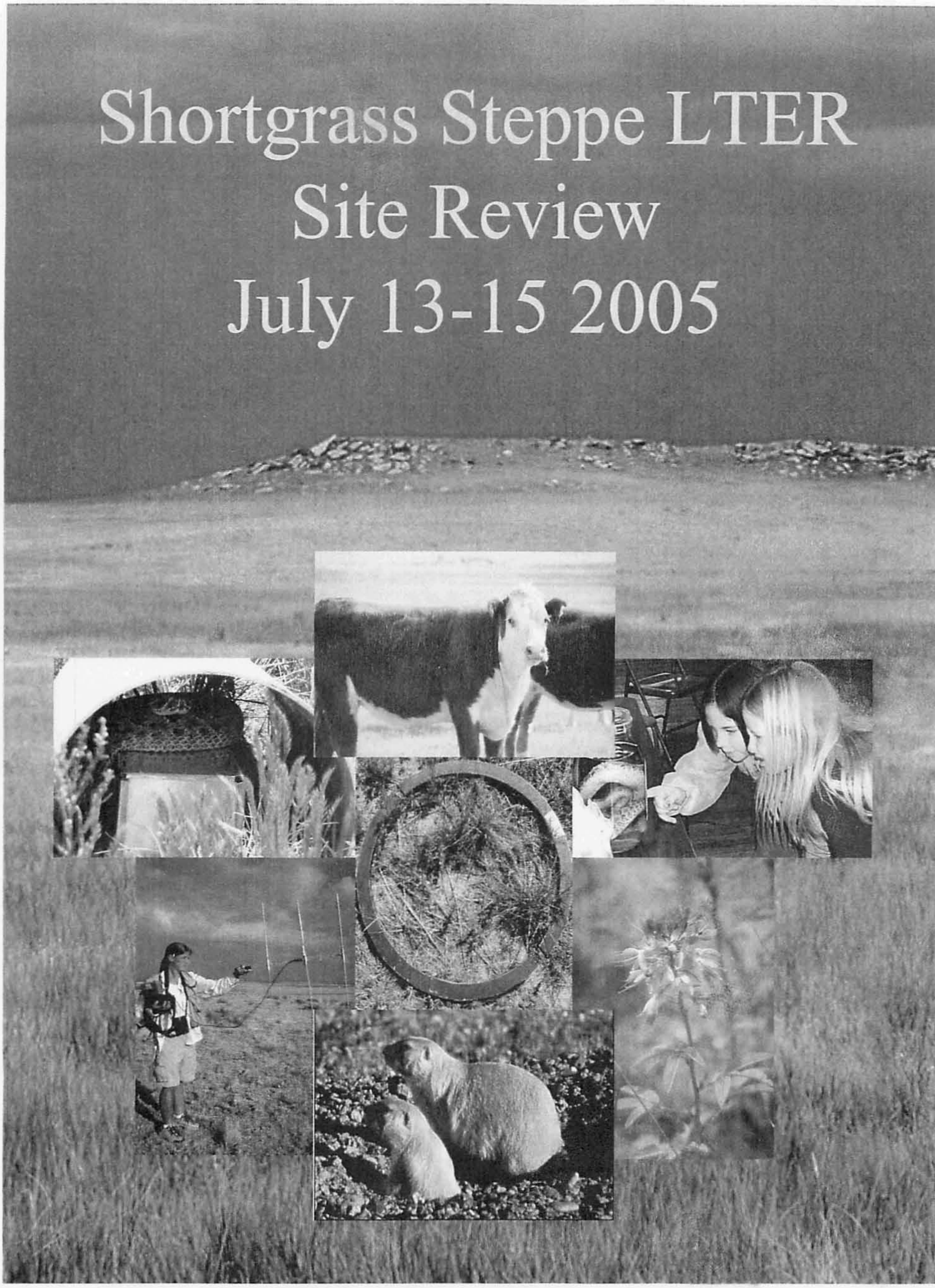
Shortgrass Steppe LTER
Site Review
July 13-15 2005



Acknowledgements

The photographs on the cover of this document were taken by researchers on the shortgrass steppe or participants in our education programs. We thank them for allowing us to use their images.

Laurel Hartley
Mark Lindquist
Lisa Savage
Amy Yackel Adams

We thank Amelia Lauenroth for her excellent design of the cover.

Proposed Agenda for SGS Site Review

Wednesday, July 13

Late afternoon, site review team arrives. CSU Van to Transport to Armstrong Hotel
8:00 PM Review team meets at Jay's for dinner and preliminary meeting with Henry Gholz

Thursday, July 14 – B215 NESB and SGS field sites

7:00 Vans depart from Armstrong Hotel for CSU campus. A continental breakfast at B215 NESB with site review team and some SGS-LTER PI's

7:30 Welcome and comments:
- Tony Frank, Provost, Colorado State University
- Larry Chandler, Associate Area Director, USDA ARS Northern Plains Area
- Lee Sommers, Director, Colorado State Agricultural Experiment Station
- Steve Currey, District Ranger, Pawnee National Grassland

8:00 Introduction and overview of SGS-LTER Program – Gene Kelly
8:30 Biogeochemistry Research Activities - Indy Burke
8:50 Plant-Grazing Dynamics Research Activities – Bill Lauenroth
9:10 Faunal Ecology Research Activities – Mike Antolin
9:30 Land Atmosphere Research Activities - Jack Morgan

9:50 Break
10:15 Vans depart from NESB for SGS-LTER Site

Field Tour (Planned stops for short talks and discussion)

11:15 Stop 1 – New Field Investigations & Experiments: Atmosphere-Ecosystem Interactions

Goals and Rationale - Jack Morgan
Ecosystem Water Dynamics – Bill Lauenroth
Determining Fluxes of Energy, Water & CO_2– Jack Morgan
Land Atmosphere Simulations – Adriana Beltran-Pzekurat
Global Change Modeling – Bill Parton
Paleoenvironment/Climate Studies – Alan Busacca

12:30 Stop 2 – Lunch in the cottonwoods (box lunches provided)

1:30 Stop 3 – New Field Experiment – Mountain Plover/Grazing Sites (section 1W)

Goals and Rationale - Bill Lauenroth
Plant and Livestock Responses – Justin Derner
Small Mammal and "Other Bird" Responses - Paul Stapp
Nitrogen Dynamics – Indy Burke
CO_2 and Energy Balance Responses – Jack Morgan

2:45 Stop 4 – Long Term Biogeochemistry Investigations & Experiments – Humus Plots/Cross Site Experiments

Goals and Rationale – Indy Burke
Physiography and Biogeochemistry – Gene Kelly
Si Biogeochemistry of Grasslands – Steve Blecker
Nutrient and Water Availability and Ecosystem Structure – Daniel Milchunas
Synthesis, Simulation and Cross Site Analysis – Bill Parton
Long Term Experimentation – Indy Burke

4:00 Stop 5 – Long Term Faunal Ecology Experiments – Prairie Dog Town

Goals and Rationale – Mike Antolin
Swift Foxes – Safi Darden
Prairie Dogs – Dan Tripp
Small Mammal Studies – Paul Stapp
Plant/Faunal Interactions – Jim Detling
Belowground Community Responses – Megan Quirk

5:15 Poster session/cocktail hour and meeting with graduate and undergraduate students at SGS LTER HQ. Followed by barbecue with all the investigators and students working on the SGS.

7:00 Transport Site Review team back to Armstrong Hotel

Friday, July 15 – NR 100

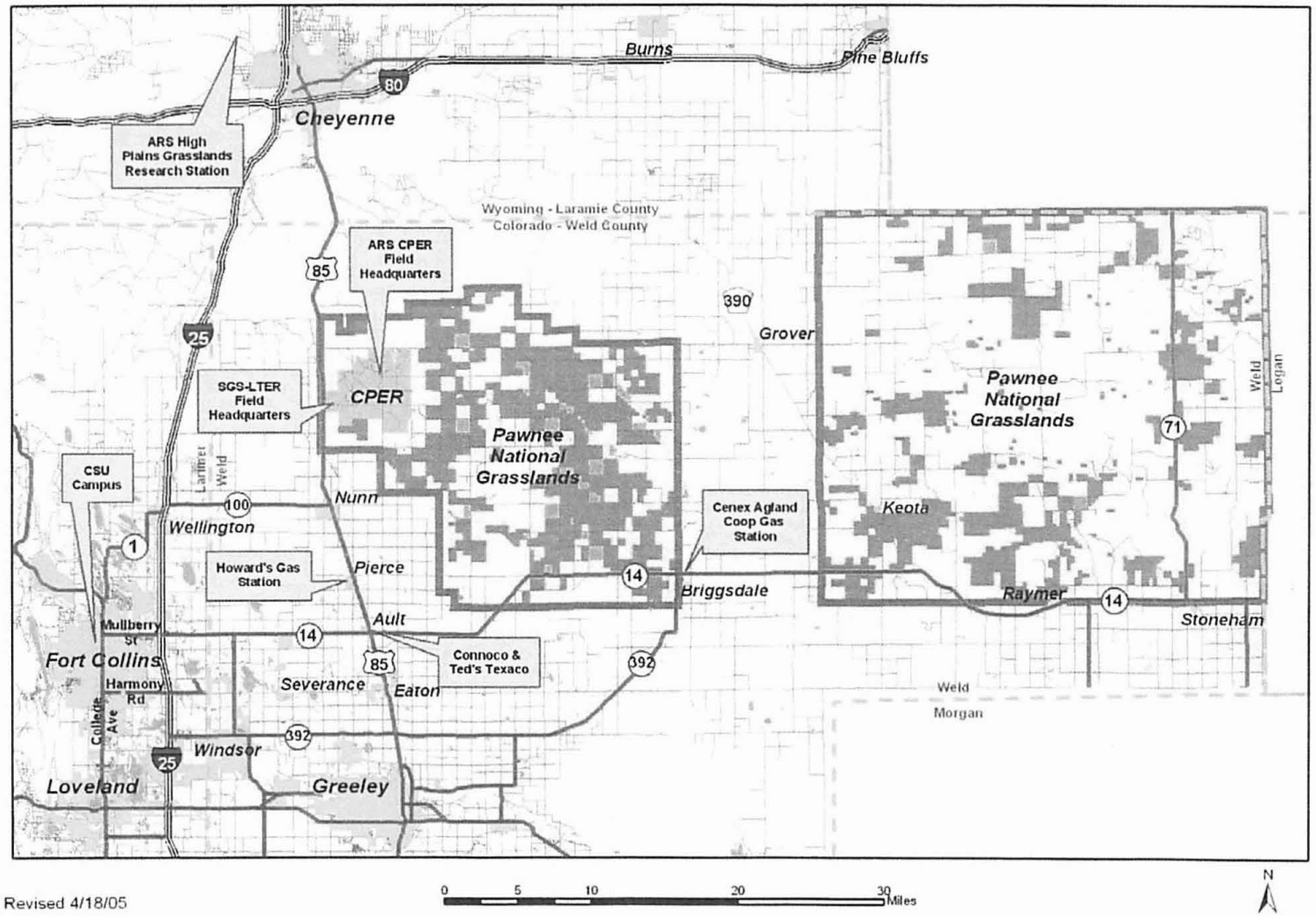
8:10 Hotel pick up
8:30 Introductions and daily schedule – Gene Kelly
8:40 Information Management – Nicole Kaplan and Bob Flynn
9:00 Education and Outreach Activities – John Moore and Laurel Hartley
9:45 Project Management – Gene Kelly
10:00 Break
10:30 Meet with graduate students
11:30 Summary and Future Plans – Gene Kelly
12: 00 Box lunches – Staff with site review team
1:00 Review team in executive/report writing session
4:30 Report from team to SGS LTER PI's

Table of Contents

Section 1:

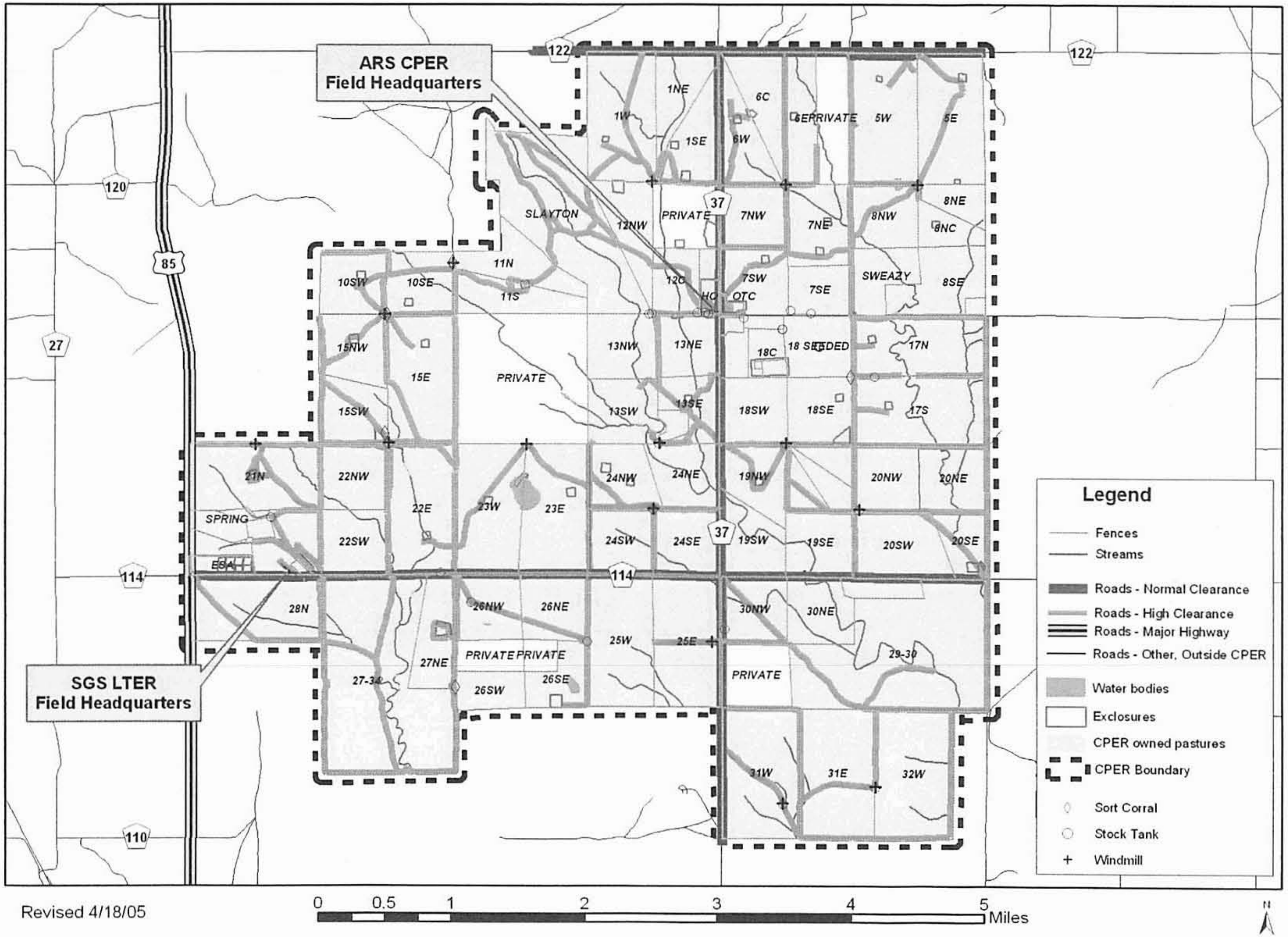
Maps of the Shortgrass Steppe Long Term Ecological Research Site and Environs

CPER / Pawnee National Grassland - General Vicinity Map



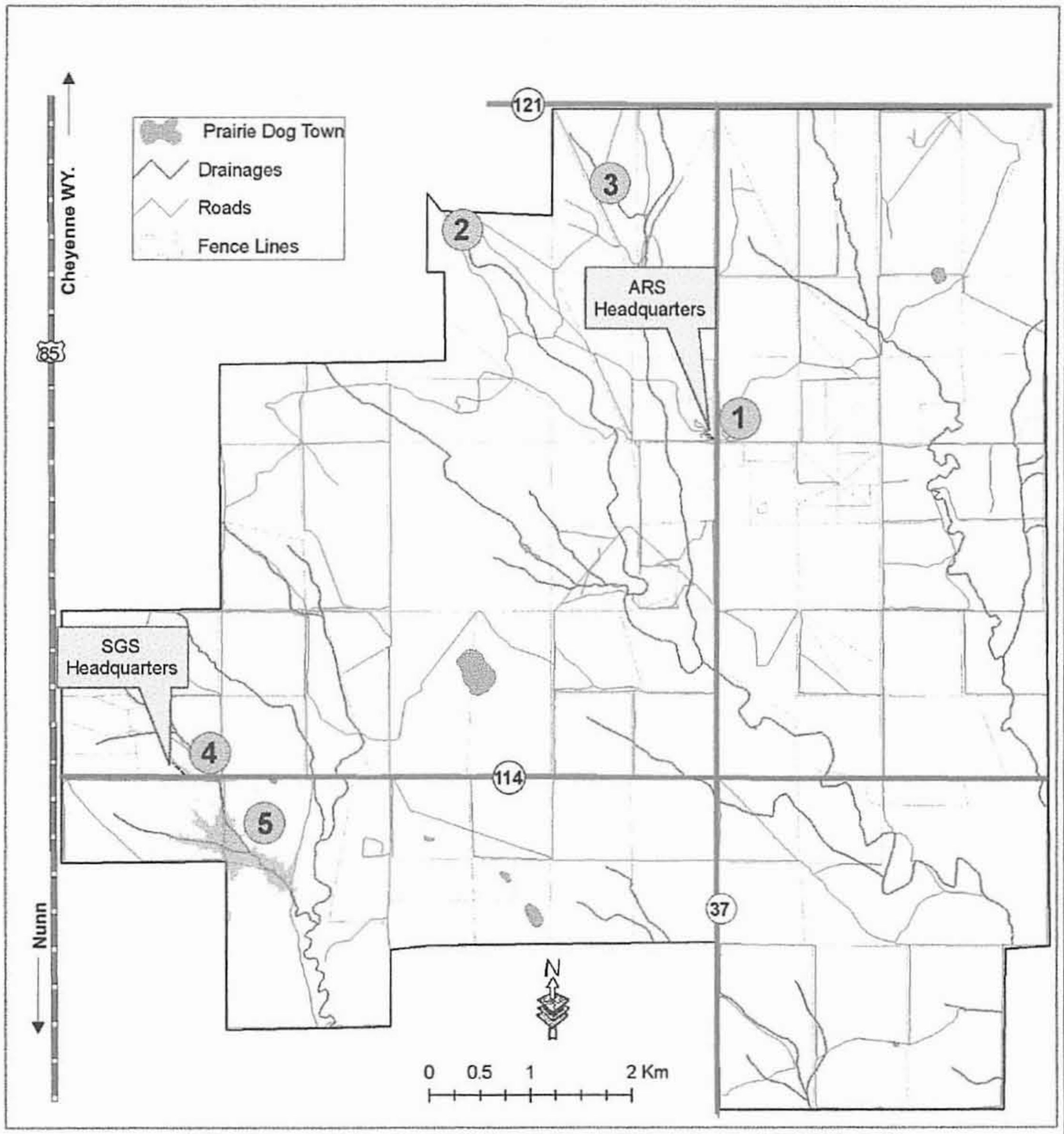
Revised 4/18/05

Central Plains Experimental Range (CPER) Detail Map



Revised 4/18/05

SGS-LTER Field Tour - July 14, 2005



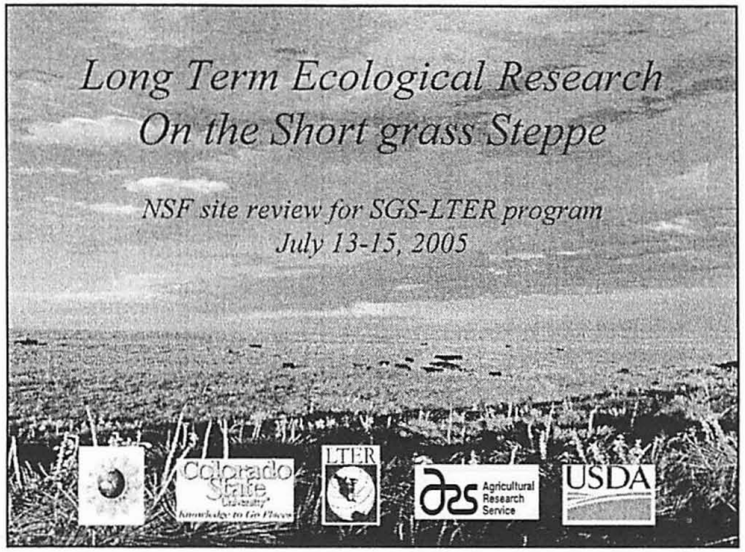
Stop 1: Atmosphere-Ecosystem Interactions, Open Top Chamber Site
Stop 2: Lunch at Slayton's under the cottonwoods
Stop 3: Mountain Plover/Grazing Sites, Section 1W
Stop 4: Long Term Biogeochemistry Investigations and Experiments, Humus Plots/Cross Site Experiment, Section 21 and SGS HQ)
Stop 5: Prairie Dog Town, Section 27/28

Section 2:

Introduction and overview of the SGS-LTER Program, Gene Kelly

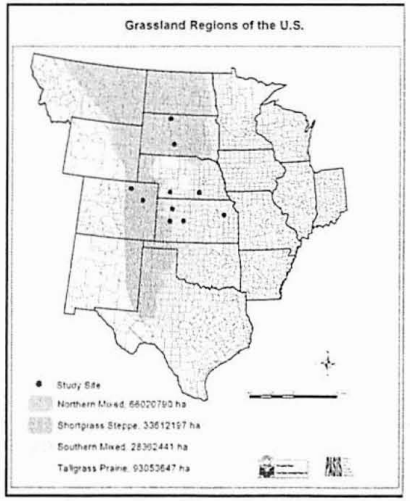
Our Agenda for today

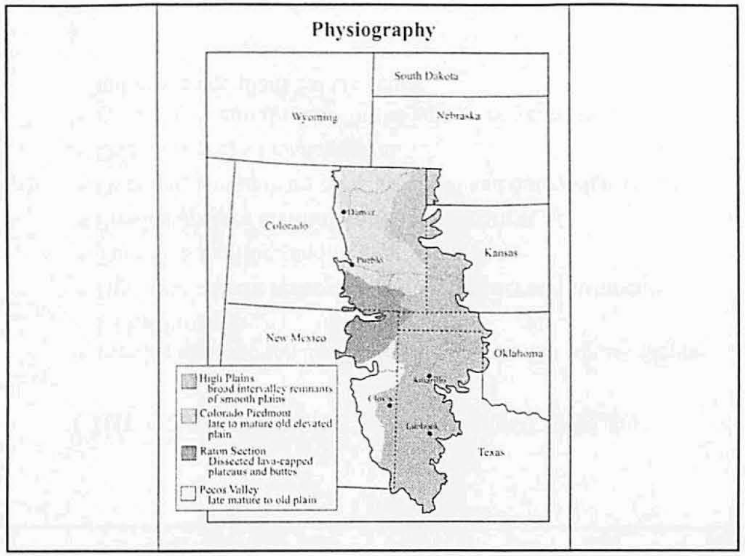
8:00 Introduction and Overview of SGS-LTER – Gene Kelly
8:30 Biogeochemistry Research Activities - Indy Burke
8:50 Plant-Grazing Dynamics Research Activities – Bill Lauenroth
9:10 Faunal Ecology Research Activities – Mike Antolin
9:30 Land Atmosphere Research Activities - Jack Morgan
10:20 Break
10:30 Vans depart from LSC for SGS-LTER Site
11:15 Stop 1 – *Land-Atmosphere Research*
12:30 Stop 2 - *Lunch in the cottonwoods (box lunches provided)*
1:30 Stop 3 – *Plant Ecosystem Dynamics Research*
2:45 Stop 4 - *Biogeochemistry Research*
4:00 Stop 5 - *Faunal Ecology Research*
5:15 Poster session/cocktail hour, followed by barbecue
7:30 Transport Site Review Team back to Armstrong Hotel

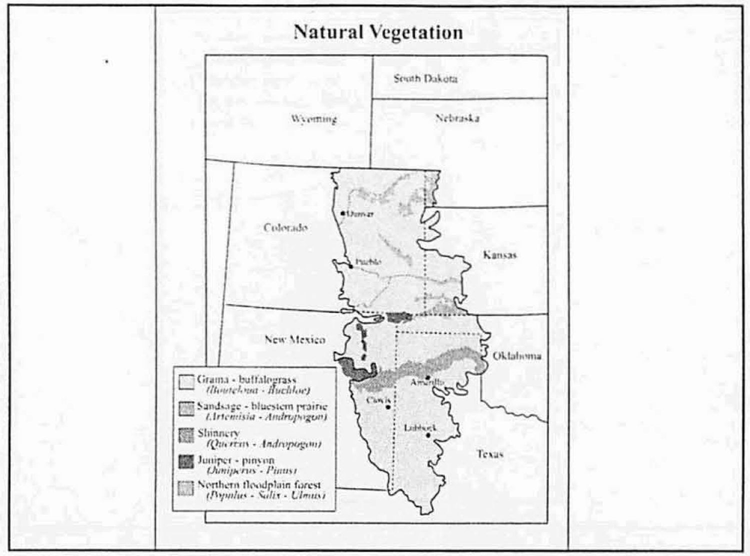


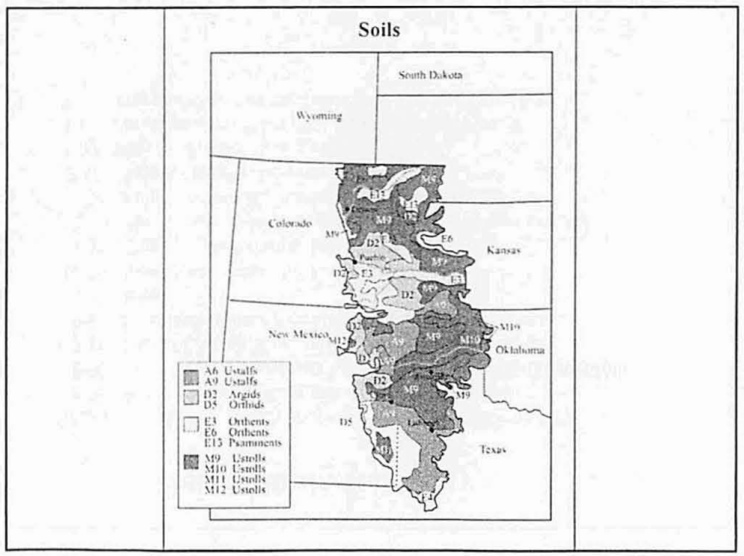
Our goals for the site review are to:

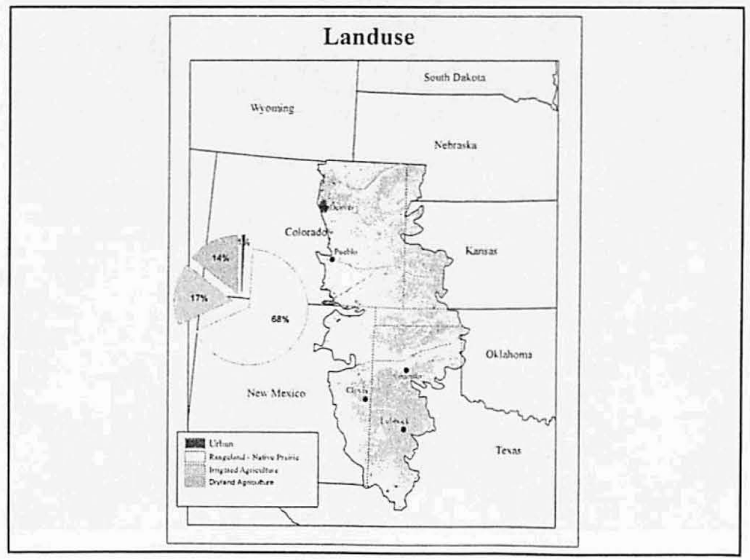
- Provide introduction and background to the Shortgrass Steppe LTER Program
- Highlight current research activities and accomplishments
- Tour SGS facilities and field research sites
- Provide updates on information management
- Overview and updates on educational and outreach activities
- Overview project management
- Present the central focus for the next three years, new initiatives and plans for the future




Physiography
South Dakota
Wyoming
Nebraska
Colorado
Denver
Pueblo
Kansas
New Mexico
Oklahoma
Amarillo
Clovis
Lubbock
Texas
High Plains
broad intervalley remnants of smooth plains
Colorado Piedmont
late to mature old elevated plain
Raton Section
Dissected lava-capped plateaus and buttes
Pecos Valley
late mature to old plain

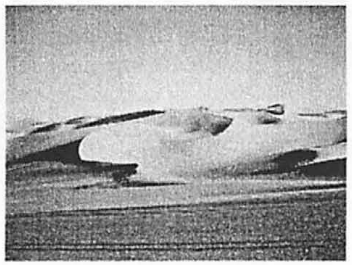

Natural Vegetation
South Dakota
Wyoming
Nebraska
Colorado
Denver
Pueblo
Kansas
New Mexico
Oklahoma
Amarillo
Clovis
Lubbock
Texas
Grama - buffalograss
(Bouteloua - Buchloe)
Sandsage - bluestem prairie
(Artemisia - Andropogon)
Shinnery
(Quercus - Andropogon)
Juniper - pinyon
(Juniperus - Pinus)
Northern floodplain forest
(Populus - Salix - Ulmus)


Soils
South Dakota
Wyoming
Colorado
Kansas
New Mexico
Oklahoma
Texas
A6 Ustalfs
A9 Ustalfs
D2 Argids
D5 Orthids
E3 Orthents
E6 Orthents
E13 Psamments
M9 Ustolls
M10 Ustolls
M11 Ustolls
M12 Ustolls


Landuse
South Dakota
Wyoming
Nebraska
Colorado
Pueblo
Kansas
Oklahoma
New Mexico
Texas
14%
17%
68%
Urban

The evolution of this grassland system was driven by ***grazing, periods of drought and landscape instability.***

These essential and interactive factors were responsible for the structure and function of this ecosystem



High inter-annual variability in precipitation:

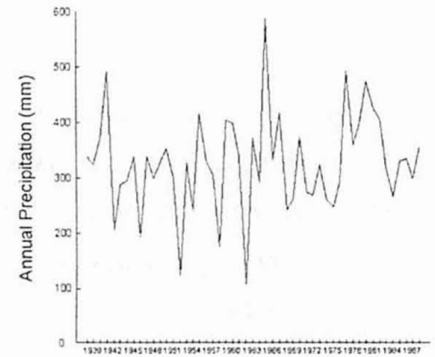


Fig. 2.22. Annual precipitation for the CPER from 1939 to 1990 (LTER unpubl. data).

