data
	Field data		
			1970 soil water - gravimetric (cottonwood) field data - 12 dates trts 1
			1971 soil water - gravimetric (cottonwood) field data - 11 dates trts 1
			1972 soil water - gravimetric (cottonwood) field data - 9 dates trts 1
			1977 soil water - gravimetric (epa) field data - 12 dates trts A-D

Table 1.4.10

			1977 soil water - gravimetric (epa) field data - 19 dates trts A-D
	Nematicide study		
			1975 soil water - gravimetric (pawnee) nematicide study field data
	Network comparison		
			1972 soil water - gravimetric (pawnee) network comparison field data
			1976 soil water - gravimetric (pawnee) network comparison field data
Soil Water, Microwatershed			
	Field data		
			1969-1078 soil water - microwatershed (pawnee) field data
	Shield count data		
			1971-1976 soil water - microwatershed (pawnee) shield count data
	Summary data		
			1969-1976 soil water - microwatershed (pawnee) summary data
Soil Water, Neutron Probe			
			1980 soil water - neutron probe (pawnee) special field data (oswald's data)
	OWL		
		Field data	
			1985-1992 soil water - neutron probe (pawnee) OWL field data
	Probe 480		
		ARS	
			1979 soil water - neutron probe (pawnee) field data (probe 480) - special ARS
		Field data	
			1978-1984 soil water - neutron probe (pawnee) field data (probe 480)
		Grasshoppers	
			1980 soil water - neutron probe (pawnee) field data (probe 480)-grasshoppers (detling)
	Sandy		
		Field data	
			1984-1992 soil water - neutron probe (pawnee) SANDY field data
	Shale		
		Field data	
			1984-1992 soil water - neutron probe (pawnee) SHALE field data
	Silt		
		Field data	
			1986 soil water - neutron probe (pawnee) SILT field data
	TOPO		

Table 1.4.11

		Field data	
			1984-1992 soil water - neutron probe (pawnee) TOPO field data
	Ungrazed esa		
		Field data	
			1983-1992 soil water - neutron probe (pawnee) ungrazed esa field data
Soil Water, Transects			
	Field data		
			1971-1978 soil water - transects (pawnee) field data
Weather			
			1937-66 grover precipitation data
			1937-66 kauffman precipitation data
			1940-68 ars rain gauge data (pawnee) -program fms01 tabulates ppt data
			1940-70 cper precipitation data
			1940-73 cper temperature data table of monthly max and min (english units)
			1940-73 cper weather data (english units) missing 1942
			1940-73 cper weather data (metric units) missing 1942
			1945-67 kauffman temperature data
			1946-67 grover temperature data
			1948-70 cper temperature data
			1969-74 cheyenne weather 16 readings
			1969-84 weather data (pawnee central plains
			1970-73 cper rain gauge data
Weather, CR21X			
			1986-1994 cr21x weather data -messages about missing and erroneous data
	Summary 15-min data		
			1986-1994 cr21x weather data -summary 15-min data
	Summary daily data		
			1986-1994 cr21x weather data -summary daily data
	Summary hourly data		
			1986-1994 cr21x weather data -summary hourly data
Weather, CR21X, Raw Data			
			1986 cr21x weather data -raw data 10- 6-86 to 10-20-86
			1986 cr21x weather data -raw data 10-20-86 to 11- 3-86
			1986 cr21x weather data -raw data 11- 3-86 to 11-18-86
			1986 cr21x weather data -raw data 11-18-86 to 12- 2-86
			1986 cr21x weather data -raw data 12- 2-86 to 12-16-86
			1986 cr21x weather data -raw data 12-16-86 to 12-30-86

Table 1.4.12

			1986 cr21x weather data -raw data 12-30-86 to 1-13-87
			1986 cr21x weather data -raw data 5-30-86 to 6-13-86
			1986 cr21x weather data -raw data 6-13-86 to 6-27-86
			1986 cr21x weather data -raw data 6-27-86 to 7-11-86
			1986 cr21x weather data -raw data 7-11-86 to 7-25-86
			1986 cr21x weather data -raw data 7-25-86 to 8- 8-86
			1986 cr21x weather data -raw data 8- 8-86 to 8-22-86
			1986 cr21x weather data -raw data 8-22-86 to 9- 5-86
			1986 cr21x weather data -raw data 9- 5-86 to 9-20-86
			1986 cr21x weather data -raw data 9-20-86 to 10- 6-86
			1987 cr21x weather data -raw data 1-13-87 to 1-27-87
			1987 cr21x weather data -raw data 1-27-87 to 2- 9-87
			1987 cr21x weather data -raw data 10- 8-87 to 10-22-87
			1987 cr21x weather data -raw data 10-22-87 to 11- 6-87
			1987 cr21x weather data -raw data 11- 6-87 to 11-20-87
			1987 cr21x weather data -raw data 11-20-87 to 12- 4-87
			1987 cr21x weather data -raw data 12- 4-87 to 12-18-87
			1987 cr21x weather data -raw data 12-18-87 to 1- 2-88
			1987 cr21x weather data -raw data 19-12-87 only
			1987 cr21x weather data -raw data 2- 9-87 to 2-23-87
			1987 cr21x weather data -raw data 2-23-87 to 3-10-87
			1987 cr21x weather data -raw data 22-10-87 only
			1987 cr21x weather data -raw data 3-10-87 to 3-23-87
			1987 cr21x weather data -raw data 3-23-87 to 4- 7-87
			1987 cr21x weather data -raw data 4- 7-87 to 4-21-87
			1987 cr21x weather data -raw data 4-21-87 to 5- 5-87
			1987 cr21x weather data -raw data 5- 5-87 to 5-19-87
			1987 cr21x weather data -raw data 5-19-87 to 6- 2-87
			1987 cr21x weather data -raw data 6- 2-87 to 6-16-87
			1987 cr21x weather data -raw data 6-16-87 to 6-30-87
			1987 cr21x weather data -raw data 6-30-87 to 7-14-87
			1987 cr21x weather data -raw data 7-14-87 to 7-28-87
			1987 cr21x weather data -raw data 7-28-87 to 8-11-87
			1987 cr21x weather data -raw data 8-11-87 to 8-26-87
			1987 cr21x weather data -raw data 8-26-87 to 9-10-87
			1987 cr21x weather data -raw data 9-10-87 to 9-25-87
			1987 cr21x weather data -raw data 9-25-87 to 10- 8-87
			1988 cr21x weather data - raw data 23-12-88 only
			1988 cr21x weather data -raw data 1- 2-88 to 1-18-88