High seasonal variability in precipitation:

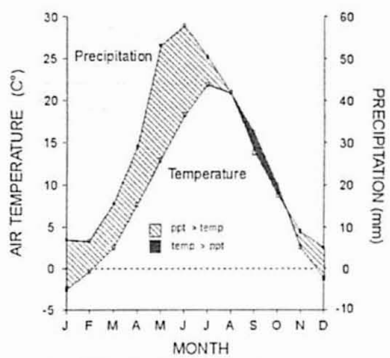
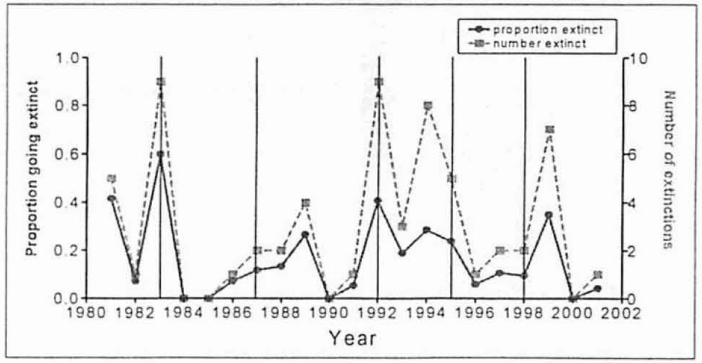


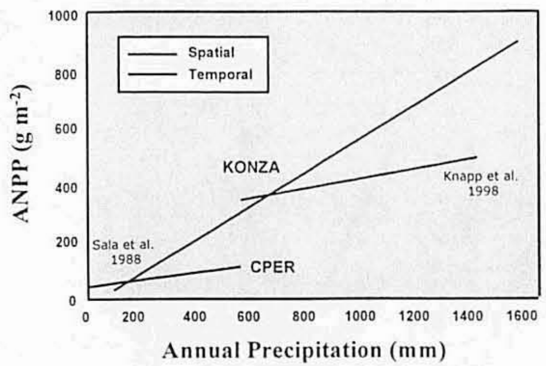
Fig. 2.23. Monthly precipitation and temperature for the CPER from 1939 to 1990 (Lauenroth and Milchunas 1991).

Prairie dog populations linked to climatic variability:



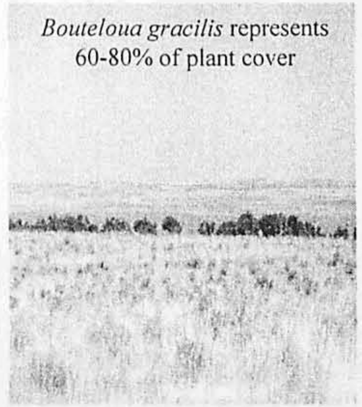
Vertical lines indicate El Niño years.

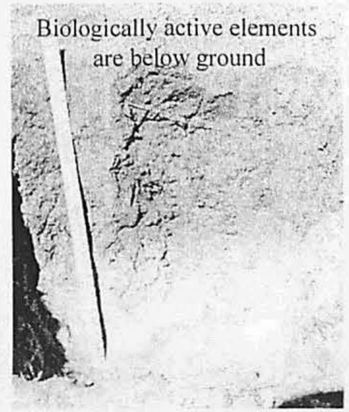
(Stapp, Antolin and Ball, 2004

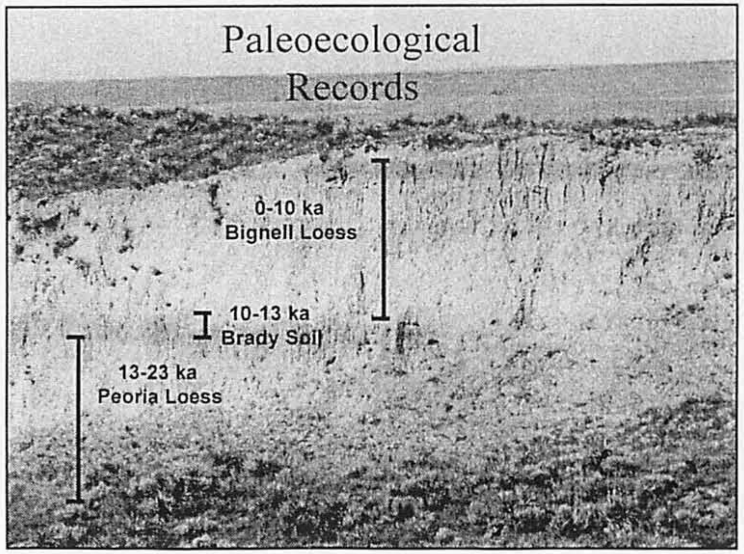


ANPP Increase with MAP

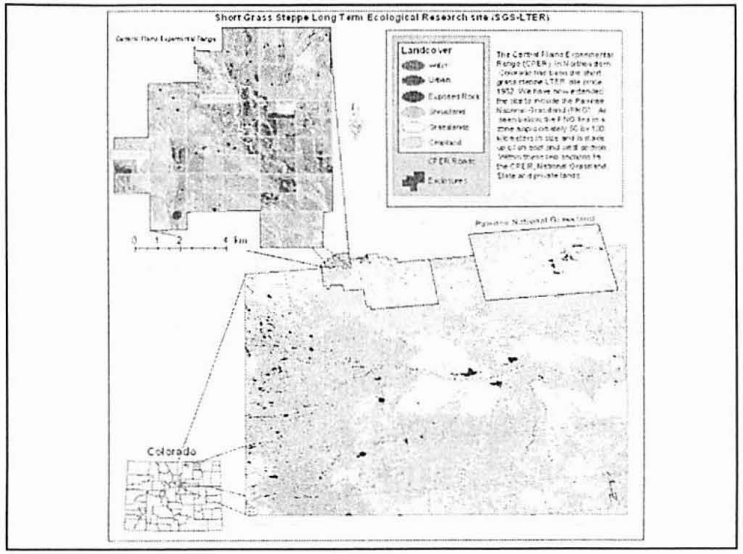
What is unique about the shortgrass steppe ?

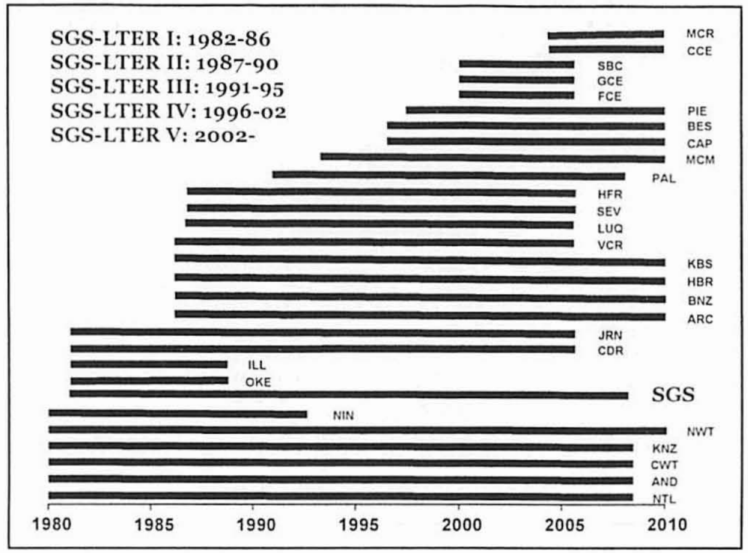






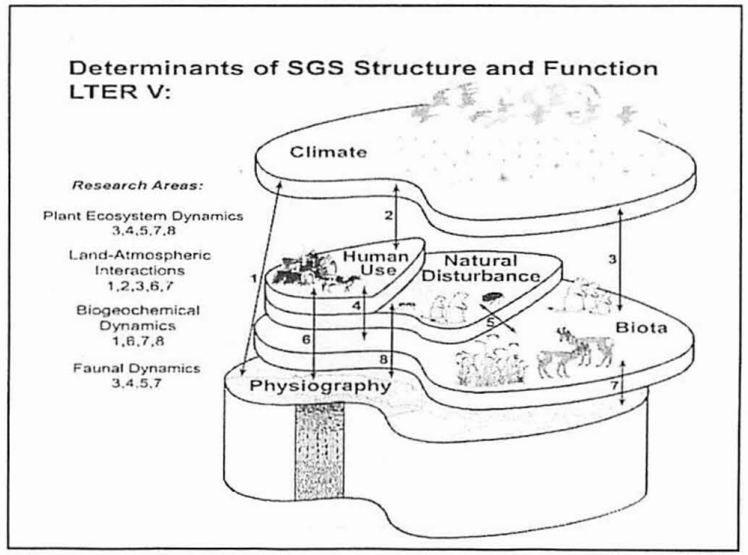
"The nature of the vegetation and the distribution of resources belowground promotes resistance of this system to disturbance and is unmatched elsewhere".





SGS-LTER conceptual framework:

- **LTER I (1982-86)**: Landscape structure and catena concept
- **LTER II (1987-90)**: Origin and persistence of spatial patterns.
- **LTER III (1990-96)**: Nested hierarchy of spatial/ temporal patterns & scales
- **LTER IV (1997-02)**: Determinants of ecosystem structure & function



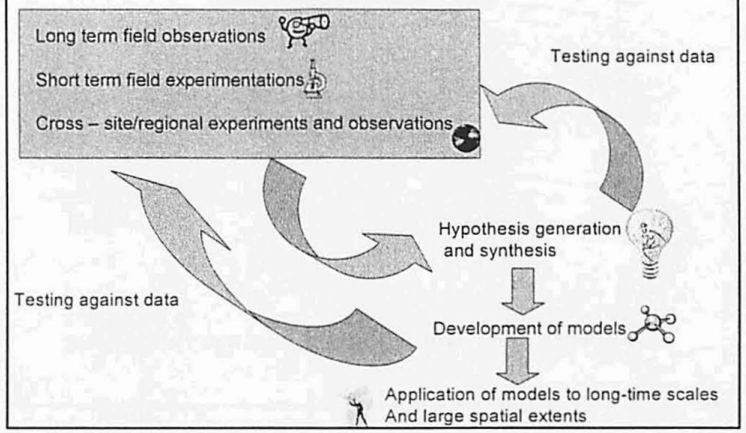
LTER V

What factors regulate the ecological structure and function of the SGS over space and time ?

How do the factors that regulate the ecological structure and function and the coupling of biotic and abiotic components vary spatially and temporally within the SGS?

What are the biotic and abiotic <u>thresholds</u> that determine the vulnerability of the SGS to changes in the factors influencing ecological structure and function?

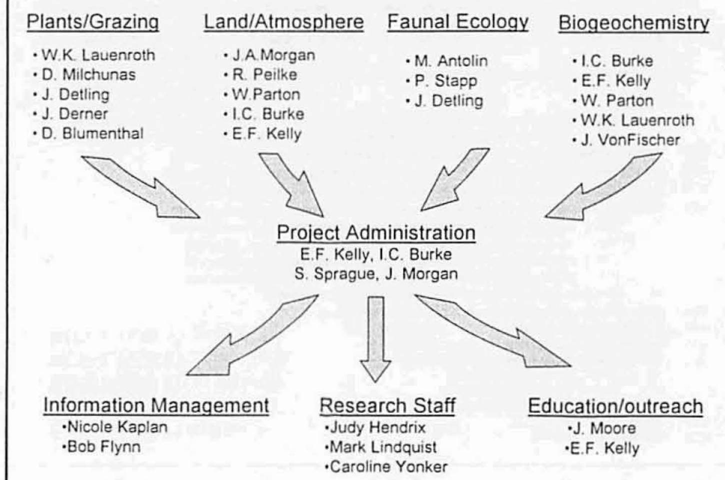
How we do our science:



SGS-LTER Leadership:

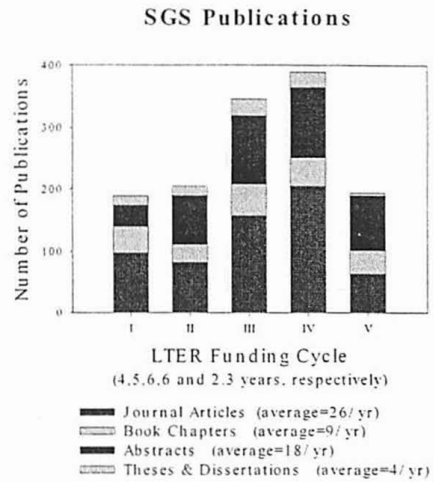
- LTER I : Lauenroth/Woodmansee
- LTER II: Lauenroth
- LTER II/III: Lauenroth/Burke
- LTER III: Burke/Lauenroth
- LTER IV: Burke/Lauenroth/Kelly
- LTER V: Kelly/Burke/Antolin

SGS-LTER Project Structure:

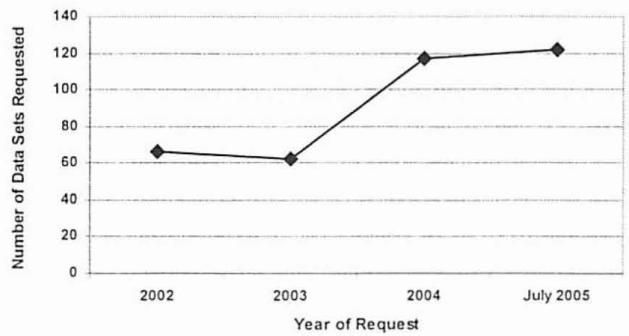


Key aspects of SGS-LTER program management:

- Distributed leadership (day-to-day)
- Working groups (L/A, BGC, P/G, FE, IM, E/O)
- Workshop every other year
- Brown Bag Seminars and PI meetings (2x month)
- E-mail, listserv and web page communications with all collaborators
- Subcontracts to support non-CSU collaborators
- Administrative and Scientific support for Grant Writing/Submission



Data: Usage Summary by Year from 2002 – April 2005



LTER K-12 Initiatives

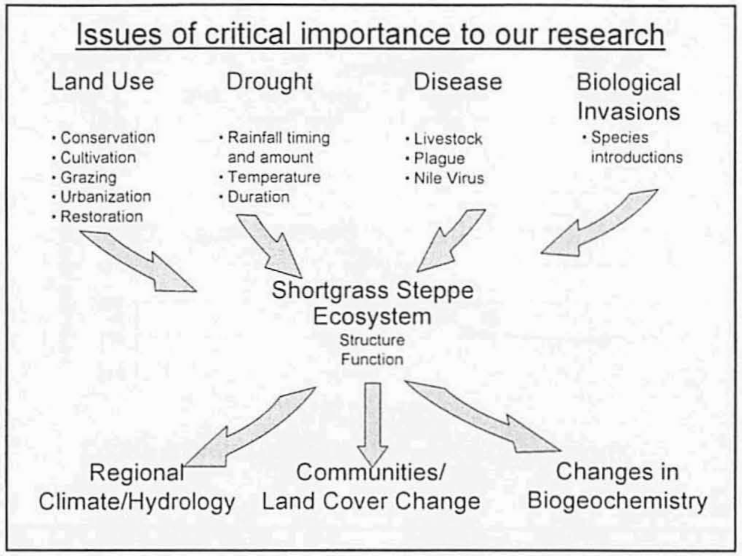
DOE UBMS	1996-2008	$ 3.2M
FSI	1958-pres	$100K yr^{-1}
NSF RAMHSS	Supplements	$10K yr^{-1}
NSF Schoolyard	Supplements	$15K yr^{-1}
NSF EdEn	2004-2006	$ 68K

LTER Undergraduate Initiatives

NSF REU	Supplements	$10K
NSF UBM	March 2005	$ 1.2M
NSF UMEB	October 2005	$ 500K

LTER Graduate Initiatives

NSF GK-12	2001-2010	$ 2.9M
NSF CLT-W	2001-2006	$ 10M
CDE MSP	2003-2006	$ 750K


Issues of critical importance to our research
Land Use
• Conservation
• Cultivation
• Grazing
• Urbanization
• Restoration
Drought
• Rainfall timing and amount
• Temperature
• Duration
Disease
• Livestock
• Plague
• Nile Virus
Biological Invasions
• Species introductions
Shortgrass Steppe Ecosystem
Structure
Function
Regional Climate/Hydrology
Communities/ Land Cover Change
Changes in Biogeochemistry

Section 3:

Field Tour Information

Stop 1: Atmosphere-Ecosystem Interactions
(Open Top Chamber Site, ARS Headquarters, CPER)

- **Overview, Goals and Rationale: Jack Morgan**
- **Ecosystem Water Dynamics: Bill Lauenroth**
- **Determining fluxes of Energy, Water and CO_2: Jack Morgan**
- **Land-Atmosphere Simulations: Adriana Beltran-Pzekurat**
- **Global Change Modeling: Bill Parton**
- **Paleoenvironment/Climate Studies: Alan Busacca**

Land Atmosphere Connections

Goal, Rationale & Integration

Long-term monitoring
weather, water, npp
Lauenroth

Long Time Scales
paleoclimate
Kelly, Busacca

Goal: determine how land use & management affect & interact with fluxes of energy, water and trace gases

Biogeochemistry Modeling
CENTURY, DAYCENT
Parton

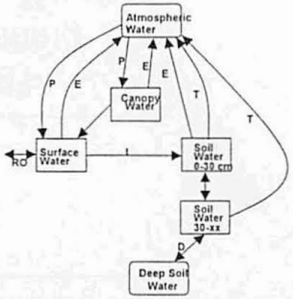
Biosphere/Atmosphere Modeling
GEMRAMS
Pielke, Beltran-Przekurat

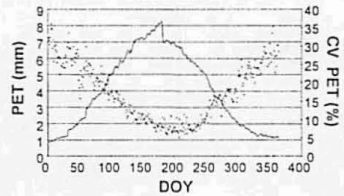
Rationale: combined modeling, experimentation & observation are required to integrate & explain past events as well as to assess sensitivity of the system to future events

Manipulations
warming, CO_2, wetting, N
Burke, Hanan, Morgan, Milchunas

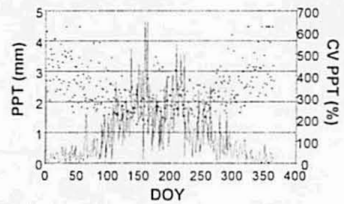
Short-term monitoring
gas fluxes/nutrient cycling
Burke, Hanan, Morgan, Mosier

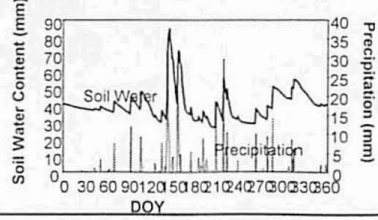
Ecosystem Water Dynamics



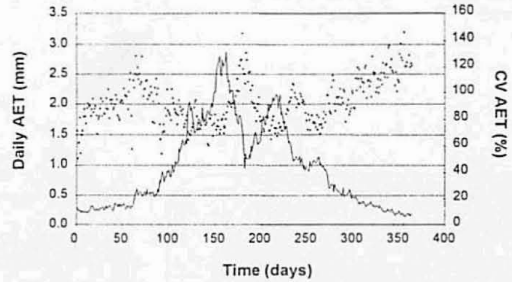


- PET - Potential Evapotransporation is large and relatively invariant (max CV=35%)
- Precipitation is low and variable (min CV=100-200%)
- These two characteristics lead to soil water dynamics very tightly coupled to precipitation.

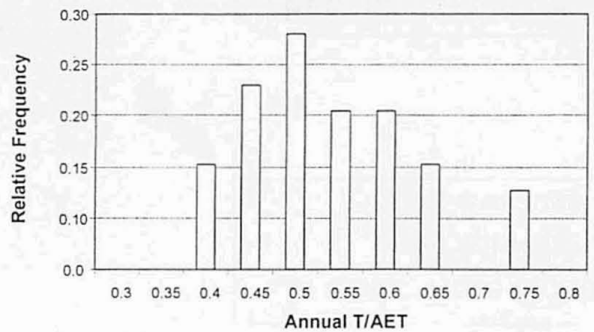




Daily AET is closely related to precipitation and quite variable (min CV=40-50%).



On average transpiration accounts for slightly more than 50% of total water loss annually.



Determining Fluxes of Energy, Water and CO_2

Morgan[*1] JA, JG Alfieri[2], PD Blanken[2], DP Smith[1], WJ Parton[3], IC Burke[3], JD Derner[4], and WK Lauenroth[3]. USDA-ARS Fort Collins, CO[1]; University of Colorado, Boulder, CO[2]; Colorado State University, Fort Collins, CO[3]; USDA-ARS Cheyenne, WY[4].
jack.morgan@ars.usda.gov

- Grasslands constitute approximately 24% of Earth's terrestrial surface (Franzluebber et al., 2002), and although rates of C fluxes are not the highest, their large land mass argues towards an important role in Earth's C cycle.

- Two popular micrometeorology methods use tower-installed instrumentation to either directly (eddy covariance, or EC) or indirectly (Bowen ratio energy balance, or BREB) determine fluxes of CO_2, water or energy.

- BREB flux systems were installed in late 1990's at the SGS site at the CPER. Analysis of CO_2 flux data in an ungrazed pasture revealed high C accumulation rates (Figure to left). Further analysis, comparing the annual NEE C uptake with NPP estimated from monthly aboveground biomass harvests (Table 1) showed NEE exceeding NPP in two wet years (1998 & 1999), and positive NEE values of 478 g C over the 4 years.

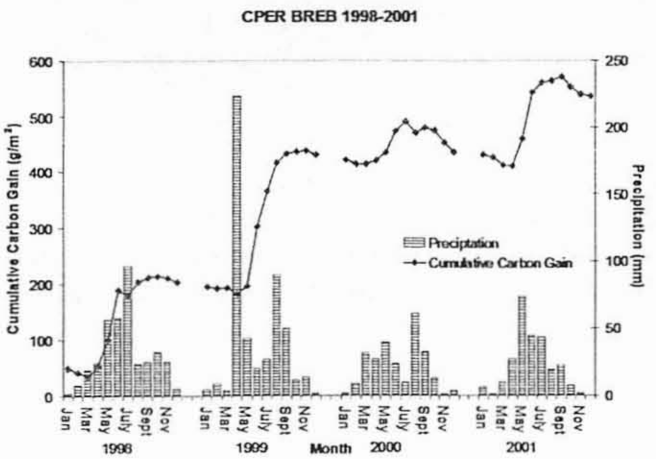
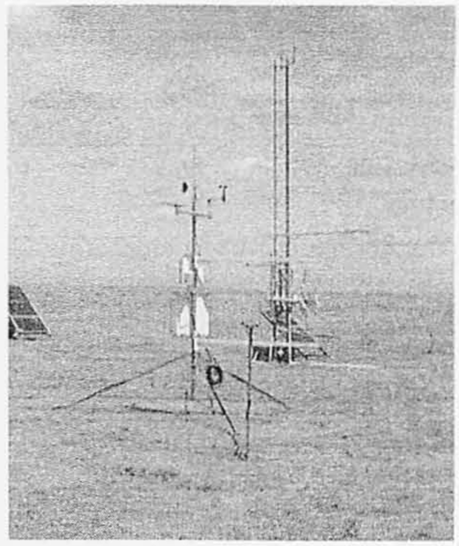


Table 1. Ecosystem productivity (Carbon uptake) at the CPER Bowen Ratio site.

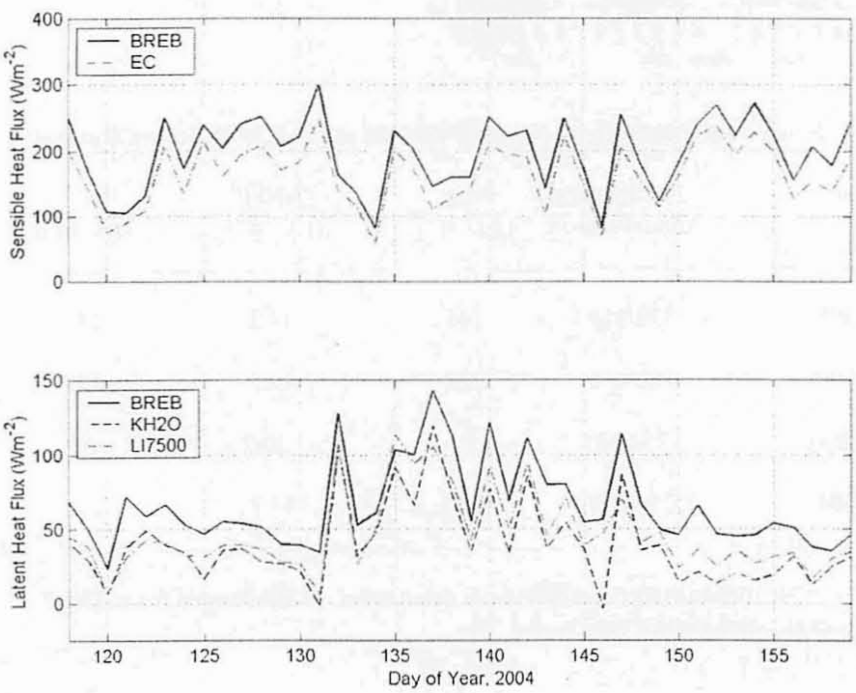
Year	Precipitation Annual/season	NEE* ($g\ C\ m^{-2}$)	ANPP! ($g\ C\ m^{-2}$)	NPP+ ($g\ C\ m^{-2}$)
1998	379/319	145	44.2	132
1999	500/466	226	49.5	148
2000	254/181	5	20.7	62
2001	259/239	102	43.7	131

*NEE = NEE from BREB; !ANPP from destructive; +NPP derived from ANPP
Morgan et al., unpublished data

Since rates of C gain from our BREB flux tower seemed higher than expected for a semi-arid grassland in which NPP averaged 97 g m^{-2} (Lauenroth and Sala, 1992), and ranged from 77 to 379 g m^{-2} over a 52-year period, we decided a more careful examination of the BREB fluxes was in order.



- An EC tower was installed in 2004 next to a BREB in a moderately grazed pasture at the Central Plains Experimental Range.
- The two methods have different theoretical and practical considerations that can affect their estimates of the components of the surface energy budget (Alfieri et al., in review).
- Measurements confirmed this possibility; in that sensible heat flux was 28% greater, latent heat 25% greater, and CO_2 fluxes 95% greater when measured with BREB compared to EC (Figure below shows seasonal comparisons of latent and sensible heat for the two methods). The discrepancy between BREB and EC flux measures was due, in large part, to different requirements in energy balance closure between the two methods, and the similarity theory in the BREB method which assumes the eddy diffusivities for sensible and latent heat, and CO_2 are all the same) (Alfieri et al., in review). **These results suggest that while trends in fluxes of energy and gases may be the same between BREB and EC methods, absolute values can vary substantially.**



Literature Cited

Alfieri, JG, PD Blanken, JA Morgan, and DP Smith. A Comparison of the Bowen Ratio Energy Balance and Eddy Covariance Measurement Techniques for Determining Surface Energy and Carbon Dioxide Fluxes over a Shortgrass Steppe Grassland. Agric. And Forest Meteor. (in review)

Franzluebber, F, AJ Franzluebber, and MD Jawson. 2002. Environmental controls on soil and whole-ecosystem respiration from a tallgrass prairie. *Soil Science Society of America Journal*, **66**, 254-262.

Lauenroth, WK, and OE Sala. 1992. Long term forage production of North American shortgrass steppe. Ecological Applications 2:397-403.

Land-atmosphere interactions in semiarid areas: Jornada Experimental Range and Shortgrass Steppe LTER cases.

Roger A. Pielke, Sr., and Adriana B. Beltrán-Przekurat, Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523

Land use-land cover changes like desertification, cultivation, irrigation are landscape modifications that often lead to changes in near surface latent and sensible heat fluxes that may affect weather and climate with feedbacks to the vegetation (Pielke, 2001). Land use practices have affected regional climate in the Shortgrass Steppe (SGS) region through their influence on surface energy partitioning and balance (Chase et al. 1999). Fully coupled atmospheric-biospheric models constitute a powerful tool for addressing the highly complex interactions between plants, soils and atmosphere. With these models, plants and atmosphere are nonlinearly interacting with each other.

An example of landscape change, associated with structural changes of the land surface, involves woody plant invasion into perennial grasslands has occurred in arid and semiarid regions globally over the past several centuries. In the Chihuahuan Desert of North America, shrub cover has increased dramatically in areas that were predominantly grasslands in the mid-1800s (Buffington and Herbel, 1965; Gibbens et al. 2005). Since the early 1900s, C_3 shrubs, mesquite (*Prosopis glandulosa*) and creosotebush (*Larrea tridentata*), have increased in cover at expense of C_4 grasses, mainly black grama (*Bouteloua eriopoda*) (Figure 1).

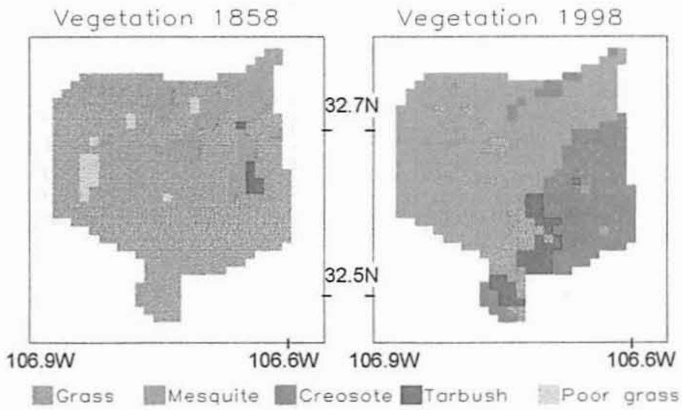


Figure 1. Vegetation distribution in 1858 and 1998 in the GEMRAMS Jornada Experimental Range model domain. Each grid cell is 1x1 km.

As part of a cross-site LTER exercise, model simulations were conducted for the Jornada Experimental Range LTER located in the northern Chihuahuan Desert. Our goal was to evaluate the effects on weather and climate of a broad scale change in vegetation from grasslands in the mid-1800s to shrublands in the late 1900's on landscape scale patterns with potential feedbacks to the vegetation. Detailed landcover maps for 1858 and 1998 as well as soils maps and observed data on vegetation and surface parameters, like albedo, were readily available and they were used to run a fully coupled atmospheric-biospheric model (GEMRAMS) for two times during the growing season, mid-spring and late-summer. Overall, the shift from a grass-dominated vegetation cover in 1858 to shrub-dominated cover in 1998 led to changes in sensible and latent heat fluxes (Figure 2).

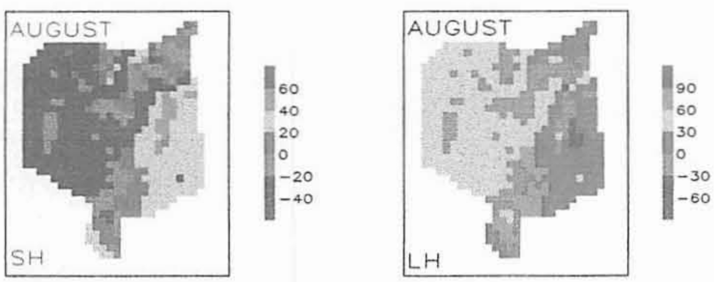


Figure 2. Differences in sensible (SH) and latent (LH) heat fluxes between 1998 and 1858 at 1300LST for August runs. Values are in W m^{-2}.

The changes in vegetation cover from 1858 to 1998 resulted in spatially heterogeneous changes in near-surface sensible and latent heat fluxes and temperature: conversion from grass to mesquite cools the near surface atmosphere and from grass to creosotebush warms it (Figure 3). Albedo was the dominant parameter controlling the energy budget.

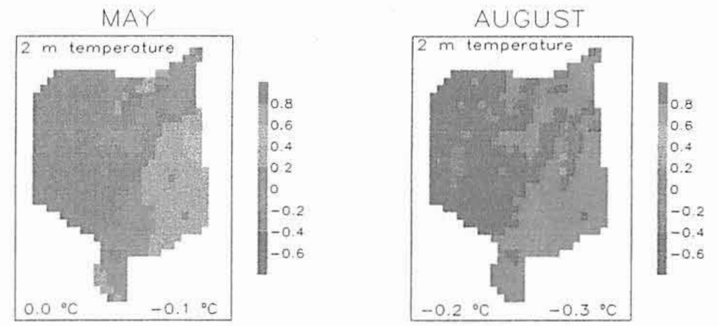


Figure 3. Differences between 1858 and 1998 at 1300LST for 2 m temperature (°C). The area-averaged differences for the daytime average (left) and at 1300LST (right) are shown in each figure.

The shift from grasslands to shrublands observed in this area has led to complex interactions between biophysical and physiological characteristics of the land and surface fluxes. These results clearly demonstrate that vegetation itself is a weather and climate variable as it significantly influences temperature and humidity, which then feedbacks to and affects the vegetation. This view supports the broader view of climate that is reported in the National Academy of Sciences report (NRC, 2005).

The same modeling approach carried out in Jornada will be used in the SGS LTER site, which includes a detailed vegetation and soils maps and parameters associated to each vegetation type, like albedo, and soil characteristics (Figure 4). Some of that data will be measuring in the fields while other will be put together from different sources and earlier measurements of CO_2 and water and energy fluxes carried out at the SGS.

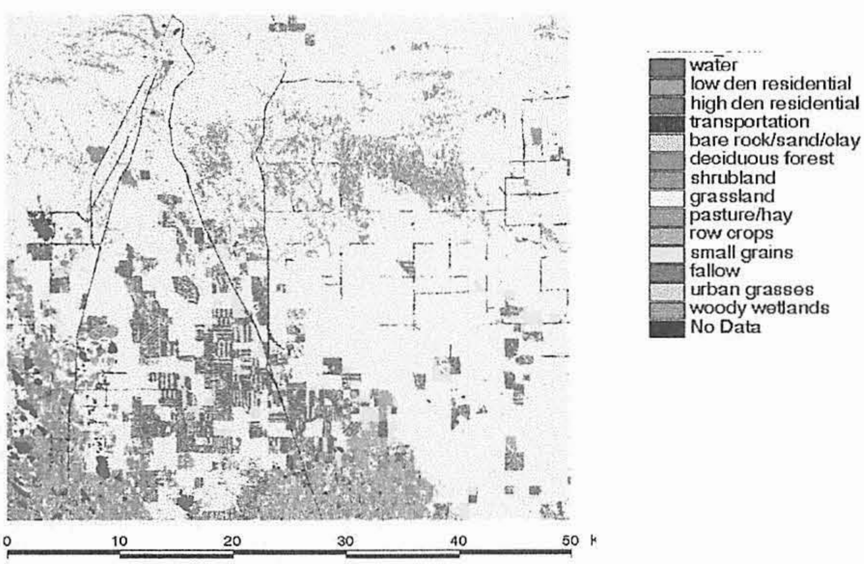


Figure 4. Vegetation types for a 50x50km grid centered at SGS, from a 30x30 m grid space National Land Cover Data (NLCD) (courtesy of Chris Hiemstra).

Seasonal model simulations will be performed to address the role of grazing practices, changes in C_3/C_4 dominance, increase of cultivated areas and irrigation, invasive weeds, and CO_2 enrichment on near surface weather and climate. Measurements of CO_2 and water and energy fluxes carried out at the SGS will be used to validate the performance of the coupled modeling system GEMRAMS.

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Land Atmosphere: Global Change Modeling Report

WJ Parton, NREL, Colorado State University, Fort Collins, CO.

The Daycent version of the Century model was used to evaluate the impact of altered environmental conditions on Great Plains grasslands. Our work focused on the impact of changing precipitation patterns, increasing air temperature, enhanced N deposition and increases in atmospheric CO_2 levels. We used the extensive data base from the Shortgrass Steppe LTER site to test and validate the Daycent Model. The data sets include information about elevated atmospheric CO_2 on plant production, soil warming experiments, N fertilizer experiments, irrigation experiments, and UV light manipulation experiments. Data from these experiments have evaluated the long term ecosystem impacts of changing atmospheric CO_2 levels, water availability, N additions, and soil warming.

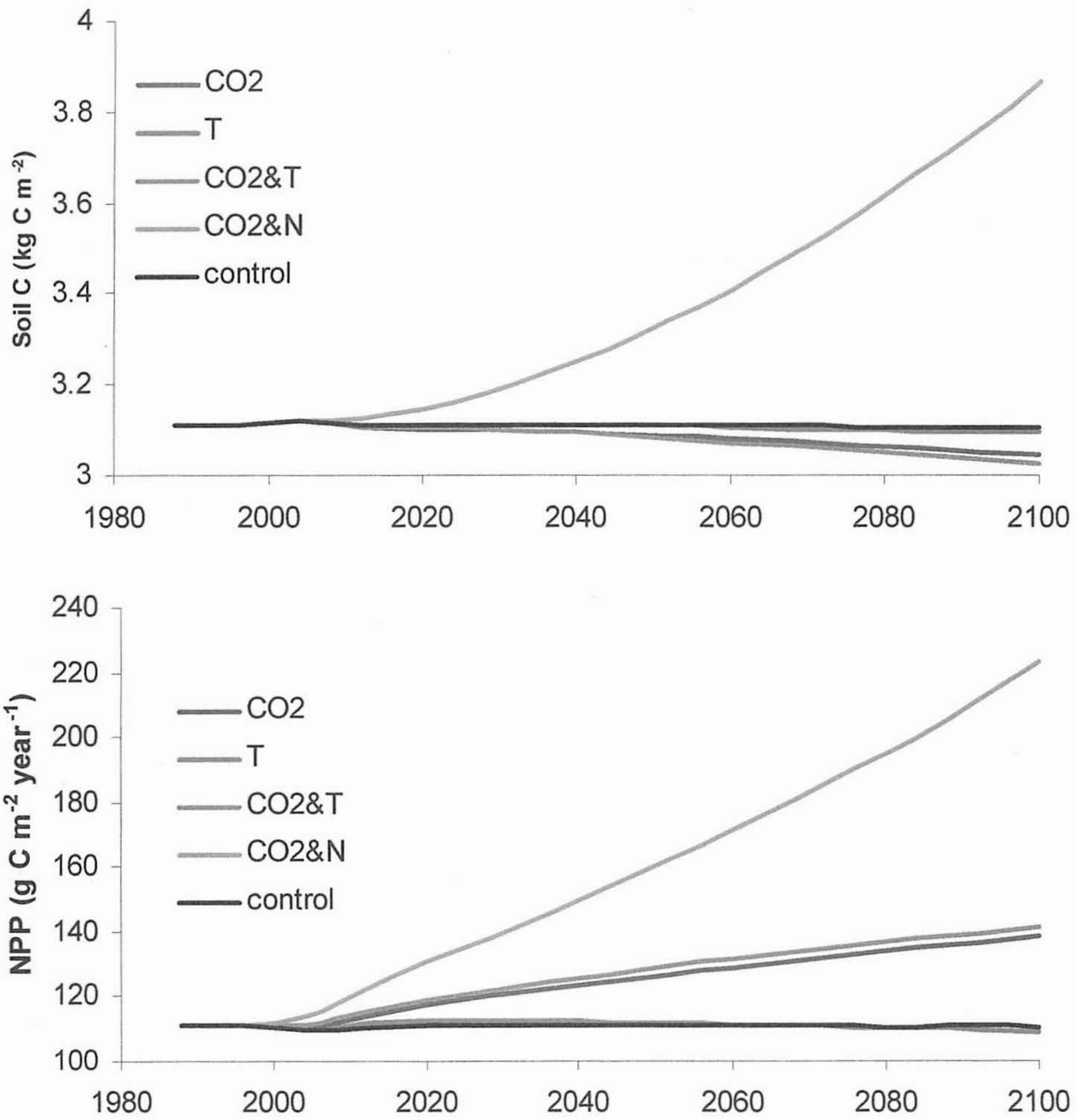
The Daycent model was used to simulate the impact of gradual increases in atmospheric CO_2 (2x during the next 100 years), air temperature (3 degrees C°) and N deposition for SGS and Konza LTER sites (Pepper et al., 2005). The results showed that increasing CO_2 and N deposition caused plant production, and nitrogen mineralization to increase at both sites. Soil carbon levels increased at both sites with increasing N deposition, however soil carbon level decreased at the SGS Shortgrass steppe site and increased at the Konza site with increasing CO_2 levels. Carbon inputs to the soil increased at both sites, however the wetter soils associated with higher CO_2 levels caused decomposition rates to increase more rapidly at the SGS site. Warming caused soil carbon levels to decrease, N mineralization rates to increase, and plant production to increase slightly at both sites. The impact of combining the CO_2, N deposition and warming treatments was generally additive.

Another important modeling effort at the SGS site is an evaluation of the impact of species shift and changes in the nitrogen content of aboveground vegetation. Results from our five year field CO_2 enhancement experiments showed that the C to N ratio increased with increasing CO_2 levels. We are currently working on a paper that compares the Daycent model results with our five year field experimental CO_2 data sets and extrapolates the long term impact of potential species shift and increasing aboveground plant C:N ratios on ecosystem dynamics and cattle weight gains.

We are working on a regional modeling effort to evaluate the impact of increasing atmospheric CO_2 levels on grasslands in the Southern Great Plains. The Daycent model has been tested using the observed data sets from field enhanced CO_2 experiments at SGS, Konza, and the Texas Tunnel CO_2 experiments and is in the process of being used to extrapolate the regional impact of elevated CO_2 levels on grasslands in the Southern Great Plains. One of the surprising results from this effort is that elevated CO_2 levels are increasing the N uptake by plants due to wetter soils with little evidence of long term nitrogen down regulation of plant production under elevated CO_2 levels. A series of papers are being written to describe the results from this modeling effort.

Another important regional modeling effort is the use of the Daycent model to simulate the impact of historical agricultural land use change on ecosystem dynamics in Northeastern Colorado (Baron et al, 2005). This study focused on the impact of agricultural land use practices on nitrogen cycling and N trace gas fluxes for the whole South Platt River Basin. NOx emission from agricultural practices is significant but most of the enhanced regional N deposition comes from industrial sources and automobiles.

Shortgrass Steppe, CO



Paleoenvironmental and Paleoclimatic Investigations

A.J. Busacca[1], M.Blinkinov[2], C.M. Yonker[3], M. Pagani[4] and E.F. Kelly[3]

Introduction: Understanding the terrestrial responses of plant ecosystems, sedimentologic systems, and pedologic (soil development) systems to global climate change is fundamental to predicting system responses to future climate change. It is increasingly recognized that we must understand *the feedbacks and interactions* between plant, sediment, and soil systems (McDonald and Busacca, 1990; Sweeney et al. in press). Fortunately, loess-paleosol sequences such as on the Great Plains, offer unparalleled opportunities to apply innovative approaches to reconstruct detailed terrestrial records (Busacca et al. 2003), although suitable loess exposures are uncommon. We are intensively studying the composition of loess sediments, ancient soils, isotopic signatures and trace fossils of plant communities to determine climatic conditions and drivers of change that prevailed in the central Great Plains over the last 10,000 years. Our previous research suggests that significant variations in Holocene climate have arrested soil formation and caused soil burial at least twice (Kelly et al., 1998, Kelly et al., 1993, Kelly and Wohl, 1994), although more recent work suggests that the record is richer and more complex.

Background: Data from the CPER (Blecker et al., 1996; Kelly et al., 1998) indicate that early Holocene paleosols (those dating between 10,000 and 8,000 ybp) generally contain more organic C than contemporary, surface soils. In contrast, mid Holocene paleosols dated between 5,000 and 3,500 ybp all contain less organic C than contemporary, surface soils. It is difficult to relate organic C content alone to changes in productivity, as it is unlikely that all microbial decomposition was arrested upon burial of the soil. Our phytolith data indicate plant production was higher in both the early and mid Holocene than currently, as the buried soils contain more than a two-fold increase in phytoliths over their contemporary counterparts. In addition, the stable C isotope composition of SOC (soil organic carbon), pedogenic carbonates and phytoliths indicates a variable plant community composition through the Holocene. When comparisons are made between contemporary and buried soils, the $\delta^{13}C$ values of organic C during the early Holocene are consistently more negative (a decrease in ^{13}C values) than both the contemporary surface and mid Holocene soils, indicating that greater amounts of C_3 vegetation persisted during this period of time relative to the mid Holocene and contemporary soils. The dominance of C_3 vegetation during that time period suggests a cooler climate than present, although new evidence from the mid-grass steppe suggests alternatively that the early Holocene climate was warmer than present, based on $\delta^{13}C$ values of organic C (Feggestad et al. 2004). Clearly, multi-proxy indicators of changes in the plant-sediment-soil system are needed. At the same time, refined dating techniques such as OSL (optically stimulated luminescence) are providing much tighter chronologies in loess sequences.

Compelling questions: What was the composition of the vegetation in short-, mid-, and tallgrass steppe the early Holocene and at other times up to the present? Are there critical feedbacks between vegetative community and dust accumulation? What are the climatic conditions driving regional change in landscapes and vegetation?

Additional isotopic and paleobotanical data, derived from a broader geographic context, is required to confidently assess Holocene <u>climate change</u> and <u>plant community composition</u> in the shortgrass steppe. We are coupling stable isotopic analyses with radiometric dating and stratigraphic, paleobotanical and micromorphological, analyses to provide both chronologic control and a broader and more robust realm of inference.

Author Affiliations:
[1] Crop and Soil Sci., Wash. St. Univ, Pullman
[2] St. Cloud State, Minnesota
[3] Soil and Crop Sci., Colo State Univ., Fort Collins
[4] Nat. Res. Eco. Lab, Colo State Univ., Fort Collins

Objectives: *The overriding objective is the reconstruction of dust, vegetation, soil development and climatic records in the western Great Plains during the Holocene.* Specific objectives include: 1) Establish isotopic records of SOC, CaCO3 and phytoliths from paleosols in SGS, 2) Examine loess/paleosol stratigraphc sequences for episodic pulses of dust associated with large changes in vegetation cover. 3) Identify key faunal and botanical remnants to create a model of plant community composition throughout Holocene. 4) Compare results against modeled vegetation changes associated with climate alone.

The parent material of the eolian aggradational part of the SGS area is loess with large areas of stabilized sand dunes. Our reconnaissance and sampling in 2003-2004 focused on a wide array of loess localities throughout eastern Colorado, western Kansas, and Nebraska (fig 1.)

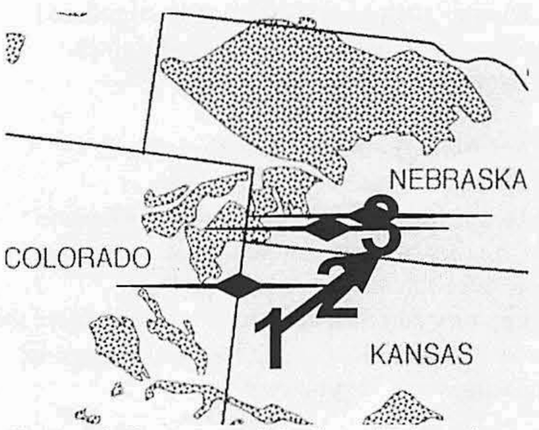


Figure 1. Location of the loess/paleosol transect sites from SW to NE: Beecher Island, CO, Old Wauneta, NB, Moran Canyon, NB. Arrow denotes direction of increasing MAP.

We laid out a transect of loess sites that trend SW-NE from eastern Colorado to SW Nebraska that are a similar distance from presumed loess sources and along a trend of increasing mean annual precipitation (MAP). We sampled a sequence of Holocene-age Bignell Loess and the subjacent Brady soil, formed in the top of Late-Pleistocene Peoria Loess, at the 'Old Wauneta' site (Jacobs and Mason, 2004) near Enders, NE.

We chose to start this work by describing and sampling the Old Wauneta site because, at 6 meters, it arguably is the thickest and most complete Holocene loess section on the western and central Great Plains (Jacobs and Mason, 2005), compared to thicknesses of generally less than 2 meters in eastern Colorado. Holocene Bignell loess at Old Wauneta contains as many as 5 buried A horizons (fig. 2). Particle size analysis and pedogenic carbonate analysis is complete for the site (fig. 2). Oversized thins sections from undisturbed samples of loess and soil horizons have been prepared for the entire sequence and analysis is underway. Samples for phytolith morphotype analysis to reconstruct plant communities is underway, as is analysis of $\delta^{13}C$ and $\delta^{18}O$ of phytoliths.

From studies of Peoria Loess, the Brady Soil, and Bignell Loess at many localities, it is known that the Brady Soil formed in the upper part of the Peoria Loess between about 13,500 and 10,000 cal yr B.P. and that it was buried by renewed loess deposition by about 10,000 cal yr B.P.

Key Findings to Date:

1. Sand content of the loess appears to be a proxy for loess deposition rate (greater sand content equaling greater loess deposition rate). Sand content of the loess was about 35-40% at the end of the latest-Pleistocene Peoria Loess deposition (fig. 2) and it increased gradually to about 55% sand by the mid Holocene. This likely indicates slow loess deposition rates at the end of Peoria Loess deposition leading to the formation of the Brady Soil on a landscape stabilized by vegetation, followed by gradual burial of the Brady Soil as loess deposition rates increased in the early Holocene. Sandier loess and an absence of soil development mark the period from about 9 to 6 ka B.P. and may be the result of deep and persistent drought conditions. Fluctuating deposition rates alternating with periods of weak soil development then dominated from the mid Holocene to the present (fig. 2).

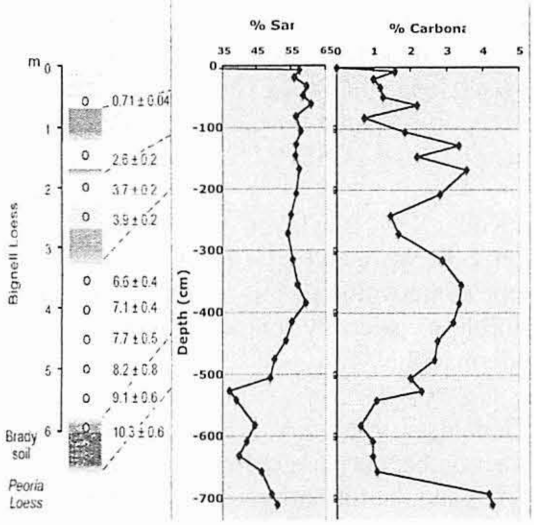


Figure 2. The sequence of paleosols at Old Wauneta, Nebraska, sampled in 2003-2004 for paleoclimatic studies. Ages in 1000s yr BP, courtesy of Joe Mason (Miao et al., 2005).

2. Rates of dust deposition at old Wauneta from 9.1 to 6.6 ka B.P. averaged 0.07cm/yr and from 6.6 ka to the 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 of the rate at old Wauneta. And full glacial Peoria Loess deposition rates at Bignell Hill, NE (Roberts et al., 2003) averaged more than 1 cm/yr from 18.9 to 16.6 ka B.P., or about *14 times* the early Holocene rate at Old Wauneta.

3. The degree of soil profile development and the features differ among the soils in the Old Wauneta section (fig. 2). This has important paleoclimatic and loess deposition rate implications Especially contrasting are the modern surface soil, a minor soil with an A-C profile (lacking a B horizon) and the Brady Soil, which has an A horizon that is darker than the surface soil and weak argillic and strong calcic B horizon features.

Although we think of climate shifts, mainly amount of rainfall, as the key driver of chemical weathering and biomass production, dust deposition rate is an underappreciated competing factor in soil development in loess-aggradational systems (McDonald and Busacca, 1990; Jacobs and Mason, 2005) because it dilutes weathering processes during periods of rapid aggradation and concentrates them during periods of slow aggradation. Thus to deconvolute the climate change signal from the deposition rate signal is the primary challenge in loess-paleosol systems.

4. Carbon isotopic signatures have been used to infer shifts between C_3 and C_4 vegetation types though time (e.g. Kelly et al., 1998; Feggestad et al., 2004). Our extraction of plant opal phytoliths from loess and paleosols at Old Wauneta, in process now, will provide a much more subtle level of reconstruction through morphotype counts (Blinnikov, et al., 2002) to quantify shifts in abundance of major plant genera and species at the site.

5. Beyond shifts in abundance of C_3 and C_4, a key question for the western Great Plains is the occurrence and distribution of woody plant species in the SGS grassland ecosystem and the controls on their distribution. We recognized in the Brady Soil at Old Wauneta widespread 1 cm diameter infilled burrows that result from the activity of Homoptera:Cicadidae, that is, cicadas. Based on our work in the Palouse Loess (O'Geen et al. 2001) that we have determined that cicadas live *only in the presence of a woody shrub component as host*. In the Palouse of the Pacific Northwest, the host is *Artemisia* and the burrows, when pervasive in paleosols there, indicate a full glacial tundra steppe environment (O'Geen et al. 2001).

The Brady Soil formed at the climatic transition of late Pleistocene to Holocene climate at a time of low loess deposition rate and transition from a cool C3 to warm C4 plant communities (Feggestad et al., 2004), yet the significance of cicada burrows and the ecological role of their shrub host is not known. Is shrub expansion possibly tied to suppression of lightning-strike fire regimes?

More significantly, Jacobs and Mason (2004) reported from their pioneering work at Old Wauneta and other sites that cicada burrows were unknown in paleosols in Holocene Bignell Loess. In our field studies, however, we observed cicada burrows in the lower part of the paleosols at 1 m and 3m depth, which we are investigating using thin section micromorphology and are using phytoliths to search for the identity of the woody plant host.

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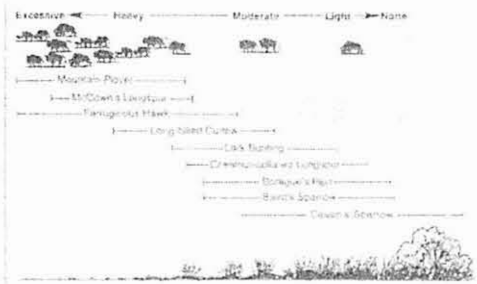
Section 3:

Field Tour Information

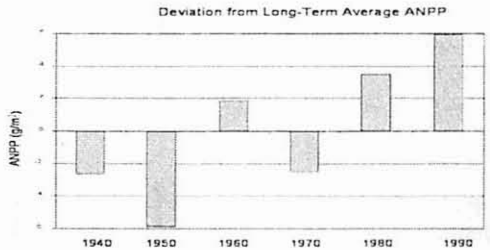
Stop 3: Mountain Plover/Grazing Sites (Section 1W, CPER)

- **Overview, Goals and Rationale: Bill Lauenroth**
- **Plant and Livestock Responses: Justin Derner**
- **Small Mammal and "Other Bird" Responses: Paul Stapp**
- **Nitrogen Dynamics: Indy Burke**
- **CO2 and Energy Balance Responses: Jack Morgan**

Livestock grazing strategies to manage shortgrass steppe to increase landscape scale heterogeneity.



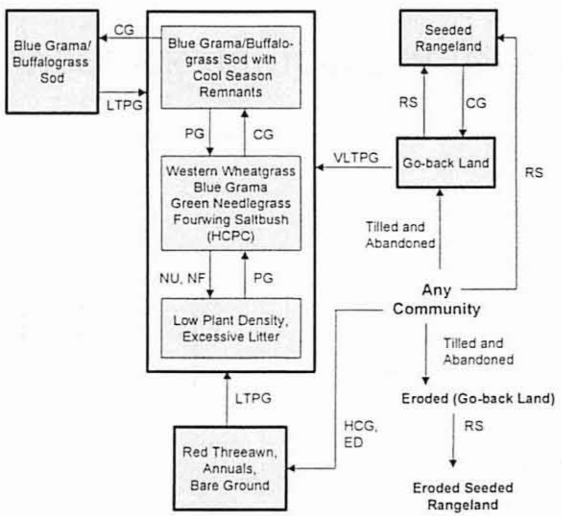
Responses of grassland birds to historical levels of grazing by large mammals (Knopf 1996).