Table 1.4.13

			1988 cr21x weather data -raw data 1-18-88 to 2- 2-88
			1988 cr21x weather data -raw data 10- 4-88 to 10-18-88
			1988 cr21x weather data -raw data 10-18-88 to 11- 1-88
			1988 cr21x weather data -raw data 11 -1-88 to 11-14-88
			1988 cr21x weather data -raw data 11-14-88 to 11-28-88
			1988 cr21x weather data -raw data 11-28-88 to 12-13-88
			1988 cr21x weather data -raw data 12-13-88 to 12-23-88
			1988 cr21x weather data -raw data 12-23-88 to 1- 3-89
			1988 cr21x weather data -raw data 2- 2-88 to 2-15-88
			1988 cr21x weather data -raw data 2-15-88 to 3- 1-88
			1988 cr21x weather data -raw data 3- 1-88 to 3-15-88
			1988 cr21x weather data -raw data 3-15-88 to 3-29-88
			1988 cr21x weather data -raw data 3-29-88 to 4-12-88
			1988 cr21x weather data -raw data 4-12-88 to 4-27-88
			1988 cr21x weather data -raw data 4-27-88 to 5-11-88
			1988 cr21x weather data -raw data 5-11-88 to 5-26-88
			1988 cr21x weather data -raw data 5-26-88 to 6- 9-88
			1988 cr21x weather data -raw data 6- 9-88 to 6-23-88
			1988 cr21x weather data -raw data 6-23-88 to 7- 8-88
			1988 cr21x weather data -raw data 7- 8-88 to 7-22-88
			1988 cr21x weather data -raw data 7-22-88 to 8- 6-88
			1988 cr21x weather data -raw data 8- 6-88 to 8-22-88
			1988 cr21x weather data -raw data 8-22-88 to 9- 6-88
			1988 cr21x weather data -raw data 9- 6-88 to 9-20-88
			1988 cr21x weather data -raw data 9-20-88 to 10- 4-88
			1989 cr21x weather data -raw data 1- 3-89 to 1-17-89
			1989 cr21x weather data -raw data 1-17-89 to 1-31-89
			1989 cr21x weather data -raw data 1-31-89 to 2-14-89
			1989 cr21x weather data -raw data 10-10-89 to 10-24-89
			1989 cr21x weather data -raw data 10-24-89 to 11-07-89
			1989 cr21x weather data -raw data 11-07-89 to 11-21-89
			1989 cr21x weather data -raw data 11-21-89 to 12-05-89
			1989 cr21x weather data -raw data 12-05-89 to 12-19-89
			1989 cr21x weather data -raw data 12-19-89 to 1-02-90
			1989 cr21x weather data -raw data 2-14-89 to 3- 1-89
			1989 cr21x weather data -raw data 3- 1-89 to 3-15-89
			1989 cr21x weather data -raw data 3-15-89 to 3-28-89
			1989 cr21x weather data -raw data 3-28-89 to 4-11-89
			1989 cr21x weather data -raw data 4-11-89 to 4-25-89

Table 1.4.14

			1989 cr21x weather data -raw data 4-25-89 to 5-09-89
			1989 cr21x weather data -raw data 5-09-89 to 5-23-89
			1989 cr21x weather data -raw data 5-23-89 to 6-06-89
			1989 cr21x weather data -raw data 6-06-89 to 6-20-89
			1989 cr21x weather data -raw data 6-20-89 to 7-05-89
			1989 cr21x weather data -raw data 7-05-89 to 7-19-89
			1989 cr21x weather data -raw data 7-19-89 to 8-15-89
			1989 cr21x weather data -raw data 8-15-89 to 8-29-89
			1989 cr21x weather data -raw data 8-29-89 to 9-13-89
			1989 cr21x weather data -raw data 9-13-89 to 9-26-89
			1989 cr21x weather data -raw data 9-26-89 to 10-10-89
			cr21x weather data -information about processing raw data
			cr21x weather data -information about processing raw data
			cr21x weather data -information about raw data
Weather, Standard			
	Field data		
			1969-1994 standard weather (pawnee) field data
	Output summary table		
			1969-94 standard weather (pawnee) output summary tables
	Summary data metric units		
			1969-94 standard weather (pawnee) summary data metric units
	Yearly summary table		
			1969-1994 standard weather (pawnee) yearly summary table

Table 1.4.15