Average decadal-scale departures of aboveground net primary production (ANPP) from the long-term average for the Central Plains Experimental Range.
The dates on the x-axis are the beginning year of the decade.

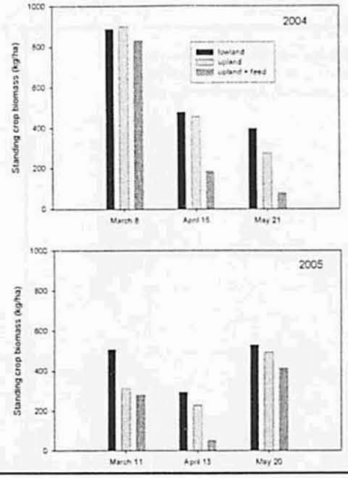
State-and-Transition Model for SGS

Shortgrass Steppe – MLRA 67B - Loamy



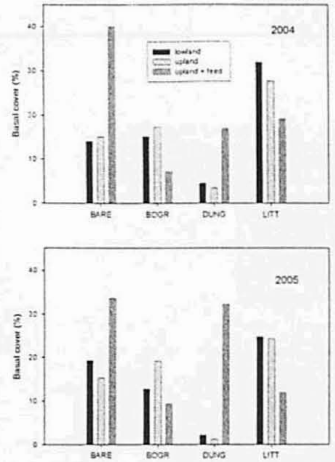
CG - continuous grazing w/o adequate recovery opportunity, **ED** - excessive defoliation, **HCG** - heavy continuous grazing, **HCPC** - Historic Climax Plant Community, **LTPG** - long term prescribed grazing (>40 yrs), **NF** - no fire, **NU** - non use, **PG** - prescribed grazing with adequate recovery period, **RS** - range seeding, **VLTPG** - very long term prescribed grazing (>80 yrs)

Standing crop



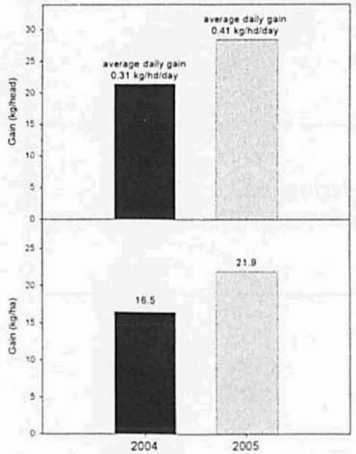
- Much different initial forage amounts on offer between years
- Marked reductions observed in feed sites across years by mid-April
- Increase in standing crop in mid-May 2005 attributable to favorable precipitation in late-April

Basal cover



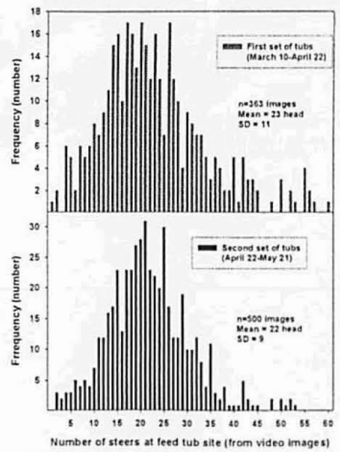
- Achieved targeted objectives of >30% bare ground, high amounts of dung and low levels of litter at feed sites only
- Consistent patterns observed in both years, despite contrasting precipitation patterns

Livestock gains



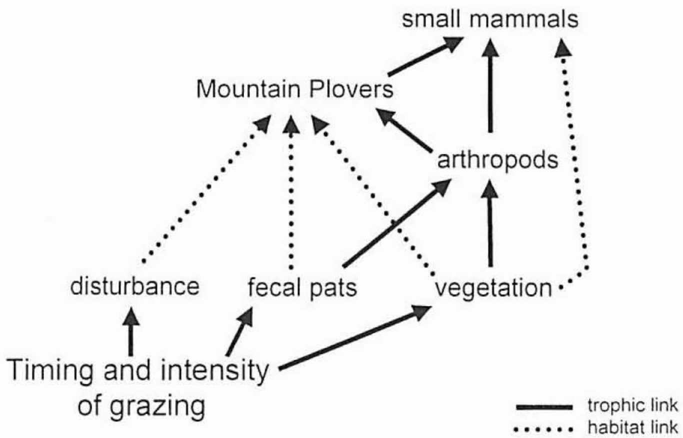
- Adequate gains given very high grazing pressure
  - comparable to expected gains under moderate stocking
- Approximately 5000 kg of supplement feed fed
  - $0.55/kg for feed
- Gain/ha about twice that observed for moderate stocking on saltbush-dominated pastures in early spring (8 kg/ha, Demer and Hart 2005)

Livestock numbers at feed site



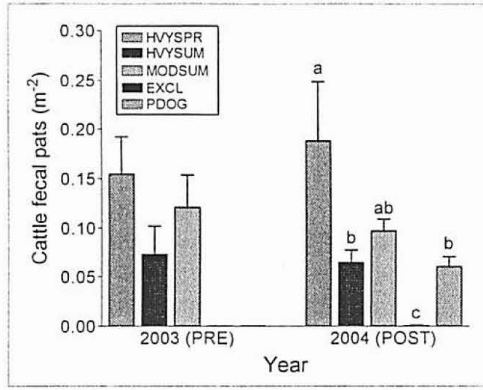
- On average, about 2 head per feed tub
- Approximately 20% of livestock herd at feed tub site
- Consistent use of feed tubs during 2004, less consistent in 2005 (data not shown)

Direct and indirect effects of grazing on Mountain Plovers



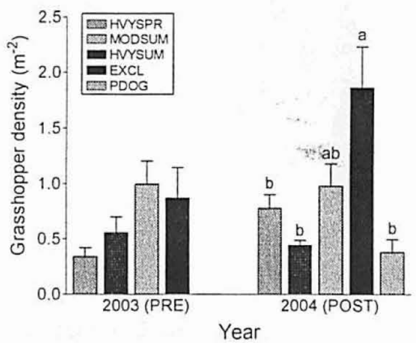
Cattle fecal pats

Density of cattle fecal pats increased by 22% in heavy-spring grazed plots, primarily near feeding areas.



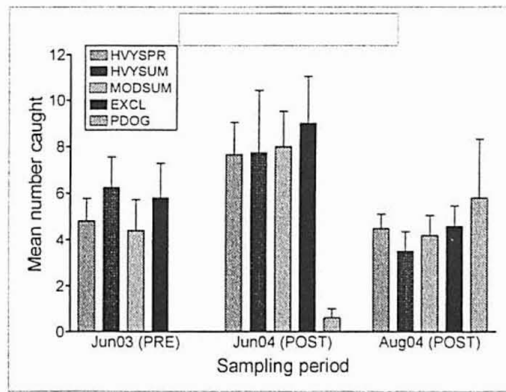
Grasshopper abundance

Grasshoppers, important prey for songbirds, were most abundant in exclosures, and increased significantly in exclosures and on heavy spring grazed plots.



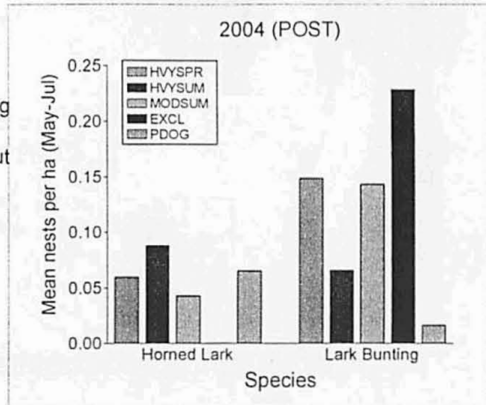
Thirteen-lined ground squirrels

Squirrels were equally abundant among grazing treatments. Small mammals may take longer to respond to grazing.



Grassland bird nests

Heavy summer grazing may benefit Horned Larks (and plovers) but remove nesting cover for Lark Buntings.

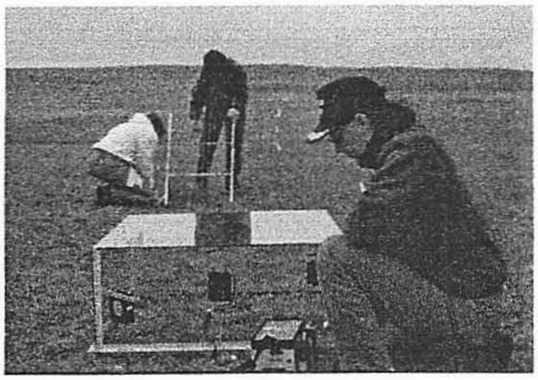


Livestock Grazing Management on the Shortgrass Steppe and CO_2 Exchange

Morgan*[1] JA, DR LeCain[1], DP Smith[1], JD Reeder[1], JD Derner[2], WK Lauenroth[3], WJ Parton[3] and IC Burke[3]. USDA-ARS Fort Collins, CO[1]; USDA-ARS Cheyenne, WY[2]; Colorado State University, Fort Collins, CO[3]. jack.morgan@ars.usda.gov

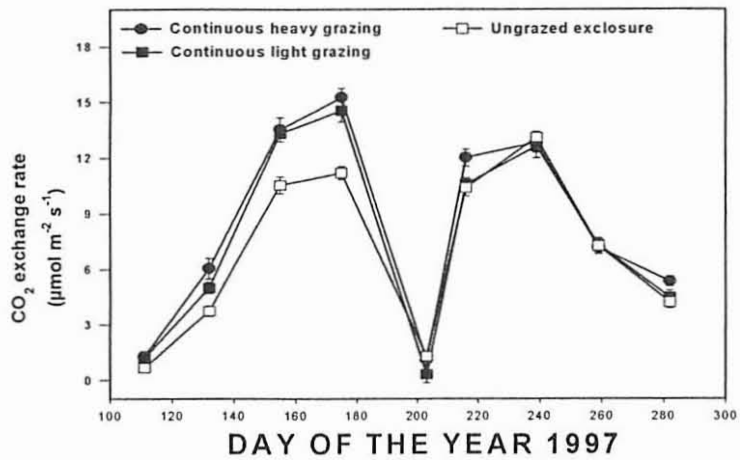
I. Background; soil C research and chamber experiments

- Long-term grazing experiments suggest that with recommended stocking rates, soil C either remains unchanged, or in some cases, can increase in the semi-arid grasslands (Derner et al., 1997; Reeder et al., 2004; Schuman et al., 1999).
- Little information is available on short-term impacts of grazing on C Cycling.



Chamber methods can be a useful and relatively inexpensive tool for determining CO_2 fluxes of soil/plant systems and their components, and they are best suited for small plots where micrometeorology techniques are not appropriate due to inadequate fetch. Our past use of such chambers (**Fig. 1, left**) at the Shortgrass Steppe site (LeCain et al., 2002) and also in near-by pastures of northern mixed prairie (LeCain et al., 2000) have shown that net ecosystem CO_2 exchange is significantly affected by stocking rate such that;

(i) **early spring photosynthesis is occasionally enhanced in grazed vs. non-grazed pastures (Fig. 2, below),**



(ii) **changes in plant community due to species shifts under moderately and heavily–grazed pastures (C_4 grasses increase under grazing) can alter the seasonal dynamics of CO_2 flux and its response to temperature, although**

(iii) **recommended grazing practices do not notably alter the seasonal C exchange when compared to ungrazed pastures (Table 1, below).**

		CO_2 exchange rate	
Treatment	1995	1996	1997
		(μmol m^{-2} s^{-1})	
Continuous heavy grazing	6.1	3.9	5.2
Continuous light grazing	7.2	4.0	4.8
Ungrazed exclosure	6.9	4.0	4.3
	ns	ns	ns

Table 1. CO_2 exchange rates under different grazing intensities.

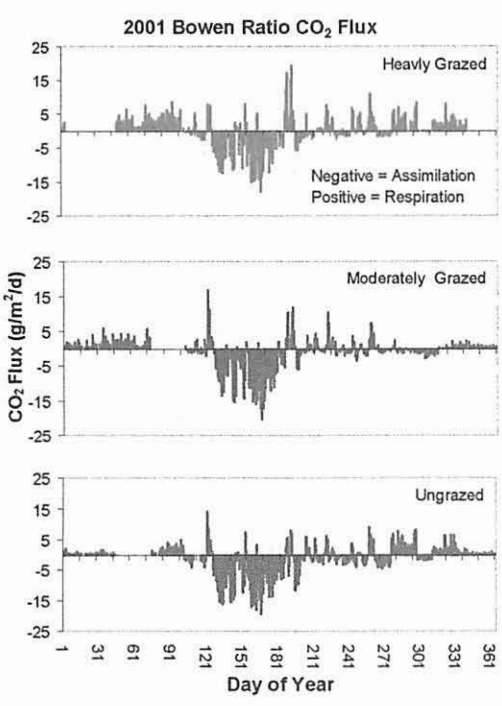
II. Micrometeorology CO_2 Flux Experiments

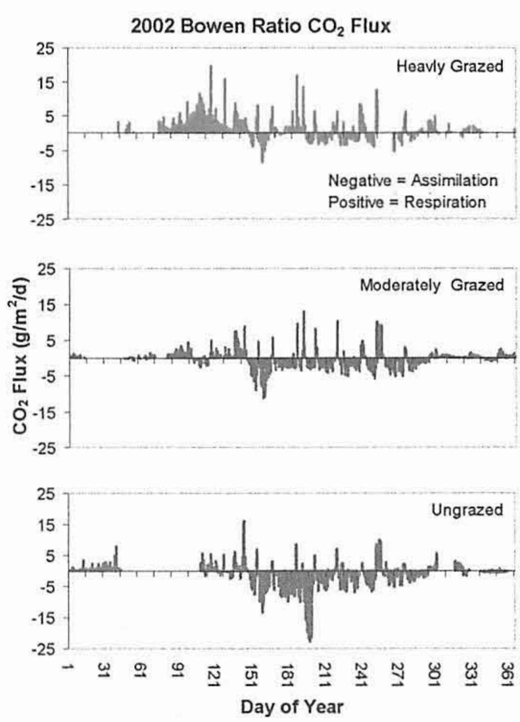
- Bowen Ratio Energy Balance (BREB) CO_2 flux systems installed in late 1990's to begin a CO_2 flux monitoring program to better understand seasonal dynamics.

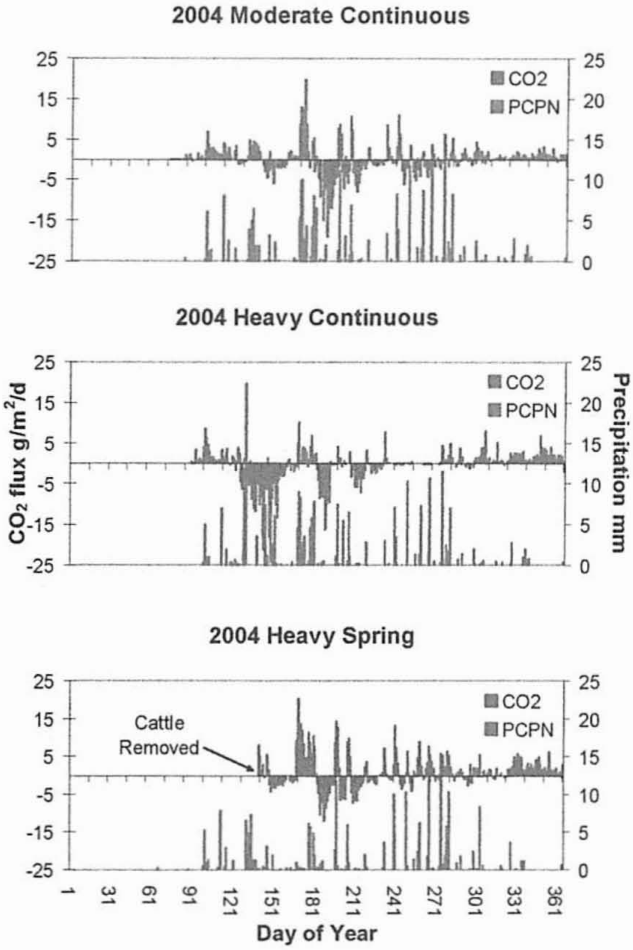
- **Experiment 1 (2001-2003).** Grazing treatments: Continuous heavily grazed (75% removal), Recommended moderately grazed (40% removal), Ungrazed

- **Year/Precipitation Responses: 2001** (precip. 80% of long-term average) no grazing treatment effect on NEE; **2002** (precip. 50% of long-term average) NEE lowest in the heavily grazed pasture, highest in the ungrazed pasture, intermediate in moderately grazed pasture.

- **CONCLUSION: While the SGS may be resilient in the long-term to grazing, in the short-term, livestock removal or reductions in stocking rate may be important for maintaining a positive C balance in the face of drought.**







- **Experiment 2 (2004-2006).** Grazing management for Plover Habitat
  - Mod. Continuous
  - Heavy Continuous
  - Heavy Spring
- **Results from year one of this experiment do not reveal any dominant treatment patterns in CO_2 fluxes, although precipitation seems to be an important driver.** Significant precipitation events are often followed by brief periods of CO_2 efflux, followed by enhanced CO_2 uptake.

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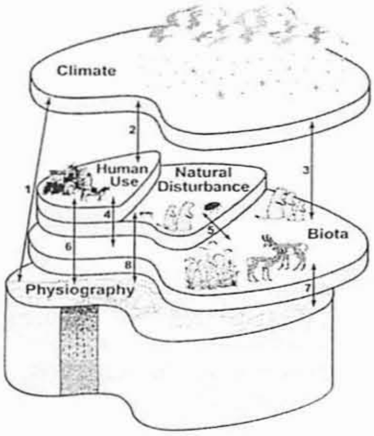
Section 3:

Field Tour Information

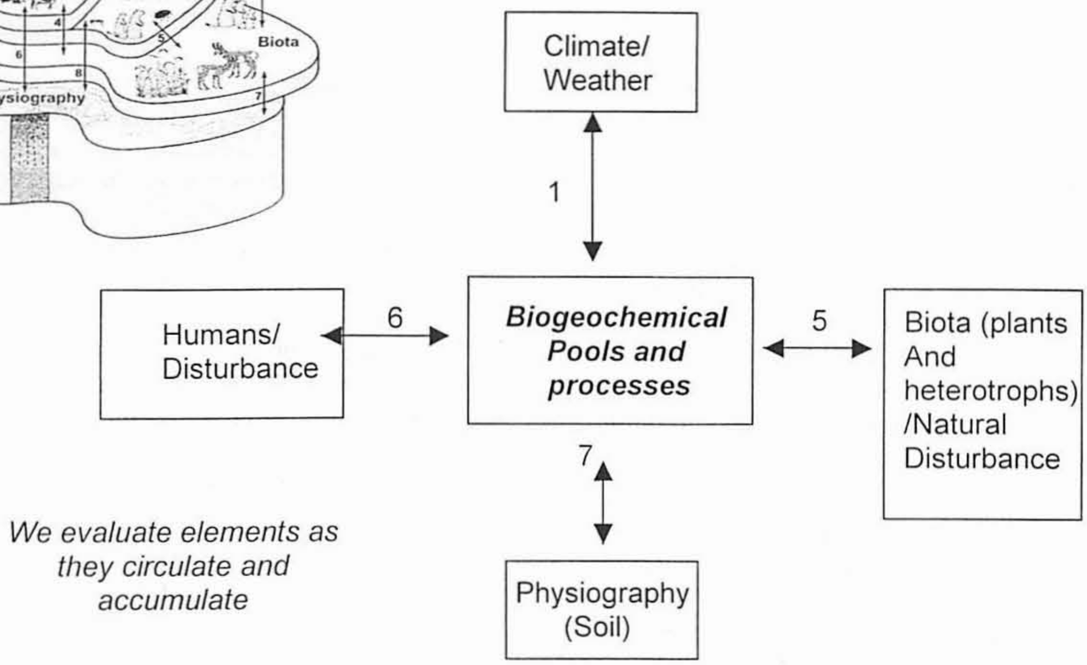
Stop 4: Long Term Biogeochemistry Investigations and Experiments (Humus Plots/Cross Site)

- **Overview, Goals and Rationale: Indy Burke**
- **Physiography and Biogeochemistry: Gene Kelly**
- **Si Biogeochemistry of Grasslands: Steve Blecker**
- **Nutrient and Water Availability and Ecosystem Structure: Daniel Milchunas**
- **Synthesis, Simulation and Cross Site Analysis: Bill Parton**
- **Long Term Experimentation: Indy Burke**

Biogeochemistry Field Tour, July 14, 2005



Conceptual Framework



Highlight 1: Interactions between physiography and biogeochemistry

a. Physiographic Influences on Nutrient and Ecohydrological Conditions in the Shortgrass Steppe

C.M. Yonker, I.C. Burke, W.H. Parton, W.K. Lauenroth and E.F. Kelly[1]

Introduction:
The physiographic controls on soil variability in the SGS region are geologic substrate, local topography and landscape age. More specifically, the sand, silt and clay distribution within soil profiles, steepness and elevation of hillslope gradients and the degree of soil development affect nutrient and soil water dynamics, often at relatively short temporal and spatial scales.

Background:
We conducted new field experiments to separate the effects of soil texture and topography on net primary productivity and biogeochemical dynamics. Our key questions are: 1) How do texture, topography, and landform age influence water dynamics and biogeochemical cycles, and 2) how important are lateral vs. vertical flows of water in the shortgrass steppe ecosystem?

Soil-Landscape Systems of the SGS:
We established a series of three toposequences on texturally different geologic substrates (sandy, silty and clayey) where biogeochemical variations in soils as a function of landscape position (Fig. 1a) and landscape age (Fig. 1b) are evaluated. By incorporating soil texture, topography and age into our project design, we cover the range and variability in physiographic controls that influence SGS ecosystem structure and function.

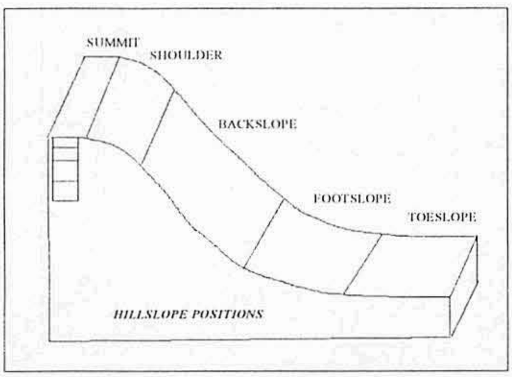


Fig 1a. Landscape positions within a hillslope.

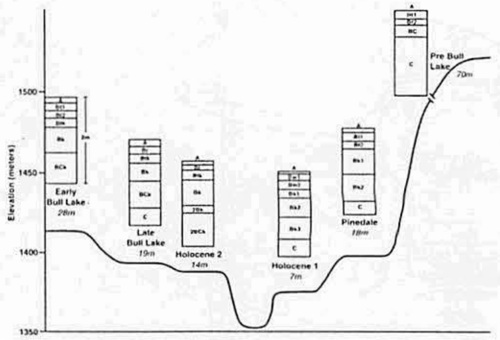


Fig 1b. South Platte terrace sequence, east PNG.

Compelling Questions:
1) What is the long-term distribution of water across landscape units?
2) What is the range in key soil chemical properties that reflect the biogeochemistry and water status of the unsaturated zone?
3) What are the ecohydrological, and pedological controls on water distribution within landscapes?
4) How does the redistribution of water along landscapes influence the ANPP, species composition and vulnerability of the system?

Key Results to Date:
1) Variability in SOC within hillslopes is as large as regional variability.
2) Differences in soil properties resulting from weathering are highly variable among landscapes of different age.
3) Soil hydrological variations are driven by local textural and topographic variations.

Key Papers:

Huffman, S.A., Cole, C.V., Yonker, C.M. and E.F. Kelly (In Prep) The Degree of Soil Development as Indicated by a Phosphorus Index.
Yonker, C.M., Rossi, R., and E.F. Kelly (In Prep). Pedologic controls on local versus regional variability in soil carbon storage in the central Great Plains grasslands.

(a)

(b)

(c)

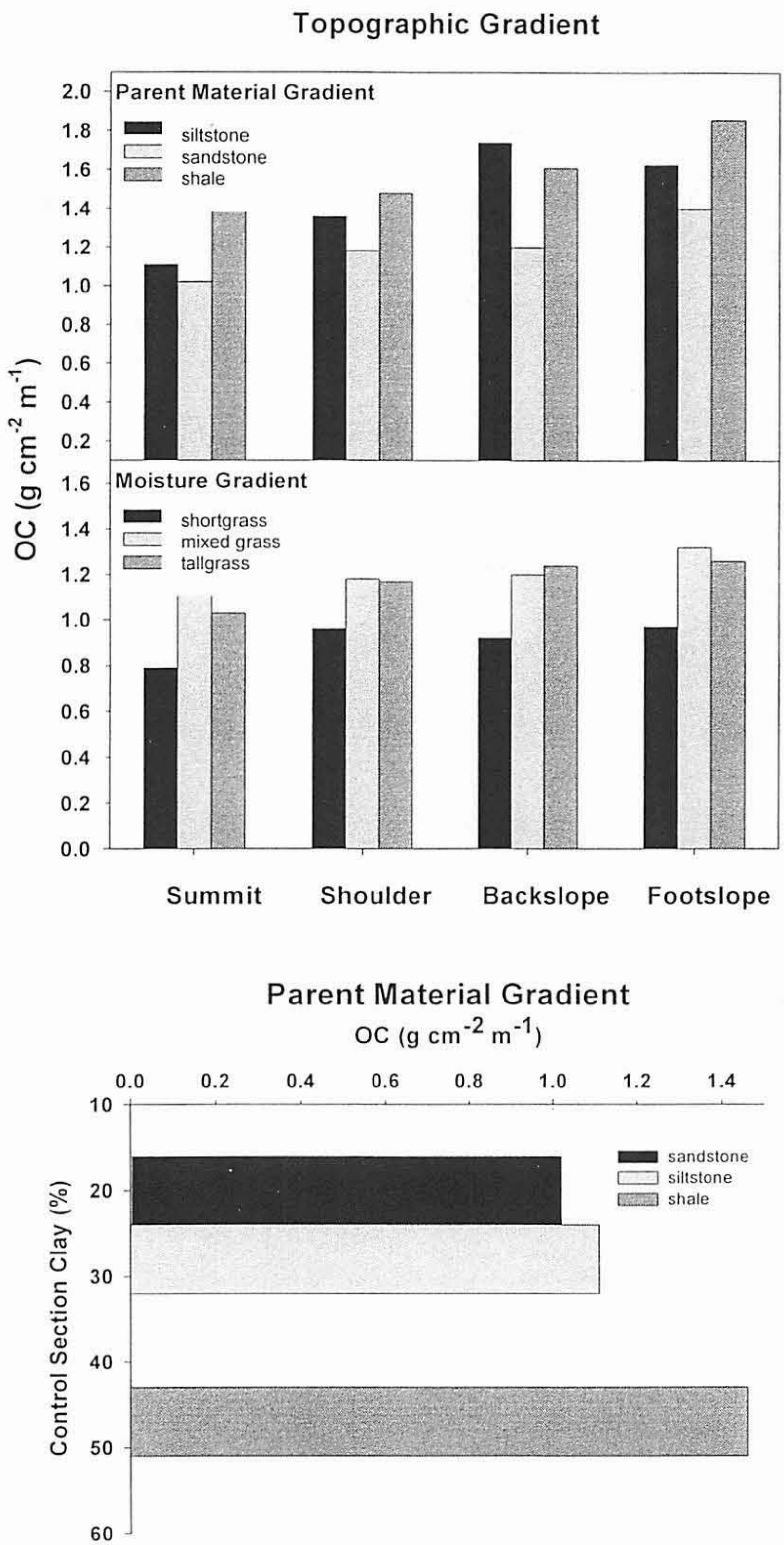
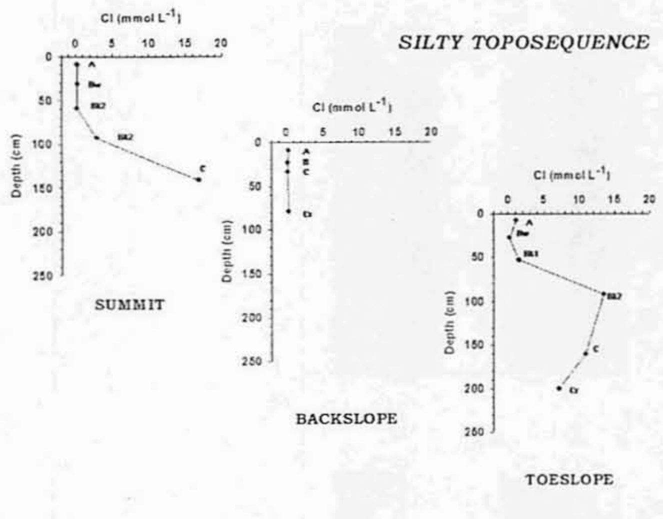


Figure 2. (a) Local variations in SOC as a function of parent material and topography, (b) Regional variability SOC as a function of MAP in summit landscape positions, (c) variations in SOC as a function of subsurface clay content (data from Yonker et al, in Prep)



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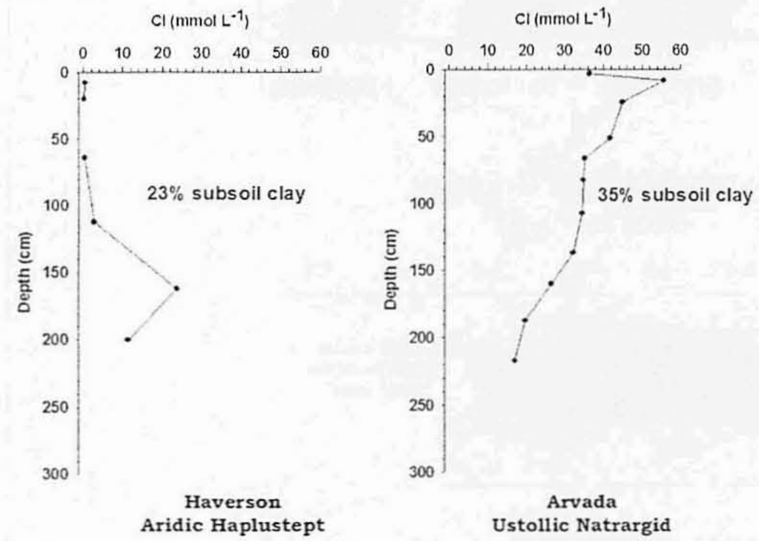
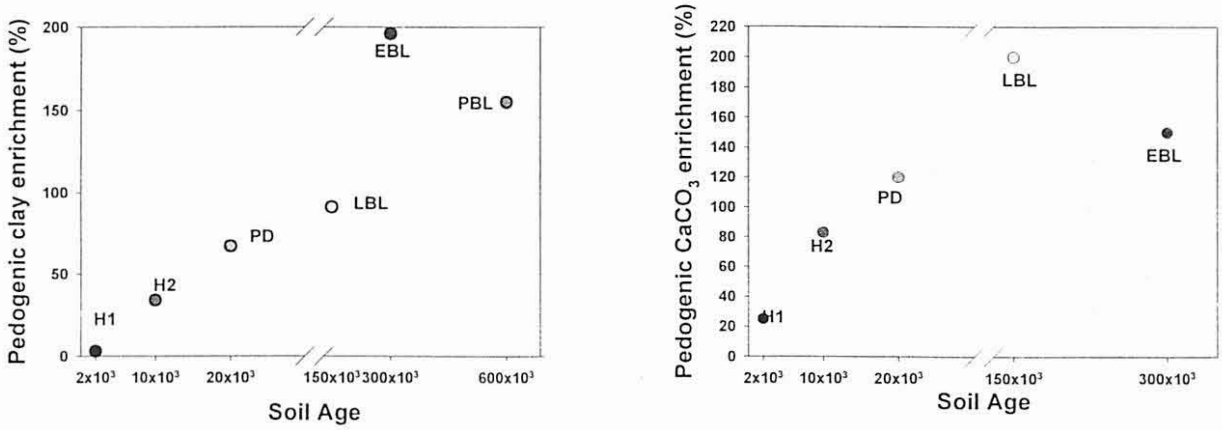
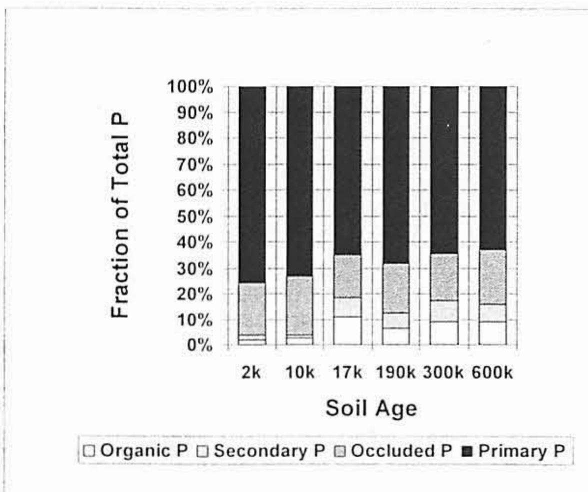


(b)

Figure 3. (a) Chloride mass balance for siltstone parent material across hillslope, (b) Chloride mass balance as a function of texture. Higher Cl levels suggest more capillary rise in finer texture soils (data from ongoing hillslope studies).

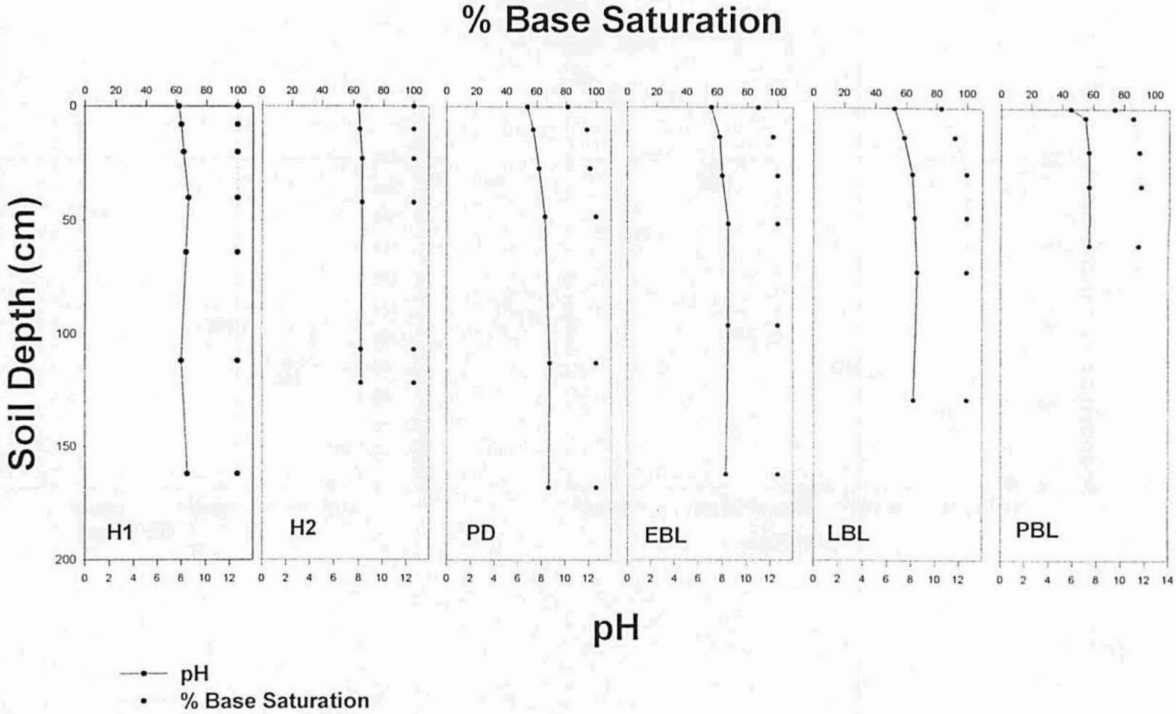


(a)

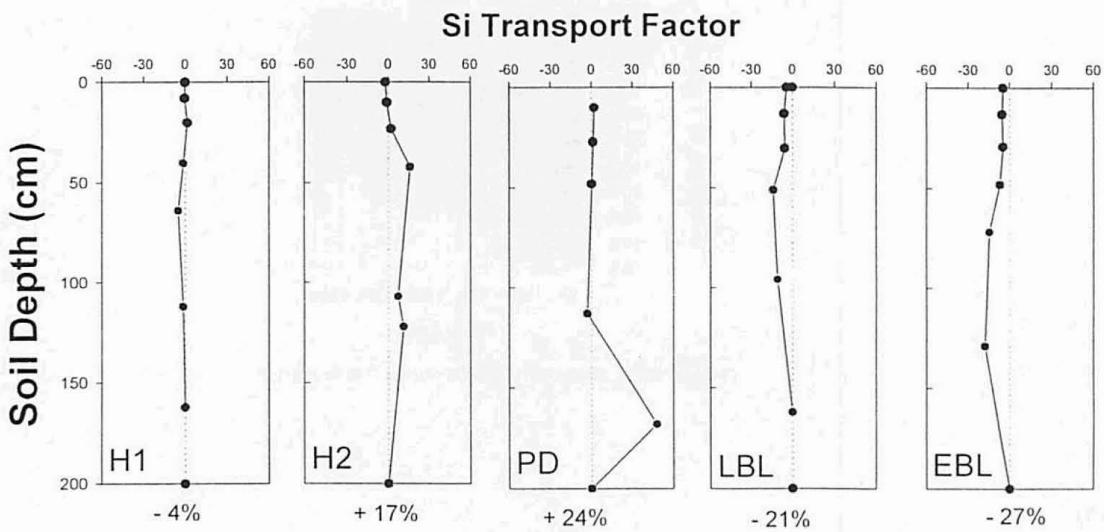


(b)

Figure 4. (a) Variations in pedogenic clay and $CaCO_3$ as a function of landscape age, (b) Fractionation of Soil P across chronosequences. (data from Huffman et al, In Prep)



(a)



(b)

Figure 5. Variations in soil chemical properties as a function of landscape age (a) ph and % base saturation, (b) total soil silica, (H1= 2K, H2= 10K, PD= 17K, EBL = 190, LBL = 190K, PBL = 600K)

Highlight 1: Interactions between physiography and biogeochemistry

b. Mobilization of terrestrial silica in grassland systems: A cross-site study to evaluate the potential importance of grasses on Global Silica Biogeochemistry.

S.W. Blecker[1], R.L. McCulley[2], L.A. Derry[3], O.A. Chadwick[4], and E.F. Kelly[1]

Introduction: The global carbon and silica cycles are known to be closely linked in the oceans. Marine diatoms account for over 50% of the particulate export flux of organic carbon from the surface to the deep oceans, and thus play a critical role in the regulation of atmospheric CO_2. The productivity of important diatom-dominated regions is silica-limited (*Dugdale et al.*, 1995), and so fluxes of silica from the terrestrial environment to the oceans may play a central role in the global carbon cycle over geologic time scales.

Background: Weathering of silicate minerals in soils is generally believed to be the driving force behind the delivery of silica to riverine systems and ultimately to oceans (*Froelich et al.*, 1992). Most assessments of the controls on silica export from the terrestrial environment have largely ignored the role of biogenic silica stored in soils and vegetation, assuming that mineral weathering reactions alone control this flux (e.g. *Berner*, 1995). However, as noted above, growing evidence exists for a major role for biogenic silica in controlling silica storage in and export from the terrestrial environment. We and others (e.g. *Conley*, 2002) hypothesize that there is a critical link in global biogeochemistry between the biogeochemical silica in terrestrial systems and its export to the better documented marine biogeochemical cycle of Si. Because available evidence suggests that grassland systems are a particularly large and active reservoir of biogenic silica (*Derry et al.*, 2002:2005), we argue that global expansion of grasslands during the late Neogene could have had important consequences for both marine and terrestrial Si cycles, and thus the global carbon cycle. Despite its potential significance for the global silica (and carbon) cycle, the biogeochemical behavior and residence time of biogenic Si in terrestrial grassland ecosystems is largely unknown.

Objectives:

1) Determine the amounts of biogenic Si stored above and below ground in grassland ecosystems.
2) Quantify the influence of biogenic Si on weathering rates in soils.
3) Characterize the isotope (Ge/Si or δ^{30}Si value) of biogenic Si in soils.
4) Determine is the relative importance of grasslands to the entire Si budget and flux to aquatic systems.

Key Results:

1) In shortgrass systems, higher plant Si contents; lower annual biogenic inputs and larger soil biogenic Si pools are the rule (Figure 2).
2) Soil biogenic Si turnover increases from short to tallgrass systems (Figure 3).
3) In all grasslands, biogenic Si cycling tends to have a positive impact on mineral weathering (Figure 4).
4) Though weathering trends are apparent, these hydrologically complex systems require more intensive characterization to fully exploit the utility of Ge/Si ratios in discerning stream Si provenance (Figure 5).
5) Our results point out the importance of grasslands in the mobilization of Si from terrestrial ecosystems.

Author Affiliations:

[1] Dept. of Soil and Crop Sciences, ColoState Univ., Fort Collins, CO
[2] Dept. of Biology, Duke Univ., Durham, NC
[3] Dept. of Geol., Cornell, Univ., Ithaca, NY
[4] Dept of Geog., UCSB, Santa Barbara, CA

Global Implications: Scaling up our grassland Si data, we've estimated that 7 Tg Si are stored annually in the biomass of grassland systems across North America and 3,800 Tg Si are stored as soil phytoliths. Our calculations for non-woody grassland ecosystems worldwide, increase these numbers to approximately 60 Tg Si for aboveground biomass and 33,000 Tg Si for soil phytoliths. Compared to the global estimate of 2-7 Tg Si annual storage in global biomass (*Conley 2002*), our figures show that biogenic Si pools are potentially much larger.

A number of paleoceanographic indicators show interesting behavior around the time of the apparent Mio-Pliocene grassland expansion. A noted shift in Ge/Si at that time correlates with increased weathering intensity in the Himalayan foreland, an event closely correlated with the expansion of grasslands worldwide (*Quade et al., 1989; France-Lanord and Derry, 1994*). The pool sizes and turnovers reported from our cross-site work suggest that the Mio-Pliocene expansion of grasslands might have influenced chemical fluxes of Si to the oceans; however, the interpretation of these signals has been a matter of debate for some time.

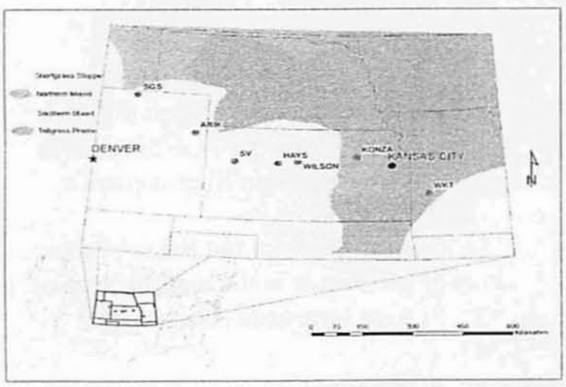


Figure 1. Site Location Map

References:

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Conley D.J. 2002. Terrestrial ecosystems and the global biogeochemical silica cycle. Global Biogeochem. Cycles 16:681-688.

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Quade, J., Cerling, T.E., Bowman, J.R.. 1989. Development of Asian monsoon revealed by marked ecological during the latest Miocene in northern Pakistan. Nature 342:163-166.

Figure 2. Above- belowground contributions of biogenic Si across the grassland climosequence

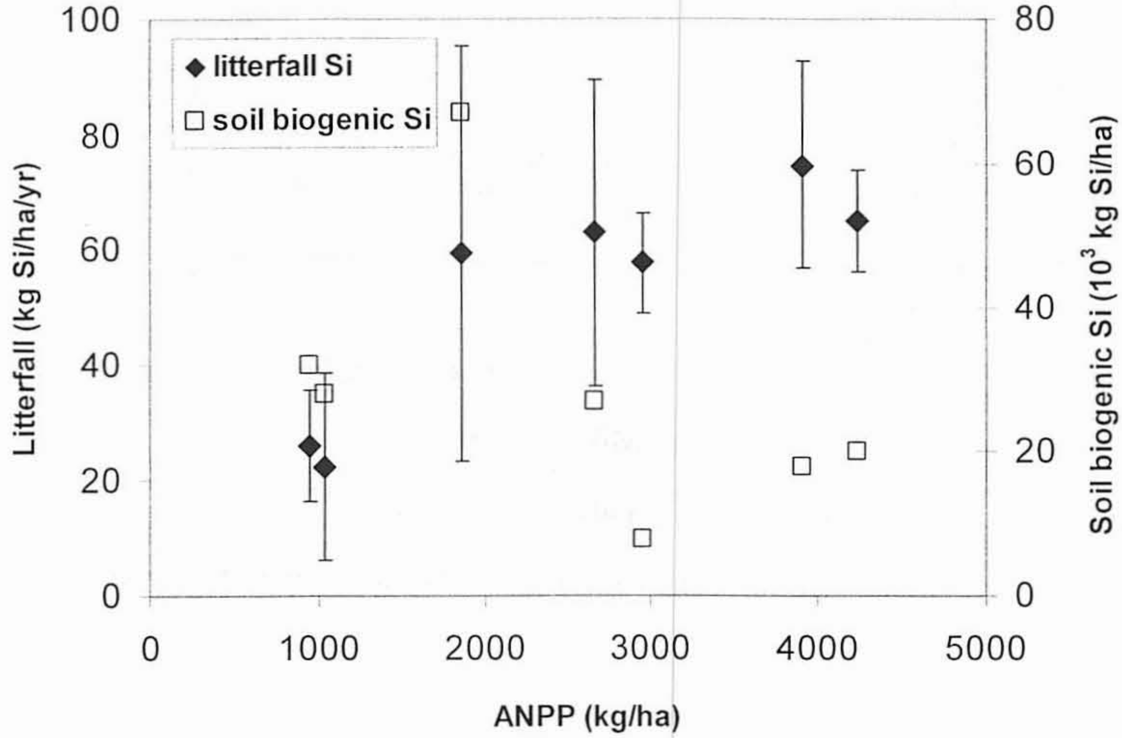


Figure 3. Estimated turnover time for soil biogenic Si across the grassland climosequence

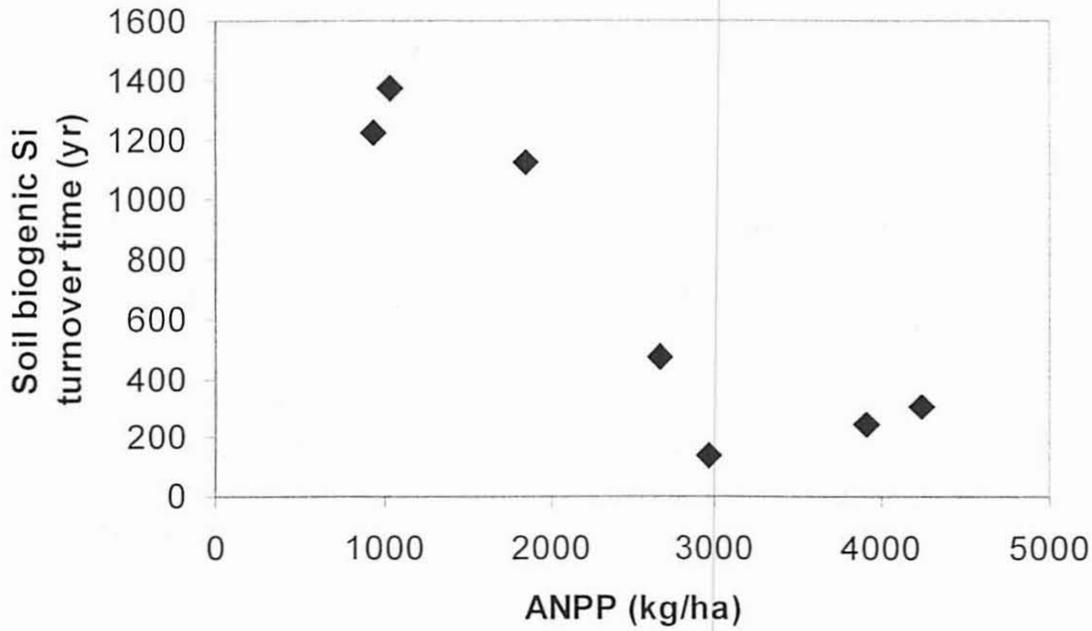
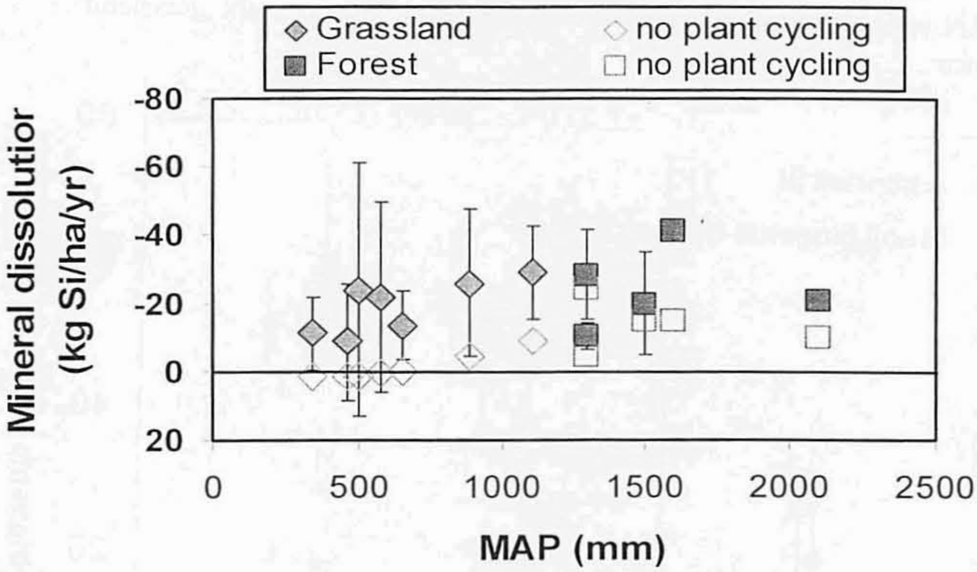


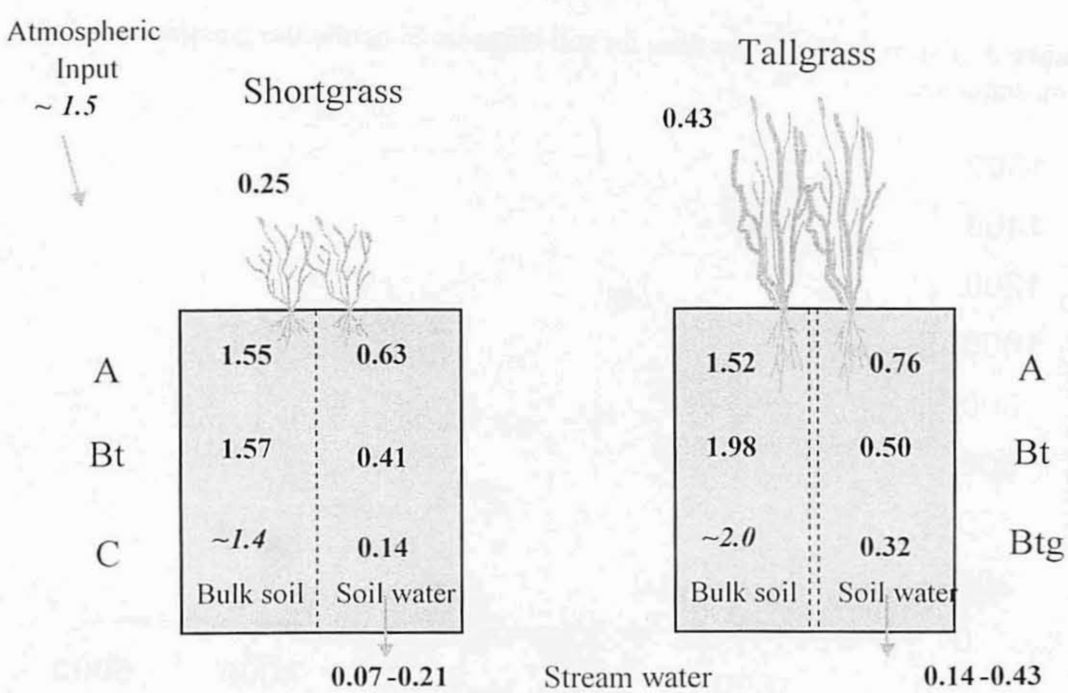
Figure 4. Estimated impact of plant Si cycling on mineral weathering



Mineral dissolution = (Input) – (Output)

Mineral dissolution = (Input + plant Si release) – (Output + plant Si uptake)

Figure 5. Ge/Si ratios for major grassland Si pools



Highlight 2: Interactions between nutrient and water availability and ecosystem structure: How do N and H_2O influence plant community dynamics?

a. Long term core data collection and synthesis of long term data (Daniel, Milchunas et al Ecological Applications)

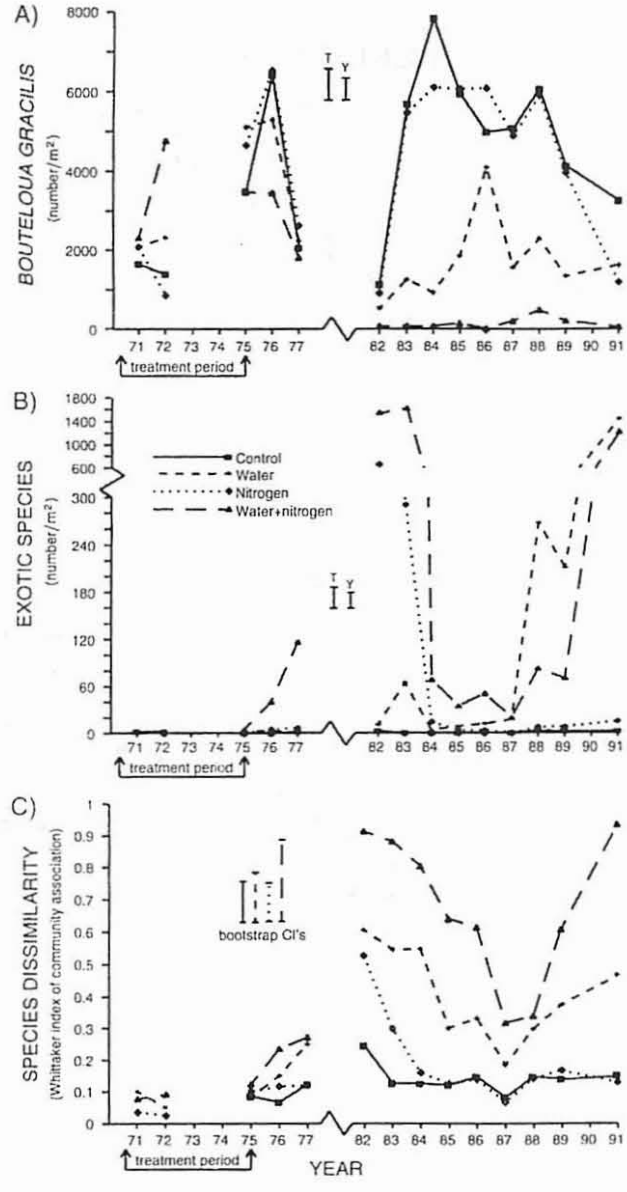
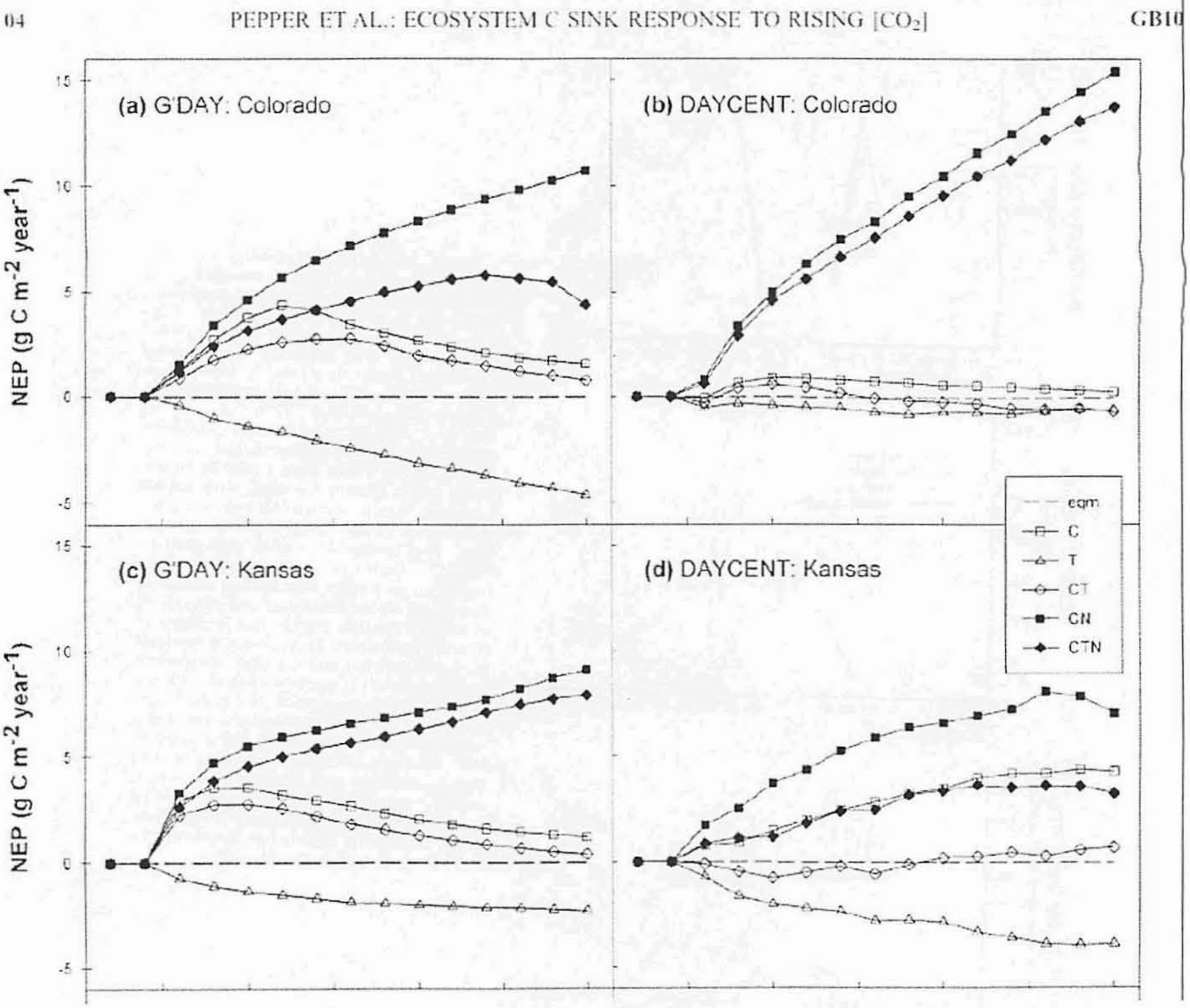


FIG. 1. (A) Density of *Bouteloua gracilis* tillers in control and water-, nitrogen-, and water-plus-nitrogen-enrichment treatments during the first two and the last year of the 5-yr stress-treatment period, 1 and 2 and 7 through 16 yr after cessation of treatments. Confidence intervals (Tukey's HSD, $P \leq 0.05$) with letter "T" are for comparing treatments within years, and "Y" for years within treatments. (B) Density of exotic (invader-"weed") species for treatments and years described above. There were a total of 10 different exotic species recorded, with *Kochia scoparia*, *Salsola iberica*, *Sisymbrium altissimum*, and *Cirsium arvense* the most abundant. Populations of native opportunistic "weed" species were distributed among treatments and years in a fashion similar to that shown for the introduced and naturalized exotic species. (C) Species dissimilarity of control replicate no. 1 vs. control replicate no. 2, and each nutrient-enrichment treatment replicate vs. its respective control within a particular year. A value of "1" indicates no species in common between the two communities that are contrasted, and a value of "0" indicates all species in common and each in the same proportion in the two contrasted communities. Values were calculated using density data and Whittaker's (1952) index of community association. Bootstrap CI's are bootstrap confidence intervals.

b. Assessment of our current knowledge and projecting the future: Synthesis, Simulation, and Cross Site Analysis

Synthesis and Simulation (Pepper et al. 2005)



Cross Site Analysis: LIDET (Parton et al.)

LIDET is a long-term litter decay experiment where common litter types (12 different root and leaf litter types) were distributed to 28 sites around the world. Litter bags were sampled annually for 10 years at the temperate sites and more frequently at the tropical sites up to a four year period. Indy Burke and Bill Parton are part of a team of scientists who have been working on data generated by the LIDET experiment. The common litter types include leaf and fine roots from grassland and forest systems which had a range of different initial lignin and nitrogen contents. We are working on a series of papers that describe mass loss and nitrogen release from the root and surface litter bags.

We had climate data from all of the sites and were able to correlate litter mass loss rates to the different climatic factors. Variables such as the century abiotic decomposition index (DEFAC), annual evapotranspiration (AET), mean annual temperature, and annual rainfall were correlated to the mass loss rates. AET and DEFAC were the best variables and DEFAC was shown to be a better index of decomposition using the AIC model comparison statistics. Figure 1 shows the correlation of DEFAC to the average first phase decay rates (average K values for the first 50% of mass loss for all the surface litter material).

Results show that decay rates are positively correlated to DEFAC for tropical and temperate forest systems and that there is little change in K for dry vs wet grasslands (low vs high values of DEFAC). The tall grass prairie sites (KONZA, and Cedar Creek) have virtually the same mass loss rates as the shortgrass and desert grassland sites (dry grasslands have 20 to 30 % of the precipitation at KONZA and CDR). We currently believe that the apparently high surface litter decay rates at the dry grasslands sites where litter is exposed to direct solar radiation is caused by photodegradation. Current experiments at the SGS site show that surface litter decay is enhanced by photodegradation.

The other major part of our LIDET data analysis was to evaluate the patterns of nitrogen release from decomposing litter as a function of the initial N content of the litter and litter biomass remaining. Figure 2 shows the patterns of N release as a function of litter biomass remaining and initial N content of the litter for the tropical and temperate forest sites. The results for the low N litter (0.4% initial N) show that fraction of the initial N increases as the litter biomass remaining decreases until 50% of the initial biomass (50 to 80 % increase) and then decreases with further decreases in litter biomass remaining. The same pattern occurs for the medium and higher initial N content litter with the amount of N immobilization in to the litter decreasing with increasing N content . This pattern of N release as a function of biomass remaining and initial N content of the litter is amazingly similar for temperate and tropical forest sites.

The most surprising result from our study show that N release from decomposing surface litter in dry grassland sites (figure 3a) releases N at the same rate as the biomass is released (no net N immobilization during decomposition) and that initial N content has no impact on N release from the surface litter. These results were not expected and suggest that photdegradation might be the major control on surface litter decay and N release from decomposing litter. Biological decay of litter with low N contents requires that N is immobilized into microbes during decomposition and results in the increased N content of low N litter shown in figure 2. The other surprising pattern is the N release from root litter bags (figure 3b) which shows a similar pattern of N being released and the litter biomass is being released. We do not have any explanation for this patter of N release for the root litter since we would have expected at least minimal N immobilization into the root litter since the initial N contents were around 0.8 %. The results from surface and root litter decay in dry grassland suggest that there is not net N immobilization during decomposition of litter. This pattern of N release for surface or root N release would not be represented correctly in any of the current ecosystem models.

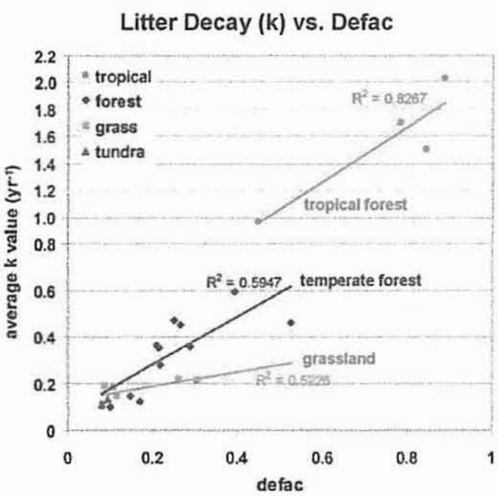


Figure 1 – litter decay versus defac by biome.

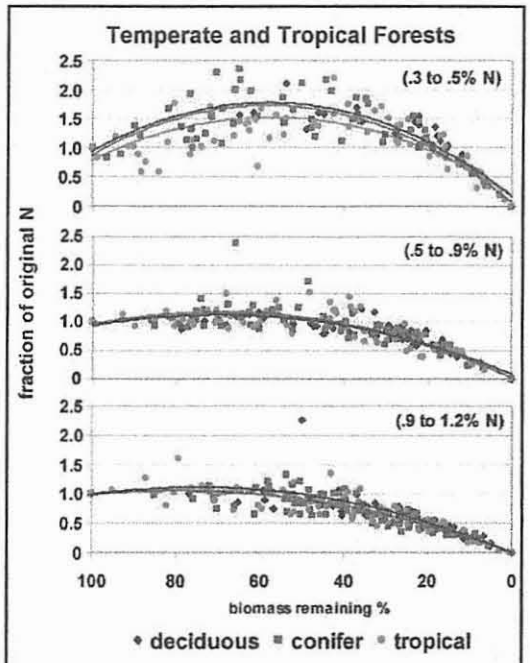


Figure 2 – temperate and tropical forest N release patterns.

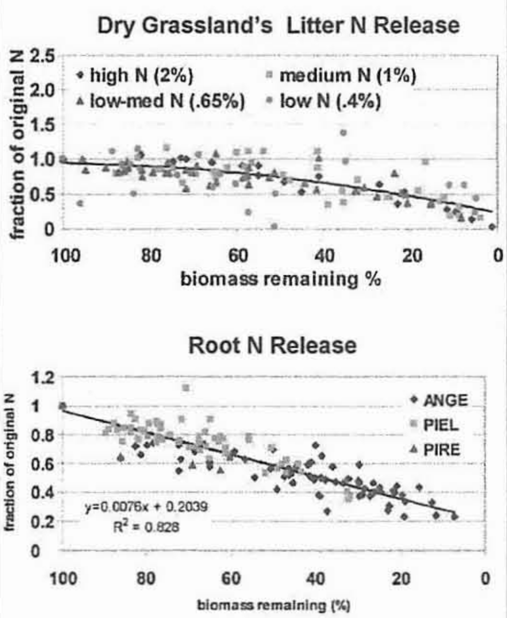


Figure 3 – dry grassland surface litter and root N release patterns.

c. Long term experimentation (Indy, Lowe et al in prep and Burke et al in prep)

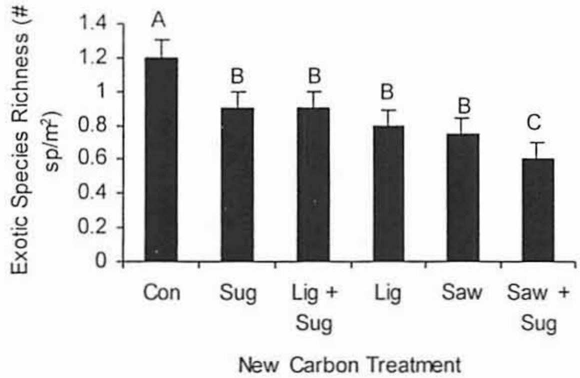
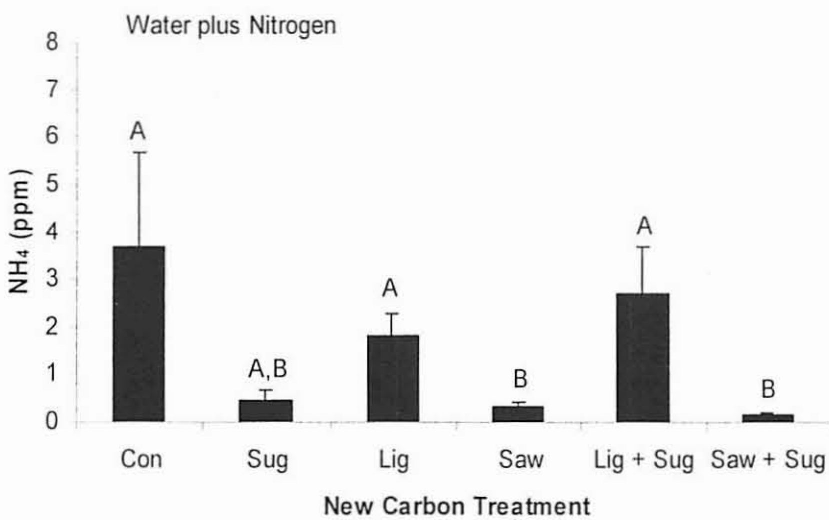


Figure 3. Effect of carbon treatments added from 1998-2001 (control, sugar, lignin plus sugar, lignin, sawdust, and sawdust plus sugar) on average exotic species richness. Error bars are one standard error of the mean. Columns with the same letter are not significantly different at P=0.05.



Section 3:

Field Tour Information

Stop 5: Long Term Faunal Ecology Experiments
(Prairie Dog Towns, Section 27/28, CPER)

- Overview, Goals and Rationale: Mike Antolin
- Swift Foxes: Safi Darden
- Prairie Dogs: Dan Tripp
- Small Mammal Studies: Paul Stapp
- Plant/Faunal Interactions: Jim Detling
- Below Ground Community Responses: Meghan Quirk

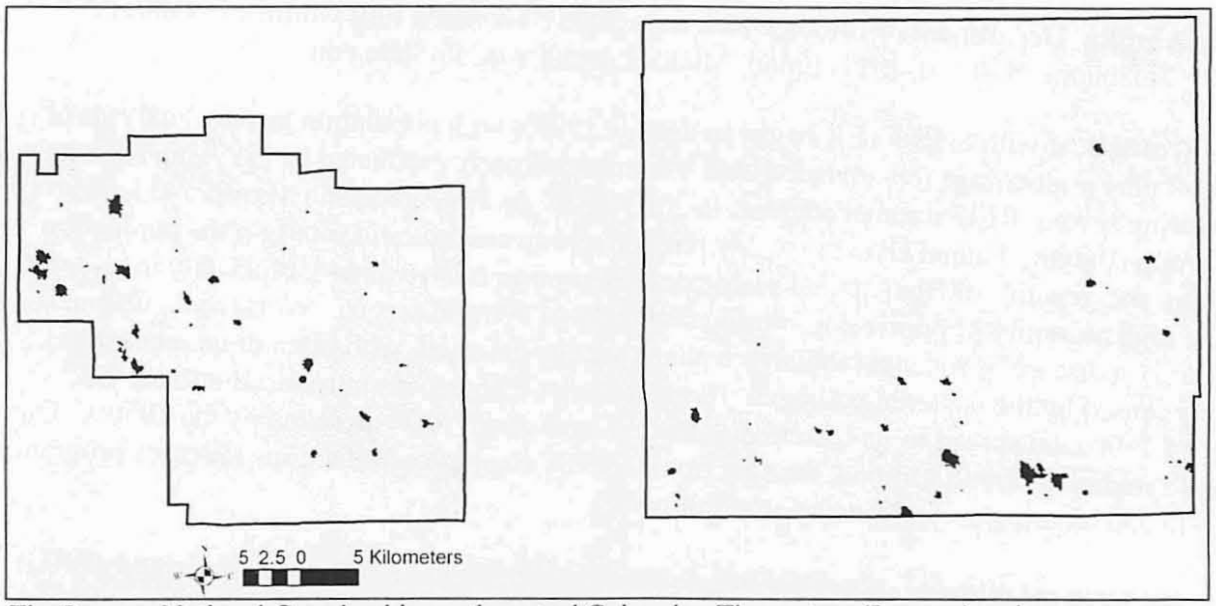
Mike Antolin, Department of Biology, Colorado State University, Fort Collins, CO 80523-1878. Telephone: 970-491-1911. Email: Michael.Antolin@ColoState.edu

My involvement with SGS-LTER began in the late 1990's with population genetic analyses of Black-tailed prairie dogs (co-advisor to MS student Jen Roach, graduated in 1999), and through mentoring several REU summer students in 2000-2002. In 1992 I became a co-PI and leader of the group studying Faunal Dynamics. My research group continues to focus on the population biology and genetics of Black-tailed prairie dogs (*Cynomys ludovicianus*), especially in regards to the high mortality of prairie dogs during outbreaks of sylvatic plague. Worldwide, plague is primarily a disease of rodents (although humans are also infected, with often dramatic results), and is caused by the bacterial pathogen, *Yersinia pestis*. Plague was introduced into the US around 1900, and spread to its current distribution west of the 100th meridian by the 1950's. Our plague studies receive additional funding from the NSF Ecology of Infectious Diseases program. Recent and ongoing projects include the following:

1. Long-term monitoring of prairie dog colonies on the Pawnee National Grassland (PNG) and the Central Plains Experimental Range. The PNG is administered by the United States Forest Service (USFS) and represents approximately 80,000 ha of publicly owned land embedded within a checkerboard of lands under federal, state, and private ownership. It is divided into eastern and western units (Pawnee and Crow Valley, respectively) separated by a 16-km wide strip of private land. A greater proportion of the western Crow Valley Unit is contiguous federal grassland than is the eastern Pawnee Unit. The Central Plains Experimental Range (CPER), located on the northwestern corner of the PNG, is a research area established in 1939 and administered by the US Department of Agriculture / Agricultural Research Service to study the effects of grazing on sustainability of the short grass prairie.

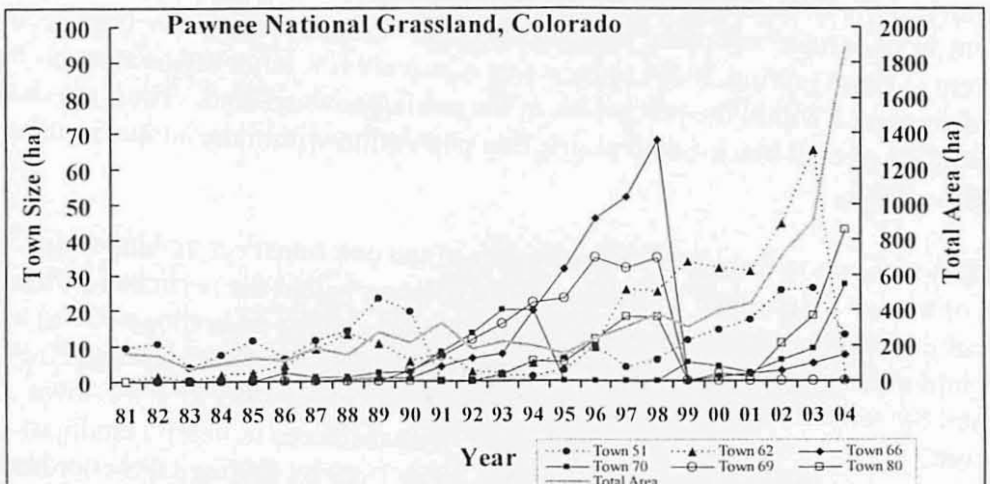
Survey 1981-2004 -- Since 1981, USFS personnel have monitored the location, activity (i.e. extinct or active), and size of 60 of the prairie dog towns on the PNG. Since 1995, when prairie dogs recolonized the CPER, an additional ten towns have been monitored by the SGS-LTER. Another 16 prairie dog towns monitored by the USFS on the PNG were active in the years just before 1981 but went extinct before the long survey began. Two of these have been recolonized recently. Recent surveys (spring 2005) suggest that relatively few large towns exist on the private land interspersed within the patchwork of the publicly owned land. Thus, the data are representative of the overall black-tailed prairie dog population within the administrative boundaries of the PNG.

Prairie dog town size was measured as the perimeter of the outermost active burrows of a town, with the area of a town determined by the minimum polygon within the perimeter. From 1995 to the present, colonies were mapped using global positioning satellite technology (GPS) and incorporated into a Geographic Information System (GIS) using Arc/INFO 9.0 and ArcView 3.2 (Environmental Systems Research Institute, Redlands, CA). From 1981 to 1994, town perimeters were mapped using surveying equipment, with distances to nearby landmarks measured. These maps were incorporated into the GIS in 1999 by finding GPS coordinates of landmarks used as ground controls, digitizing paper maps for the GIS, and scaling the towns to size based on the ground control points.



The Pawnee National Grassland in north-central Colorado. The eastern (Pawnee) and western (Crow Creek) administrative boundaries are shown in black, with the patchwork of public (gray shapes) and private ownership. Dark black shapes show the largest extent of the 86 prairie dog towns between 1981 and 2004.

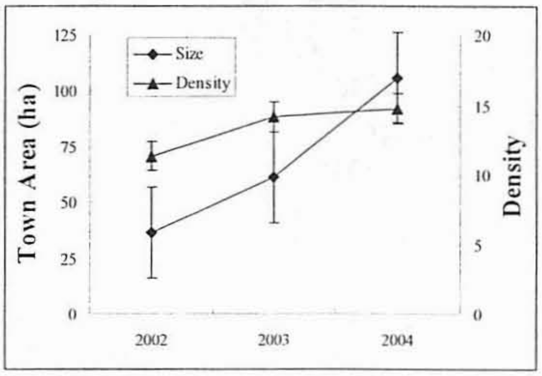
Prairie dogs have been severely impacted by the introduction into North America of *Y. pestis*, the bacterium that causes plague. Plague has converted prairie dogs into metapopulations, by causing local extinction of prairie dog towns during outbreaks, with subsequent recolonization 2-4 years after the disease wanes. Analyses of these data revealed that plague outbreaks are more common during wetter and cooler periods (Stapp et al. 2004), but are uncommon during hot dry years of drought, like those from 2000 to 2003 (see below). Overall, prairie dogs have increased on the PNG and CPER, and currently occupy 1,880 ha (about 1.5 % of the total area). However, as can bee seen clearly below, individual towns experience large fluctuations in size.



Total area (ha) occupied by prairie dogs on the Pawnee National Grassland (solid thick line), based on the survey conducted between 1981 and 2004. Areas of six representative towns from the western PNG demonstrate the fluctuation in size of towns after they are colonized but before they are decimated by plague.

2. Estimation of prairie dog abundance – Dan Tripp and Mike Antolin

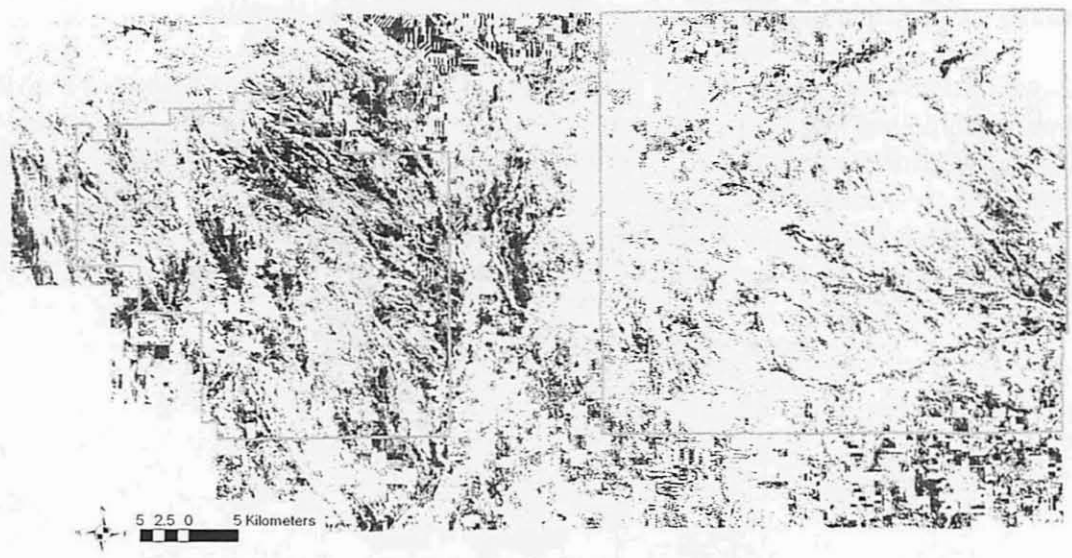
In 2002, we initiated visual counting of prairie dog colonies. This work is being led by MS student and technician Dan Tripp, in collaboration with a Ph.D. student in the Department of Fisheries and wildlife Biology at CSU, Brett McClintock. In 2004 this was expanded to include all towns on the western PNG, as part of the regular population monitoring. Visual counts indicate that while average colony size has increased on the CPER and PNG, that prairie dog density has also increased as the drought of 2002 ended.



Visual counts on all towns on the CPER and the western PNG are now a permanent feature of the monitoring on the LTER. We are working, to calibrate the index counts from these methods with robust density estimates via mark-resight procedures. Six towns will be more intensively enumerated in 2005 and 2006, at the same time that visual counts continue.

3. Mapping of suitable habitat on the Pawnee National Grassland and Central Plains Experimental Range.

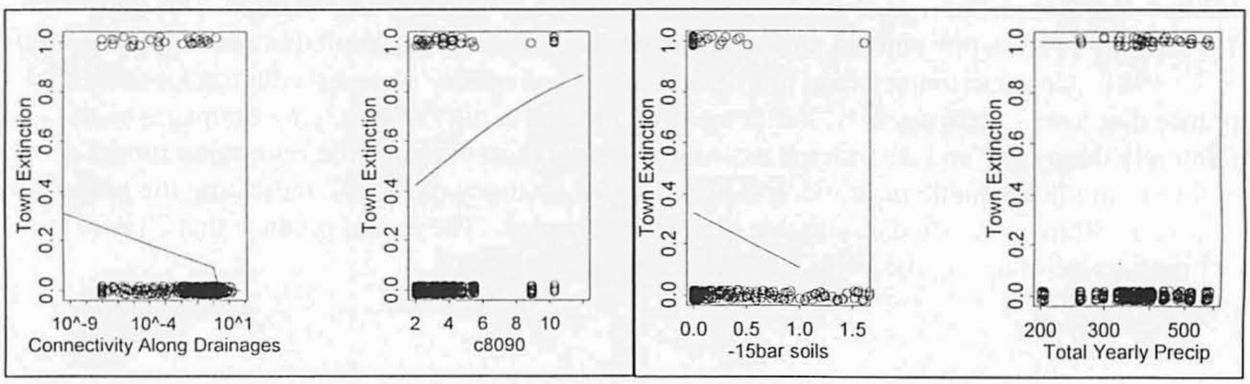
This work was carried out in collaboration with Post-doctoral Researcher Becky Eisen and graduate student Lisa Savage, with additional funding from the Colorado Division of Wildlife and the Pawnee National Grassland. Understanding the habitat requirements of Black-tailed prairie dogs within the short-grass prairie will be useful in identifying areas most suitable for prairie dog persistence. The objectives of this study were to 1) identify landscape features predictive of suitable prairie dog habitat within the short-grass prairie of the Pawnee National Grassland (PNG) in north central Colorado, USA. and 2) create a spatially explicit model, from a Geographic Information System that predicts how much of the PNG is suitable prairie dog habitat. Long term surveys of prairie dog towns on the PNG between 1981 and 2004 show that 1.5% of the PNG is presently occupied by prairie dogs, with 3% occupied at some point in time since 1981. Comparison between prairie dog towns and nearby unoccupied areas revealed that prairie dog towns were on drier, flatter areas in close proximity to low lying drainages with relatively deep soils and east-facing exposures. Evaluation of a logisitic regression model's ability to predict suitable prairie dog habitat yielded accuracy of 68.6%, indicating the proportion of pixels (30 m^2) classified as suitable that were occupied. The model predicts that 23% of publicly-owned land on the PNG is suitable prairie dog habitat.



Map of suitable prairie dog habitat on the PNG (publicly-owned land is shaded gray), based on a probability cut-off of 0.556. Suitable habitat for black-tailed prairie dogs on the PNG is characterized by dry, flat, east-facing areas where density of low-lying drainages is high and soils are deep.

4. Climatic and landscape correlates of extinction and colonization of Black-tailed prairie dogs

To follow up on the discovery that plague outbreaks are clustered during years with El Niño climatic patterns (cooler, wetter) during the last 24 years of survey on the PNG, Ph.D. student Lisa savage has created a statistical model of plague occurrence. The data set now extends to 2004, with 5 new outbreaks after the end of the drought of 2001-2003. Climate data (temperature, rainfall) from four widely spaced weather stations on the PNG were imputed to determine conditions at each prairie dog town, spatial data and soils data were derived from the GIS we have created. Logistic regression analysis (with AIC) shows that three factors regularly predict plague outbreaks: connectivity (more isolated towns), cooler summers (ratio of days > 26° to > 32°), and soils with the capacity to retain moisture (water potential, -15 bar, at 30 cm depth). Other factors, like total rainfall, were poor predictors of plague outbreaks.



3. Population genetic analyses of prairie dogs (see poster)

Ph.D. student Lisa savage has also extended population genetic analysis of prairie dogs on the CPER colonies to include three years of sampling (1997, 2000, 2001). This study continues an earlier population study conducted on the western PNG (Roach et al. 2001). Analyses are based on variation of seven microsatellite markers and the control region of the mitochondrial DNA (mtDNA). At this scale, evidence for sex-biased gene flow among prairie dog towns: physical distances between colonies are related to genetic distances of maternally inherited mtDNA markers, but not of bi-parentally inherited microsatellites.

	Exclude all pops but source	Exclude some pops but not source	Exclude source but not other pops	Exclude all pops sampled	p-value used: 1/sample size
1997	16 19.75%	51 62.96%	4 4.94%	10 12.35%	p=1/82=0.012
2000	13 9.22%	117 82.98%	6 4.26%	5 3.55%	p=1/141=0.007
2001	16 12.90%	98 79.03%	5 4.03%	5 4.03%	p=1/124=0.008

Assignment tests indicate that ~10% of individuals captured on prairie dogs towns have genotypes consistent with them being immigrants or the offspring of immigrants.

Marker – distance measure	r^2 (1997)		r^2 (2000)		r^2 (2001)	
Microsatellite F_{st} – drainage	-0.32		0.03		-0.51	
Microsatellite F_{st} -Euclidean	-0.28		0.07		-0.60	
mtDNA F_{st} –drainage	0.68	*	0.63	*	0.73	*
mtDNA F_{st} –Euclidean	0.54	*	0.52	*	0.58	*

Population genetic analysis of indicate that genetic distances between towns (F_{st}) was correlated with both direct (Euclidian) distances between towns and distances along drainages.

4. Effects of diet on facultative torpor in Black-tailed prairie dogs.

This project comprises the thesis and dissertation work of Erin Lehmer, who graduated with a Ph.D. in spring 2004. Six peer-reviewed publications have resulted thus far. Prairie dogs present a model system for the study of torpor because of their broad geographic distribution, and because the ability of animals to enter torpor depends upon numerous physiological and environmental factors. Black-tailed prairie dogs practice facultative torpor, rather than obligate hibernation. The objective of this research was to examine how diet quality and habitat conditions influence facultative torpor in Black-tailed prairie dogs along elevational gradients in northern Colorado. Dietary analyses showed that prairie dogs prefer plants with high in lipid and nitrogen content, relative to other available plant species. Prairie dogs at lower elevation entered more shallow and infrequent torpor than prairie dogs at higher elevations. During the deepest drought in 2002, a single colony (town 22 on the CPER) at low elevation exhibited torpor patterns that resembled true hibernation, while an adjacent colony (CPER 5) did not. No genetic differences between the colonies could be found, but subtle differences in moisture and diet may have been responsible for the difference. Collectively, the study underscores that torpor can result in significant energy savings, and is an essential component of the life-history of prairie dogs, allowing them to persist in habitats where food resources fluctuate seasonally and where environmental conditions are often unfavorable.

5. Population dynamics of burrowing owls in relation to fluctuations in prairie dog populations.

Ph.D. student Reesa Conrey has initiated a population study of burrowing owls in summer 2005.

Safi K. Darden, Animal Behaviour Group, Department of Population Ecology, Institute of Biology, University of Copenhagen, DK-2200 Copenhagen, Denmark. Telephone: +45 3532 1325. E-mail: s-kdarden@bi.ku.dk

I am conducting my doctoral research on **swift fox (*Vulpes velox*)** behavior and ecology on the Central Plains Experimental Range (CPER site) and on a study site 10 miles east of the CPER on the Pawnee National Grassland (PNG site). This three year project (start: December 2003) is investigating a number of factors contributing to our understanding of intra-specific communication and of the spatial and social organization of this species. My advisor is Dr. Torben Dabelsteen at the University of Copenhagen. Funding for this project is provided by the University of Copenhagen. Logistical support is provided by the SGS-LTER. I have outlined the project and some preliminary results below.

1. Space use

At the start of study, four trapping grids (each grid: 20 traps spaced 1.6 km apart) were laid out to capture and mark swift foxes on the CPER and on the PNG (2 grids each site) with VHF transmitters. Only adult foxes were collared, and a subsequent targeted trapping effort was conducted to capture the mates of these previously collared foxes. In total, 20 adult and 16 juvenile foxes were captured in 190 trap nights. Efforts have been made to keep the number of collared foxes at 20 individuals since these initial captures in December 2003 and January 2004. Using telemetry data collected from foxes across the 24-hour period during winter and summer seasons, I have been able to calculate their home-range and other space-use characteristics. I have found that swift fox home-ranges on the two study sites range in size from 5 to 11 km^2 (fixed kernel estimation), with males using slightly larger areas than females. Neighboring foxes tend to have some degree of overlap in their space use, while members of the mated pair overlap in space use by as much as 100%. Movement data gathered at half hour intervals during the active period between sunset and six hours after sunset, show that foxes can traverse their entire home-range in half an hour and use areas of the home-range differentially in terms of the amount of time spent in each area.

2. Social organization

The swift fox has been described as a socially monogamous species, but extra-pair paternity and additional adults at the den during pup rearing have been recorded. In addition to the information acquired from telemetry data, I am collecting hair samples from each captured fox for genetic analysis to directly investigate swift fox social organization and interaction. DNA extracted from each sample is being analyzed using 8 microsatellite loci that will give insight into relatedness and gene flow within the study population. I will also look at paternity and determine the degree to which the social father in a family group is also the genetic father.

3. Physiology

I am looking at physiological parameters in the swift fox in relation to observed behavioral events (see points 4, 5, and 6 below) using non-invasive field endocrinology. In order to document the timing of reproductive events in individuals, feces collected every third day from scent stations at active den sites are analyzed for fecal androgens, estrogens and progestins in collaboration with the St. Louis Zoo Endocrine Laboratory, St. Louis, Missouri. Fecal corticoid concentrations are also being quantified to establish the overall physiological state of individuals within the study population and possible differences between males and females.

4. Long-range communication

I have found that both male and female swift foxes produce at least two long-ranging vocalizations associated with the mating season: the barking sequence and the 'meow' call. In a previous study, I demonstrated that the barking sequence exhibits a high degree of individuality and may have sex specific characteristics. A transmission experiment carried out in January 2004 on the PNG site has provided evidence that the barking sequence ranges a minimum of 500 m. Results from the first trials of a playback experiment started in February 2005 show that male foxes have a strong vocal response (producing both barking sequences and 'meow' calls) to a simulated intrusion of a strange male fox. The response seems to be graded, with the strongest responses occurring when the simulated intrusion occurs close to a mated pair's core area. This may be an indication of territoriality in this species, which to date, has not been shown directly.

5. Scent marking

Scent marking has not been studied in the swift fox and I am particularly interested in the use of fecal material in intra-specific communication, as new techniques are being developed for surveying swift fox populations using scat. Over 200 km of scat searches along transects, trails, two-tracks, and fence-lines have revealed that the foxes use fecal material for marking in a number of ways. For example, they tend to mark the burrows of their prey species, places where new holes have been dug, on top of coyote feces, and at conspicuous places in the landscape. They also use a system of latrines, which are collections of scats of various ages that probably are visited by more than one individual. The largest latrines are concentrated in home-range overlap areas and may act as 'information centrals' for neighboring individuals.

6. Parental investment

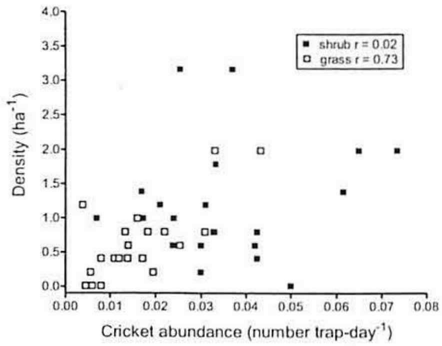
Using a combination of natal den observations and telemetry, I am quantifying aspects of parental care with the aim of investigating individual quality and possible differences in male and female investment. Preliminary results show that overall, males and females most likely contribute equally to raising the young post weaning, although individuals do show variation in their degree of parental investment.

Paul Stapp, Department of Biological Science, California State University, Fullerton, CA 92834-6850. Telephone: 714 278 2849. Email: pstapp@fullerton.edu

My involvement with SGS-LTER began in 1992. Since that time, I have directed and participated in several research projects. My current research can be divided into three areas:

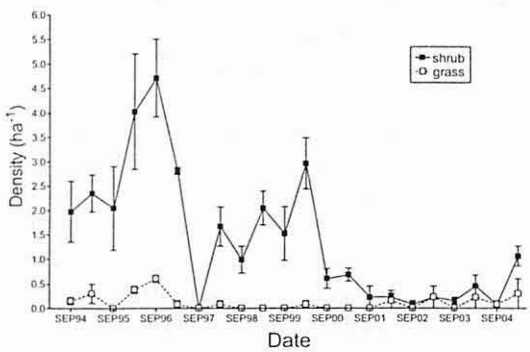
1. Long-term studies of small mammal communities and their resources

Since 1994, **Mark Lindquist** and I have conducted long-term field studies of small mammal populations on grassland and shrub-dominated sites (studies of diurnal ground squirrels began in 1999). In 1998 and 1999, I began sampling arthropod populations and vegetation, respectively, on the trapping webs to monitor changes in habitat and food resources. Also in 1994, I initiated spotlight counts of rabbits for one night each season along a 32-km route to track changes in the abundance of rabbits. Parallel surveys of relative abundance of coyotes and foxes (via scat counts) are conducted each season to estimate predator abundance. In addition, annual BBS and CBC data on raptor populations are available for the SGS-LTER site. I am assembling a long-term data set on trends in small mammal populations, their resources and predators, with the aim of deciphering the relative importance of climate, bottom-up (food resources) and top-down (predators) factors as determinant of variation in small mammal abundance.



Some highlights:

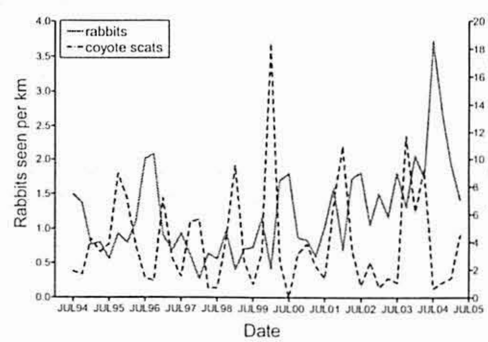
Density of grasshopper mice, the most common species captured, were strongly related to abundance of insect prey (crickets, tenebrionid beetles), but only on grassland sites (**Fig. 1**). Prey availability may be an important determinant of population density on grassland sites, which provide less cover and may be lower-quality habitat for rodents than shrub sites.



Shrub areas seem to be sources for deer mice, which spill over into grasslands only during spring when mouse densities in shrub areas are high. Small mammals like deer mice were severely affected by the recent drought and had only begun to recover in early 2005 (**Fig. 2**).

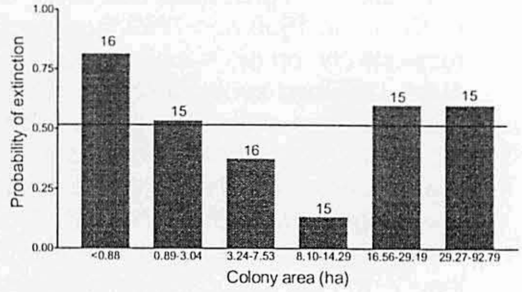
Rabbits have increased over the past four years of drought, largely as a result of increases in numbers of black-tailed jackrabbits, which are associated with arid conditions (**Fig. 3**). Our scat indices suggest little consistent variation in coyote abundance over this period, although spring coyote numbers are positively related to rabbit numbers the previous autumn.

Cross-site activities: In July 2005, I will submit a proposal to NCEAS to support development of a Working Group to analyze and synthesize results of long-term studies of small mammals across the latitudinal gradient of semiarid and arid grasslands represented by the SGS, Sevilleta and Jornada LTER sites. Invited participants include the LTER PIs responsible for designing and maintaining these projects, as well as at least one LTER graduate student.

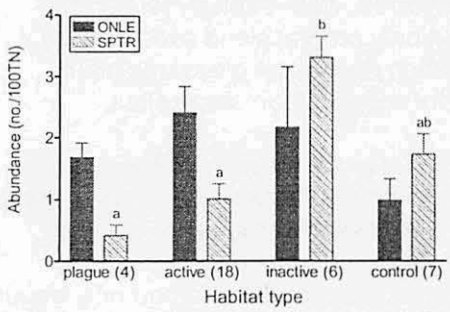


2. Ecology of prairie dog colonies

In SGS-LTER IV, I quantified the biodiversity associated with prairie dog colonies in five, paired colony and grassland sites. These studies demonstrated strong differences among species in their responses to prairie dog disturbance: species such as horned larks, grasshopper mice and earless lizards were more common in colonies, whereas lark buntings, skinks and ground squirrels were more abundant in areas without prairie dogs (Stapp and Van Horne *in press*). Overall, these results suggested that the ecological effects of prairie dogs in shortgrass steppe were less striking than in more productive grassland ecosystems, where the contrast between colonies and adjacent vegetation is greater.



The ecology and dynamics of prairie dog colonies are a major focus of my current research. In 2002, I analyzed 21-years of records of plague extinction and recolonization of colonies on the Pawnee Grasslands (Stapp et al. 2004). These analyses revealed three important results. First, plague epizootics tend to follow with changes in weather associated with El Niño Southern Oscillation climatic events. Second, large colonies were as likely to go extinct as small ones, presumably because of the higher risk of plague in large, dense populations (**Fig. 4**). Third, probability of extinction was more related to the fate and size of the nearest colony, rather than distance *per se*, suggesting that dispersal of prairie dogs to the next nearest colony, regardless of distance, may spread plague among colonies. Taken with recent population genetic studies, these results suggest that the introduction of plague has significantly altered the metapopulation dynamics of prairie dogs.

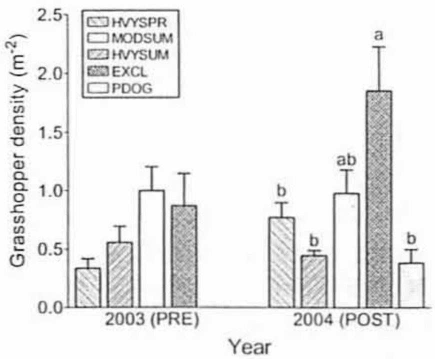


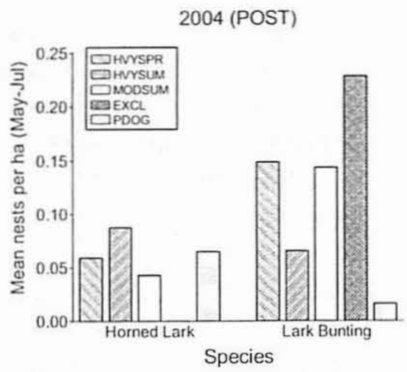
A recent (2003) award from NSF has allowed us to study the ecology of plague more closely. My role in this collaborative project (**Mike Antolin, Colleen Webb**, CSU; **Ken Gage**, CDC) has focused on the role of small mammals as reservoir or amplifying hosts, as well as the ecology of their fleas. Sampling in 35 colony and grassland sites in 2004, including four sites that were hit by plague, revealed that thirteen-lined ground squirrels were less numerous in colonies, but that grasshopper mice, a species known to be resistant to plague, were equally common in colonies and grassland sites (controls; **Fig. 5**). Surprisingly, there were no apparent effects of plague on any small mammal populations through the remainder of the year (*see poster*). **Dan Salkeld**, the postdoc on the project, is leading the field efforts and is also studying the ecology of the fleas. **Abby Benson**, a MS student, is studying the population ecology and dispersal of ground squirrels in and out of colonies (*see poster*).

3. Effects of livestock grazing on grassland animals

In collaboration with CSU (**Bill Lauenroth**) and ARS (**Justin Derner**) scientists, in 2003 I began an experimental study of the effects of intensive spring and summer grazing on shortgrass steppe, with the aim of determining whether grazing could be used to create habitat for the threatened Mountain Plover (proposal submitted to USDA-NRI). My role has been to study responses of small mammals, nesting birds and arthropods in these grazing treatments, moderately grazed pastures, long-term grazing exclosures, and prairie dog colonies. This project served as the thesis project for my MS student, **Katie Levensailor** (*see poster*).

Analyses are ongoing, but we have seen very few differences in abundance of most consumer populations in response to changes in timing and intensity of grazing, at least during the first year post-treatment. Most terrestrial consumers in SGS are adapted to low vegetation structure and may take longer to respond to changes in grazing than plants and soils. Grasshoppers and nesting birds may be exceptions (**Fig. 6, 7**).





Plant/Faunal Interactions

James Detling, Department of Biology, Colorado State University, Fort Collins, CO 80523-1878. Telephone: 970-491-5393. Email: jimd@nrel.colostate.edu

My involvement with LTER involves primarily studies of the effects of black-tailed prairie dogs on vegetation, other herbivores, and soil and plant nitrogen. Recent and ongoing projects include the following:

1. Long-term effects of prairie dogs on plant biomass, cover and species composition
Since 1997 we have been monitoring five prairie dog colonies for aboveground plant biomass, nitrogen concentration, cover, and species composition. As expected from studies at other sites in the mixed-grass prairie, grass biomass is lower (by an average of 30%) and forb biomass is higher (by a factor of 2, on average) on prairie dog colonies than in off colony sites. However, these differences are not nearly as great as the differences on more productive mixed-grass prairies. Moreover, species composition is similar on and off prairie dog colonies, and prairie dog disturbances to not appear to be facilitating invasion by exotic species.

2. Use of prairie dog towns by cattle
Based on earlier studies in northern mixed-grass prairie in which bison preferentially used prairie dog colonies as sites to graze, we conducted a study of cattle use on 12 prairie dog colonies on our SGS site. Results indicated that cattle on the SGS neither preferred nor avoided prairie dog colonies as sites to graze. Rather, they used them in proportion to their availability in the landscape. While on prairie dog colonies, prairie dogs foraged at the same rate (71 bites/min) as when they were off the colonies (70 bites/min).

3. Effects of prairie dog colony age on vegetation
A study nearing completion by graduate student Laurel Hartley is investigating the effect of colony age (~4 years vs. >20 years since colonization) on biomass, cover, species composition, and plant/soil N relationships. As with our long-term study, grass biomass is lower and forb biomass higher on prairie dog colonies, but the differences increase very little with time since colonization. This contrasts with studies on the mixed-grass prairie in which grasses are nearly eliminated from prairie dog colonies in as little as 10 years following colonization. In colonies that recently died of plague, the differences in biomass on and off colonies began to narrow within a year.

4. Effects of prairie dogs on floral abundance and insect pollinators
A study in the final year of data collection by graduate student Kelly Hardwicke is testing the hypothesis that the greater forb abundance on prairie dog colonies provides a more abundant supply of floral resources, and that there is a larger insect pollinator community on prairie dog colonies than on uncolonized grassland. Data to date indicate that both the dominant pollinator orders, Hymenoptera and Lepidoptera, were observed foraging 2-3 times more frequently on prairie dog colonies than on similar uncolonized sites.

5. Density and distribution of harvester ants on and off prairie dog colonies
This year, graduate student Christina Alba is beginning a study to determine whether grazing and soil disturbance by prairie dogs influences the density of ant mounds or their distribution on the landscape. In addition, she will measure the effects of harvester ants, singly and in combination with prairie dogs, on the vegetation at varying distances from their soil mounds.

Detritus, Changes in Below-ground Allocation and Food Web Stability

John C. Moore, Meghan H. Quirk, the NCEAS Detritus Dynamics Working Group

Human activities alter the availability of labile SOM and shift the plant community towards weedy species or accelerates root growth and turn-over (narrows C:N ratios of SOM and plant materials). We predict that areas liberated from cattle grazing and the extinction of prairie dogs will induce a shift in nutrient cycling and community structure towards the fungal "slow" pathway, while areas that are newly grazed and or recently colonized by prairie dogs will shift toward the bacterial "fast" pathway. We expect that an analysis of the models developed for each site will reveal that sites that retain nitrogen will be more likely to be dynamically stable than sites that retain less nitrogen (Figure 2). A prediction form the hypothesis is that native sites will possess soil food webs that are dynamically more stable than occupied sites, and that after plague epizootics remove prairie dogs, those sites will quickly converge in community composition to the native sites. The ideas are presented in Moore et al. 2003, Moore et al. 2004, and de Ruiter et al. 2005.

Figure 1

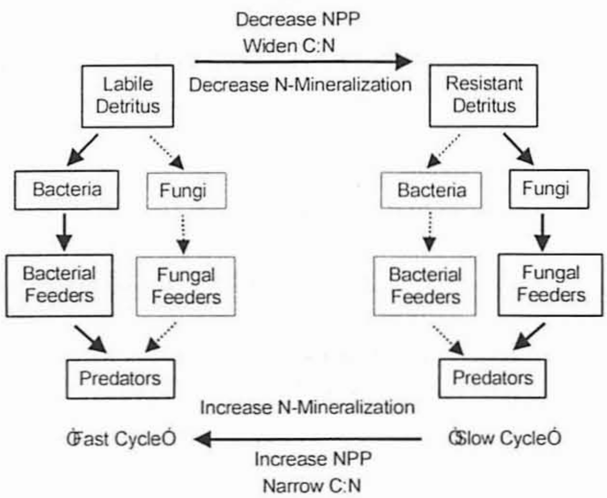


Figure 1. The soil food webs are compartmentalized into three interactive pathways – the root, bacterial and fungal energy channels. Empirical studies at the Toolik Lake and elsewhere have demonstrated that disturbance can induce changes in the relative flow of nutrients through these pathways and nutrient retention (Doles 2000, Moore et al 2003).

Figure 2

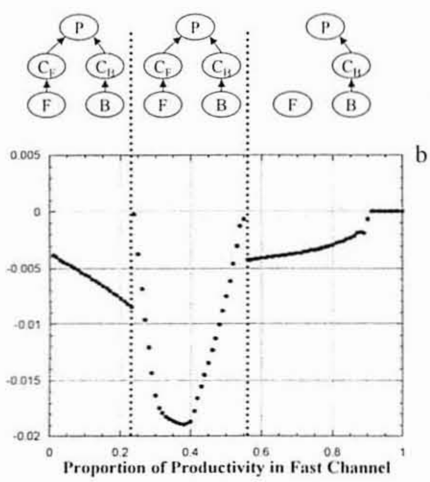


Figure 2. Simulations where the relative proportions of nutrients through the fungal and bacterial channels were altered. Stability is indexed by the most negative eigenvalue, λ. The more stable region occurs when neither the bacterial or fungal energy channel is dominant (Moore et al. 2004)

Effects of black-tailed prairie dog activity on belowground community structure in the shortgrass steppe

John C. Moore Ph.D. Advisor, and Meghan H. Quirk Ph.D. Candidate, Department of Biological Sciences, University of Northern Colorado, Greeley, CO

There are two main components of this research in prairie dog ecology. 1) in year one, an initial examination on prairie dog colonies was conducted in order to identify types of landscape effects with respect to prairie dog activity on belowground food web interactions. 2) in years two and three, the goal is to differentiate changes in belowground food web interactions by target sampling on extant and active prairie dog mounds. Specifically we are examining variations on productivity and belowground community trophic structure among different type of mounds (crater, dome and other) within inactive and active areas of two black-tailed prairie dog towns located on the Pawnee National Grasslands (PNG).

Question:
1) What is the structure of the soil food web across prairie dog colonies?
2) How do soil food webs respond to changes in prairie dog colony status (e.g., colonized, or extant)?
3) What are the relationships between the structure of the soil foodweb, the plant community and nutrient dynamics in response to changes in prairie dog colony status?

Objectives:
I. Determine how prairie dog activity (disturbance) affects belowground food webs within extant and active prairie dog colonies.
II. Determine the trophic structure of the soil communities based upon biomass estimates to identify C:N ratios and community structure.
III. Characterize aboveground plant species richness in relation to prairie dog colony status.
IV. Develop a map utilizing GPS and ArcMap® in order to characterize belowground community structure.

Hypotheses:
H1: Prairie dogs affect the shortgrass steppe (SGS) ecosystem by influencing trophic structure, by the habitat provided by burrowing, and by selective grazing of plants.

H2: The bacterial pathway has a higher rate of turnover (narrow C:N ratios) than the fungal pathway on active prairie dog colonies compared to both extant colonies and to adjacent short grass steppe.

H3: Active dome mounds will have greater densities of fungi than inactive dome, crater and other mounds due to the increased burrowing by prairie dogs and that dome mounds are considered primary entrances into the burrowing systems.

Hypothesis one focuses on data acquired in year one. Hypotheses one-three focus on data acquired in all years.

Preliminary Data for fungal-arthropod densities and interactions:

• Prairie dog activity does have an affect on belowground arthropod populations. The increased abundance of Cryptostigmata and Astigmata mite order in Active sites may be attributed to the influx of detrital material (i.e. fecal matter, fur, plant material) into the belowground ecosystem due to prairie dog activity. Lack of prairie dog activity in the Extant and Off-town sites shows a decrease in these arthropod populations.

• The slight decrease of fungal hyphae in our Active treatment in 2004 may be explained by the increased proliferation of Astigmata and Cryptostigmata populations.

• Collembola populations increased as total fungal lengths decreased over the course of 2003 for both CPER and PNG. Increased consumption of hyphae or persistent drought conditions may explain prevalent seasonal differences.

• Arthropod and fungal communities may be significantly influenced by both the physical disturbance of soil from burrowing and from prairie dog activity.

Future Directions:

• We will be gathering spatial and temporal data from future target samples and extrapolating these data in hopes to elucidate the effects of prairie dog activity disturbances on structures of belowground food webs within the shortgrass steppe ecosystem.

• Utilizing GPS technology we will be developing a map to illustrate changes in belowground food web stability dynamics.

• Investigate the effects of prairie dog mound structure on belowground food webs.

Impacts of Altered UV radiation on below ground food web communities in the Shortgrass Steppe

Quirk, Meghan H.[1], Jennifer King[2], Daniel Milchunas[3,4], Arvin Mosier[5,4], Jack Morgan[6], and John C. Moore[1]

[1]Department of Biological Sciences, University of Northern Colorado, Greeley, CO 80639; [2]Department of Ecology, Evolution and Behavior, and Department of Soil, Water and Climate, University of Minnesota, St Paul, MN 55108; [3]Forest, Range, and Watershed Stewardship Department, Colorado State University, Fort Collins, CO [4]Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523; [5]USDA-Agricultural Research Service, Soil-Plant-Nutrient Research Unit, Fort Collins, CO 80522; [6] USDA-Agricultural Research Station, Rangeland Resources Research Unit, Fort Collins, CO 80526

A three-year study was initiated in spring of 2001 in the Colorado shortgrass steppe to identify the effects of two different components of climate change; UV radiation and CO_2 on below ground and litter food webs. Interactions between UV radiation and elevated CO_2 have very seldom been studied. In the field, open-air structures were constructed of solid plastic sheet material that either passed all wavelengths of solar radiation or passed all wavelengths except for UV (280-315 nm). Litterbags containing plant tissue grown under different CO_2 conditions were placed under some of the structures to monitor decomposition and soil fauna. Precipitation under all structures was applied by manual watering, and two levels were maintained to simulate high precipitation or drought conditions. Litter grown under elevated CO_2 yielded more recalcitrant vegetative material. UV radiation had a significant effect on overall densities of arthropods. The exclusion of UV significantly favored higher numbers of arthropods over all three years. In dry conditions, densities of bacteria cells were significantly effected by the interaction between litter grown under ambient CO_2 and exposed to ambient UV radiation and litter grown under elevated CO_2 and exposed to excluded UV radiation. Litter grown under ambient CO_2 conditions and exposed to ambient UV radiation in wet conditions, however, favored higher densities of fungal hyphae. These data suggest that UV-B radiation alters belowground and litter food web structure.

Summary

- Precipitation (wet and dry treatments) did not appear to be as strong of an influential factor on overall densities of bacterial cells (Figure 3).
- There was a significant interaction between CO_2 and UV with respect to density of bacteria cells.
- Significant interactions were observed in dry treatments only (Figure 3).
- Densities of fungal hyphae were higher under ambient UV in ambient CO_2 litter (Figure 3).
- UV radiation had a significantly adverse effect on densities of arthropods.
- Exclusion of UV favored higher numbers of arthropods over all three years.
- Litter grown under ambient and elevated CO_2 yielded more recalcitrant vegetative material.
- Densities of bacteria and fungi were lower in comparison to total arthropods.
- Lower densities of fungal hyphae may be attributed to increased densities of arthropods as well as consecutive years of drought conditions.
- UV-B radiation alters the structure of belowground and litter food webs.
- In order to more accurately infer microbial activity under ambient and excluded UV radiation future examinations may include the exclusion of arthropods.

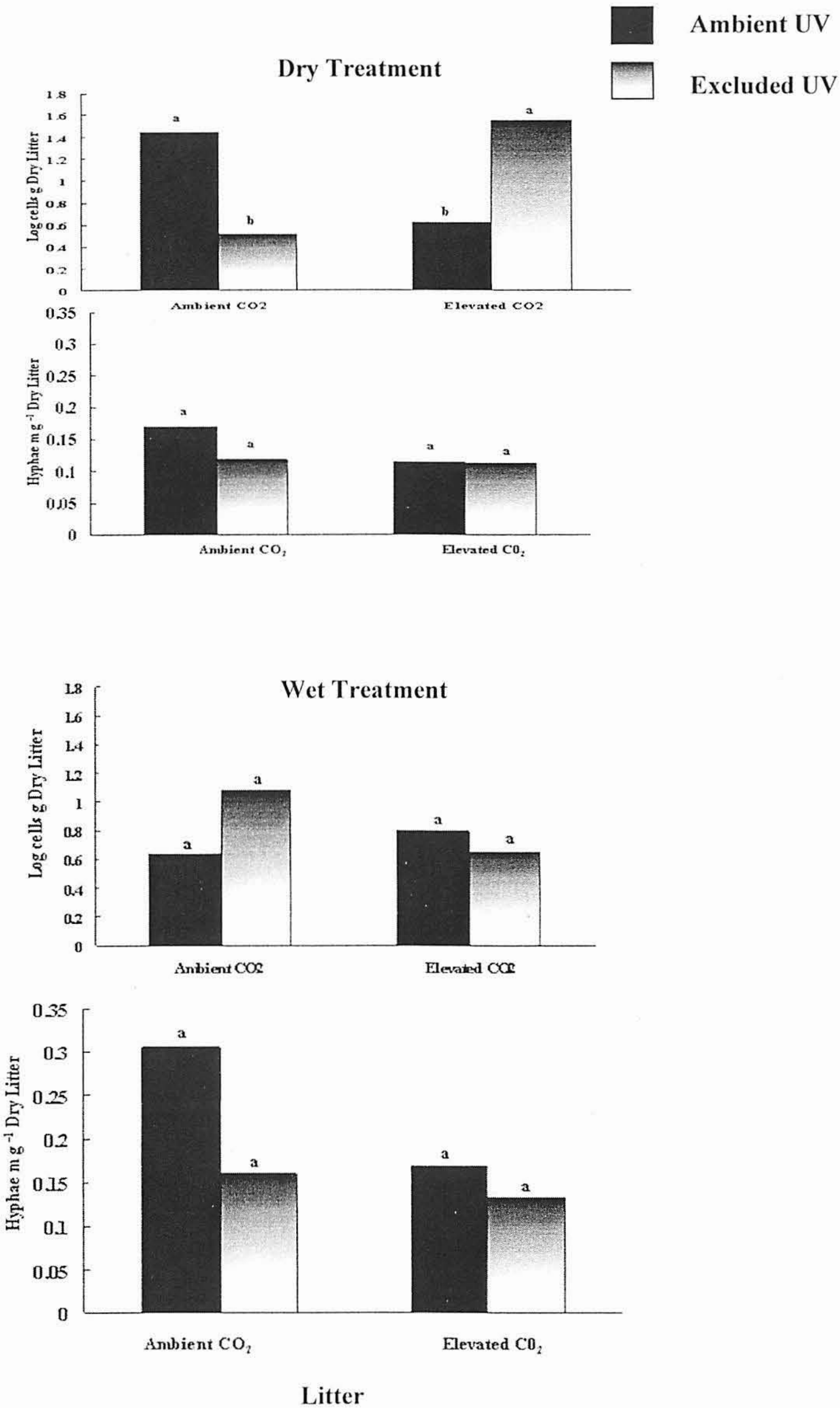


Figure 3. Significant interaction effects were observed among CO_2, UV, and Precipitation ($p<0.05$). Bars not sharing the same letter are significantly different.

Section 4:

SGS-LTER Poster Abstracts

Prairie dogs and harvester ants as disturbance agents on the shortgrass steppe: Implications for habitat heterogeneity

Chrissy Alba and Jim Detling

Department of Biology, Colorado State University, Fort Collins, CO 80523-1878

Much of the shortgrass steppe ecosystem of northeast Colorado has been converted for grazing or agricultural use since post-European settlement. Historically, the deep, nutrient-rich soils of the steppe supported the growth of plentiful forage for large, native herbivores such as bison, pronghorn, and elk. Grassland ecosystems generally are attractive to people because they support crops and domesticated livestock. As a result, more than 98% of the North American grasslands have been exploited and altered from their native state. Such a paltry remnant of native habitat does not bode well for the native flora and fauna that depend on it. Therefore, researchers are charged with studying this ecosystem to provide conservationists and managers with the tools necessary to safeguard its currently tenuous future.

A key characteristic of grasslands is that they undergo cyclic disturbance from drought and fire. These large-scale disturbances are integral to maintaining landscape-level heterogeneity. In addition to large-scale heterogeneity, there are patches, or mosaics, within the matrix of the grassland. Often, animals create localized disturbances that contribute to this patchiness. The term "ecosystem engineer" describes animals that drastically modify their habitat in order to live. Their actions in turn alter the resources available to other organisms; this can precipitate an influx or efflux of plant and animal species from the area, which results in altered species composition and distribution. I will conduct research to elucidate the disturbance effects of two grassland ecosystem engineers: the black-tailed prairie dog (*Cynomys ludovicianus*) and the western harvester ant (*Pogonomyrmex occidentalis*).

The engineering activities of these two species have important implications for native flora. First, they directly affect vegetation near their mounds (prairie dogs) and nests (ants) by clipping and eating vegetation. Second, they indirectly affect vegetation by excavating large amounts of soil, which alters soil chemistry, soil-water levels, and soil physical characteristics (e.g., changes in bulk density or dehorizonation from mixing). Third, they alter seed bank characteristics. Prairie dogs may ingest seeds while foraging vegetation, or they may graze vegetation prior to seed set. The western harvester ant, as implied by its name, forages for seeds and returns them to the nest for consumption and storage. These behaviors result in modified seed distributions and abundances, which in turn can influence plant community structure. Because prairie dogs and harvester ants are such influential and widespread components of the shortgrass steppe ecosystem, I am interested in understanding how their disturbance effects interact where they co-occur. Currently, there is scant literature that addresses this issue. To elucidate how these important ecosystem engineers alter habitat, I will measure the following: nest and burrow densities and distributions; total area of denuded soil on prairie dog and ant colonies; and aboveground vegetation dynamics.

A comparison of the Bowen ratio energy balance and Eddy covariance methods for determining surface fluxes over shortgrass steppe

JG Alfieri[1], PD Blanken[1], J Morgan[2], D Smith[2], J Wolchansky[1], RL Grossman[3]

[1]University of Colorado, Department of Geography, Boulder, Colorado 80309, [2]USDA Agricultural Research Service, Fort Collins, Colorado 80526, [3]Colorado Research Associates, Boulder, Colorado 80301

Due to both practical and theoretical differences inherent to the Bowen Ratio Energy Balance (BREB) and Eddy Covariance (EC) methods for determining surface fluxes, each of these methods can yield substantially different measures of the same flux. This research sought to quantify the magnitude and scope of these differences by analyzing data collected at the CPER during the summer of 2004. By elucidating relationships between the various energy and mass fluxes as measured by the two methods, this research was able to generate techniques that could be used to reconcile data collected by each of these methods. However, emphasis was placed on the latent heat (λE) and carbon dioxide (F_c) flux since they demonstrated the greatest differences.

When measured via the BREB method λE was observed to be as much as 40% greater than when measured by the EC method. Similarly, F_c, when measured using the BREB method, could by as much as 2.5 times greater than when measured by the EC method. However, when the BREB data was further processed using a family of polynomial relationships developed as a part of this research those differences could be reduced to less than 10%. This, in turn, allows for the development of a single long-term data set that could be used as the foundation for further research investigating the linkages between the land surface and the atmosphere.

Land-atmosphere interactions in semiarid areas: Examples from Shortgrass Steppe and Jornada LTER sites

Adriana Beltrán-Przekurat[1], Roger A. Pielke[1] Sr., Jack A. Morgan[2], Daniel R. LeCain[2] and David Smith[2]

[1] Department of Atmospheric Science, Colorado State University. Fort Collins, CO 80523. [2] USDA-ARS Rangeland Resources Research Unit, 1701 Centre Ave. Fort Collins, CO 80526.

Observations and modeling results have shown that land use practices have affected regional climate in the Shortgrass Steppe (SGS) region through their influence on surface energy partitioning and balance. A coupled atmospheric-vegetation model constitutes an appropriate tool to study the interactions and feedbacks between the vegetation, soil and the atmosphere. The Regional Atmospheric Modeling System coupled with a plant-scale model GEMRAMS is used to quantify the potential impact of these land use practices on mesoscale climatic patterns at the SGS LTER site. At the Jornada LTER, New Mexico, the conversion from the natural landscape of grasses to the current landscape of shrubs has been shown with the high resolution model version of GEMRAMS to result in significant changes in surface heat and moisture fluxes. The same modeling approach will be used in the SGS LTER site. Measurements of CO_2 and energy and water fluxes will be used to validate the performance of the coupled modeling system GEMRAMS.

Dispersal and demography of thirteen-lined ground squirrels on and off prairie dog colonies

A.L. Benson and P. Stapp

Department of Biological Science, California State University, Fullerton, CA 92834 USA

Thirteen-lined ground squirrels (*Spermophilus tridecemlineatus*) and black-tailed prairie dogs (*Cynomys ludovicianus*) are diurnal, semi-fossorial squirrels that co-occur in many areas of shortgrass steppe in northern Colorado. Grazing and burrowing by prairie dogs causes significant changes in the landscape that may negatively affect ground squirrels. Additionally, although both species live in the same areas, interactions between the two species have not been studied. We propose to study the population ecology and dispersal behavior of thirteen-lined ground squirrels in and out of prairie dog colonies. We hypothesize that colonies represent poorer quality habitat for ground squirrels, resulting in lower population densities, smaller litters, larger home range sizes, higher mortality, lower body weights, and longer dispersal distances compared to areas without prairie dogs. To test these hypotheses, we will measure population density and demographic characteristics of squirrels in and out of colonies by live-trapping on a 19-ha grid, with half of the grid on and half the grid off a large prairie dog colony. In Summer 2005, we will radio-collar eight juvenile females from colony and grassland areas to compare dispersal distances between habitats. Dispersal behavior is also influenced by the level of sociality, with asocial animals predicted to display less sex-biased dispersal. Thirteen-lined ground squirrels are among the least social of ground squirrels, but dispersal behavior has not been studied in detail in their natural habitat. We hypothesize that both frequency and distance of dispersal will be less male-biased than in other, more social, ground squirrel species. To test this hypothesis, in Summer 2006 we will radio-track 16 individuals of each sex to estimate dispersal distances. This study will provide a better understanding of species interactions in mammalian communities in shortgrass steppe and will help determine the role of sociality as a determinant of dispersal behavior.

Silica biogeochemistry across a grassland climosequence

S.W. Blecker, S.E. Melzer-Drinnen, C.M. Yonker and E.F. Kelly

Soil and Crop Sciences, Colorado State University, Fort Collins, CO 80523-1170

The importance of primary mineral dissolution and formation of secondary minerals has been recognized as a primary control on silica concentrations and fluxes in soil solutions and stream waters. Such reactions are important in understanding such earth surface processes as soil development, soil buffering against acid deposition and regulation of atmospheric carbon dioxide. Links between terrestrial and marine systems are also important in terms of Si, where Si-based diatoms play a large role in marine primary productivity. Assessments of the controls on silica export from the terrestrial environment tend to ignore the role of plant silica cycling and biogenic silica storage in soils and vegetation, assuming that mineral weathering reactions alone controls this flux. Most studies also tend to occur in forested ecosystems; though weathering in grasslands is typically less intense, they cover up to 40% of the earth's land surface.
To this end, we employed a mass balance study of Si pools and fluxes along a grassland climosequence in the Central Great Plains. Though biologically mediated Si accounts for only a few percent of the total Si in these systems, we believe that this Si is far more labile than mineral Si. In general, shortgrass systems tend to have greater pools of soil biogenic Si than tallgrass ones though the plants add less Si to the soil annually. Although these grassland systems are less weathered than temperate and tropical forests, biological Si cycling appears to impact mineral weathering on the same order of magnitude as that seen in the forested systems.

Proposed Improvements to the Shortgrass Steppe Field Station

Ingrid Burke[1], William Lauenroth[1], Ed Redente[1], Jack A. Morgan[2], Justin Derner[2], Alan Knapp[3], Jim Detling[3], Michael Antolin3, Gene Kelly[4], Nicole Kaplan[4], Rich Conant[5], John Moore[6] and J.C. Culwell[7]

[1]Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University (CSU), [2]Agricultural Research Service, US Department of Agriculture, [3]Department of Biological Sciences, CSU, [4]Department of Soil and Crop Sciences, CSU, [5]Natural Resources Ecology Lab, CSU, [6]University of Northern Colorado, and [7]Facilities Design, CSU.

The Colorado State University Shortgrass Steppe Field Station is located on the Central Plains Experimental Range (CPER) in northeastern Colorado. The field station represents a formal collaboration among CSU, the Agricultural Research Service, and the University of Northern Colorado. Experiments have been conducted on the CPER since 1938, and the Field Station has been in existence since the 1960's. The research conducted at the SGS Field Station is recognized worldwide as one of the most important sources of new ideas and important results in grassland ecology. Our research has also had major implications for land management in the region. The field station hosts classes, undergraduate research interns, graduate research, and a large number of outreach activities for groups including K-12 education, local ranchers, and conservation organizations. ***We propose to significantly enhance the Shortgrass Steppe Field Station so that it can continue to represent a multi-institutional center of excellence for research, education, and natural resource interpretation for shortgrass steppe ecosystems.***

Variability of nitrogen dry deposition across microclimates

Martin Danglemayr, Rebecca Riggle and Ingrid C. Burke

Department of Forest, Rangeland and Watershed Stewardship, Colorado State University, Fort Collins, CO 80523-1472

Anthropogenic sources of aerosol nitrogen (N) could lead to vegetation shifts and eutrophication. Our objectives were to assess deposition variability and the influence of anthropogenic N sources on deposition rates, and to obtain an estimate of N dry deposition rates for the shortgrass steppe. Our results showed that there was no significant variability in deposition rates and that dry deposition rates remained relatively constant across the shortgrass steppe.

Mediation of spatial organization in the switf fox: Preliminary observations

Darden, S. K., and T. Dabelsteen

Institute of Biology, University of Copenhagen

Animals use signals to mediate social interactions. Signalling environments often include several individuals that have access to the transmitted information, i.e. a communication network. Acoustic, chemical, and visual signals operate in this network to convey information about a signaller's identity, behaviour, and location and their transmission properties determine signal value at different distances from the signaller (spatial and temporal). This project investigates aspects of swift fox behaviour, ecology, and physiology that function in shaping swift fox communication networks and how we may use this information in the management and conservation of this species. The study is being carried out with radio-collared foxes on the Central Plains Experimental Range and the Pawnee National Grassland and will run for a total of three years.

Historical and current trapping records for heteromyid rodents in northern Colorado

Dye, J.L., and M.R. Banta

Department of Biological Sciences, University of Northern Colorado, Greeley, CO

As part of a larger project examining aspects of torpor and winter metabolism in the silky pocket mouse (*Perognathus flavus*), we attempted to trap several individuals of *P. flavus* at various sites on the Central Plains Experimental range (CPER) during summer 2004. Historical trapping records for this area include this species as well as other heteromyid rodents (*Perognathus hispidus* and *Dipodomys ordii*). For the same project we also trapped a short-grass region 15 km east of Greeley, CO. This area is on State of Colorado Public Land that is leased to a local rancher and grazed periodically by cattle and horse.

On the LTER we accumulated a total of 1580 trap nights between June-August 2004 spanning seven different sections. This resulted in the capture of eight individuals: 3 Ord's kangaroo rats (*D. ordii*), 3 deer mice (*Peromyscus maniculatus*), 1 northern grasshopper mouse (*Onychomys leucogaster*) and one juvenile cottontail rabbit (*Sylvilagus* spp.). This represents an overall trapping success rate of 0.5%, with no captures of the target species.

On the east Greeley site we accumulated 1591 trap nights between September-November 2004 all within a single section (Sec6 T5N R63W). This resulted in the capture of 228 individuals: 91 Ord's kangaroo rats (*D. ordii*), 33 deer mice (*P. maniculatus*), 33 northern grasshopper mice (*O. leucogaster*), 19 plains pocket mice (*Perognathus flavescens*), and 53 silky pocket mice (*P. flavus*) which was the target species. This capture represents an overall trapping success rate of 14.3 %, with a 3.3 % capture of the target species.

The east Greeley site appears to have a greater abundance of vegetation for an increase of ground cover and food availability. The sandy soil at the east Greeley site may also prove to be more favorable for burrowing by many individuals. Lastly, with the strain imposed by several years of drought, individuals at the east Greeley site may have been affected less by the drought than individuals on the CPER.

GIS data and tools available at the SGS LTER

Flynn, RL, and NE Kaplan

Shortgrass Steppe Long Term Ecological Research, Department of Soil and Crop Sciences, Colorado State University, Fort Collins, CO 80523-1170

Tools for gathering and viewing GIS data in the field. Handheld PC's now provide a means for gathering spatial data for LTER experiments. With these devices, field workers can navigate to and record research site information.

Tools on the SGS website for viewing and obtaining GIS data. The SGS Map Viewing Tool is available on the SGS Website for viewing, printing and capturing images of GIS data. The basic version only requires an internet browser, while the advanced version uses a freely downloadable tool for customized maps.

Tools for analysis of SGS spatial data GIS data. Analysis and modeling of data using GIS software are being performed extensively at the SGS LTER. Examples include generation of random sample points, proximity analysis, interpolation of sample data, spatial change over time, spatial correlation of physical factors (soil, water, vegetation, etc), species population and interaction modeling, and climate modeling.

GIS data layers. Various GIS data layers are available to researchers at the SGS LTER. These include static physical data (boundaries, elevation, water, pastures, roads, soils, etc.), dynamic data (prairie dog towns, burn areas, exclosures), experiment site data, and multispectral imagery.

Species interactions across three trophic levels: *Cynomys ludovicianus* colonies increase floral visitation by insects.

Hardwicke, KB, and JK Detling

Department of Biology, Colorado State University, Fort Collins, CO 80523-1878

Black-tailed prairie dogs (*Cynomys ludovicianus*) change vegetation structure and composition on the mixed grass prairie and shortgrass steppe, with active colonies showing higher herbaceous dicot coverage, reduced canopy height, and an increase in bare ground, allowing for higher germination of flowering annuals. Extensive (> 40 ha) *C. ludovicianus* colonies create large landscape patches within the prairie matrix, which pollinating insects should react to favorably if indeed floral resources are increased, and may perceive or utilize as a differing habitat type. In early summer 2003, and again throughout the entire growing season in 2004, floral resources were measured on a total of 6 colony sites on the SGS-LTER. Diurnal insect floral visitation was also measured at these same sites. Total abundance of inflorescences from all zoophilic species increased on colony sites in both years. Total frequency of insect visitation also increased on colony sites. The gross diversity of the community of diurnal insects by seems also to track the species diversity of the floral resources present in a given year. These findings show a clear link between three trophic levels, with conservation and possible management implications for optimizing suitable habitat for a thriving native pollinator community and the host plants they service on the shortgrass steppe.

Prairie dogs, plants, and plague: A study of plant community and nutrient cycling on prairie dog colonies

Laurel M. Hartley and James K. Detling

Department of Biology, Colorado State University, Fort Collins, CO 80526-1878

Black-tailed prairie dogs (*Cynomys ludovicianus*) physically influence their environment by grazing, burrowing, and actively removing taller vegetation. These activities can have profound impacts on plant communities and nutrient cycling. Effects of prairie dogs on plant community and nutrient cycling have been extensively studied in the mixed-grass prairie where grazing by prairie dogs results in decreases in standing biomass, canopy height, litter, and cover of graminoids relative to forbs. Also on the mixed-grass prairie, prairie dog grazing tends to result in increases in crude protein concentration of individual plants and increases in net nitrogen mineralization rates. Studies from the mixed-grass prairie are being used to make management decisions for prairie dogs in other ecosystems. However, the shortgrass steppe (SGS) is drier and is dominated by drought resistant species such as blue grama (*Bouteloua gracilis*) that are also resistant to grazing. Further, prairie dog colonies on the SGS are often subject to periodic extinction and recolonization events due to plague. Extinction events may serve to temporarily alleviate grazing pressure from prairie dogs. This poster presents results from a comprehensive study of the effects of prairie dogs on plant community composition and nutrient cycling on the SGS of Northeastern Colorado. Plant community composition, species richness, above and belowground biomass, shoot nitrogen, and nitrogen mineralization were measured on 3 recently colonized colonies, 3 recently abandoned colonies, and 3 colonies that have been occupied consistently for over 15 years and compared to off-colony control sites in similar habitats. The trends for the SGS are the same as those found on the mixed-grass prairie (i.e. an overall reduction in biomass, a decrease in canopy height, an increase in biomass and cover of forbs relative to grasses, an increase in plant shoot nitrogen, and an increase in nitrogen mineralization), but the magnitude of the changes on the SGS are much less and in some cases are not statistically significant.

The Colorado Front Range GK-12 Project: Connecting kids and ecology – teachers and researchers

Laurel M. Hartley[1], Meghan H. Quirk[2], John C. Moore[2]

[1]Department of Biology, Colorado State University, Fort Collins, CO 80526-1878
[2]Department of Biological Sciences, University of Northern Colorado, Greeley, CO 80639

The Colorado Front Range GK-12 Project is a joint effort of The University of Northern Colorado, Colorado State University, Weld County School District, Poudre School District and other collaborators. The theme of the project is "human impacts on ecosystems along the Front Range." The project provides funding for graduate students (the GK-12 Fellows) at the two universities to involve themselves in curriculum development and delivery within the local public school systems. It also funds summer research opportunities for public school teachers to enhance their understanding of the scientific process. GK-12 Fellows are involved in diverse science classes at all levels within the school systems. GK-12 Projects range from studies of acid deposition at Northridge HS to studies of prairie dogs at Rocky Mountain HS. One of the GK-12 Project's strengths is that it fosters lasting links between schools and community partners. Emphasis is on ensuring that public school students (and their teachers) are exposed to experiences in the field, making learning a hands-on, interactive, questions-driven experience. This brings the excitement of university research into public school classrooms and forms links between the universities and the school systems.

Ecosystem response to climate change: Sensitivity of grassland ecosystems across the Great Plains to variability in precipitation.

Heisler, JL, and AK Knapp

Department of Biology, Colorado State University, Fort Collins, CO 80526-1878

Projected changes in climate include warming of the atmosphere and increasingly variable precipitation regimes, both of which may affect soil, plant, and ecosystem properties. Water availability is an important determinant of aboveground net primary productivity (ANPP) and increasing evidence suggests that many aspects of ecosystem structure and function are quite sensitive to intra-annual variability in precipitation. ANPP is an integrated assessment of ecosystem structure and function and thus a valuable means of identifying change in response to resource availability (water). However, responses in ANPP are subject to physiological, vegetation composition, and biogeochemical constraints that are altered on different time scales. For this reason, this investigation will additionally seek to identify alterations in plant physiology/phenology, community-level processes, and soil processes – as these system attributes may act independently or interactively to drive variations in ANPP.

The overall objective of this research is to develop a mechanistic understanding between variation in ANPP and variation in precipitation across sites that span a broad precipitation, soil nutrient and species composition (short to mixed to tallgrass) gradient. This research is a multi-site study that includes the Shortgrass Steppe LTER, the Konza Prairie LTER, and the KSU Agricultural Research Center in Hays, Kansas.

Shortgrass Steppe Long Term Ecological Research

Kelly, EF[1], IC Burke[2], MF Antolin[3], WK Lauenroth[2], JC Moore[4], JA Morgan[5], JK Detling[3], DG Milchunas[2], AR Mosier[5], WJ Parton[6], KH Paustian[6], RA Pielke[7] and PA Stapp[8]

[1]Soil and Crop Sciences, Colorado State University, [2]Forest, Rangeland and Watershed Stewardship, Colorado State University, [3]Biology, Colorado State University, [4]Biological Sciences, University of Northern Colorado, [5]USDA-ARS, [6]NREL, Colorado State University, [7]Atmospheric Science, Colorado State University, [8]Biological Science, California State University-Fullerton

The shortgrass steppe (SGS) Long Term Ecological Research (LTER) site is part of a network of long-term research sites supported by the National Science Foundation. The network consists of 26 sites representing diverse ecosystems and research emphases, yet maintaining a common mission and sharing expertise and data.
The SGS site, located on the Pawnee national Grassland, uniquely represents the shortgrass steppe ecosystem within the network. We assert that the ecological structure and function of the shortgrass steppe is governed by climate, human use, natural disturbance, biota and physiography. The representation of our conceptual framework depicts the relationships between these factors and our core research areas: population dynamics, biogeochemical dynamics and land-atmosphere interactions. A summary of key research findings and current endeavors is presented for each core research area. Brief discussions of synthesis activities, cross-site projects and educational outreach activities are also presented.

LTER: Long Term Ecological Research Network

Kelly, EF, NE Kaplan, and CM Yonker

Department of Soil and Crop Sciences, Colorado State University

With an initial six sites selected in 1980, the National Science Foundation established the Long Term Ecological Research Network to study broad spatial and temporal scale environmental phenomena. Currently, 26 sites (including shortgrass steppe, SGS) represent the Network – a collaborative effort of more than 1800 scientists, students, and educators. Each site has in common a research program developed around five core research areas:

- Pattern and control of primary production
- Spatial and temporal distribution of populations selected to represent trophic structures
- Pattern and control of organic matter accumulation and decomposition in surface layers and sediments
- Patterns of inorganic inputs and movements of nutrients through soils, groundwater and surface waters
- Patterns and frequency of disturbances.

Effects of intensive livestock grazing on small mammal and macroarthropod communities in Colorado shortgrass steppe.

K.E. Levensailor and P. Stapp

Department of Biological Science, California State University, Fullerton, CA 92834 USA

Agricultural practices such as livestock grazing have been implicated as a major cause of habitat loss for native species. For some species, however, grazing may be beneficial. The Mountain Plover, *Charadrius montanus*, is a species of conservation concern in the Great Plains that prefers the short vegetation and disturbed soils that are often associated with livestock grazing. Biologists have recently advocated using grazing to create habitat for the Mountain Plover in northern Colorado, where numbers have declined, in part, because of two decades of unusually high primary production. However, intensive grazing may change interactions between plovers and other species, which may affect the suitability of the habitat *indirectly*, via changes in predation risk and availability of arthropod prey. We investigated the consequences of different grazing practices on terrestrial grassland consumers, specifically, potential nest predators such as small mammals, and aboveground macroarthropods, the major prey of plovers. In 2004, we estimated relative abundance of small mammals and macroarthropods and measured vegetation and habitat characteristics on 25, 1.10-ha plots, representing five treatments (intensive spring grazing, intensive summer grazing, moderate summer grazing, moderately grazed prairie dog colonies, and long-term grazing exclosures). Consumer abundance and diversity were compared to similar data collected in 2003, prior to the implementation of grazing treatments. There was no significance difference among treatment groups in the abundance of any small mammal species or in species richness, although exclosures tended to have the highest number of rodent species. In both years, grasshoppers were more abundant in exclosures and moderately grazed pastures than in intensively grazed treatments or prairie dog colonies. Analyses of arthropod captures in pitfall traps are ongoing.

Great Plains grassland biogeochemistry: A cross-site analysis

R.L. McCulley[1*], I.C. Burke[1], W.K. Lauenroth[1] , A.K. Knapp[2] , & E.F. Kelly[3]

[1]Department of Forest, Rangeland and Watershed Stewardship, [2]Department of Biology, and [3]Department of Soil & Crop Sciences, Colorado State University; *Deptartment of Biology, Duke University

Regional analyses and biogeochemical models suggest that ecosystem fluxes of carbon (C) and nitrogen (N) increase as precipitation increases from the semi-arid shortgrass steppe to the tallgrass prairie of the Central Great Plains; however, few field data exist to evaluate these predictions. In addition, little is known about the regional variability in the soil microbial communities controlling these biogeochemical fluxes. We measured above- and belowground net primary production, litter decomposition, soil respiration, *in situ* net N mineralization, and soil microbial community composition at 5 sites across a precipitation gradient in the central Great Plains. Aboveground net primary production, soil respiration, and litter decomposition rates all increased with increasing precipitation across the region. In contrast, *in situ* net N mineralization was not significantly different across sites, despite measurable differences in the amount of plant available N. Distinct soil microbial communities were associated with the grassland community types suggesting that alterations in microbial communities may contribute to the observed biogeochemical differences across sites. While majority of C fluxes appear tightly coupled to water availability in these grassland sites, belowground root C inputs and internal N cycling via mineralization did not. These are important ecosystem processes in Great Plains grasslands that require further study.

Proposal to investigate the role of biogenic silica on mineral weathering: A quantification of silica mobilization in diverse terrestrial ecosystems of the LTER Network

Suellen Melzer-Drinnen and E.F. Kelly

Department of Soil and Crop Sciences, Colorado State University, Fort Collins, CO 80523-1170

Silicon (Si) is the second most abundant element of the Earth's surface. In terrestrial systems, silicon is found either tied up in primary minerals, as weathering rate indicators in rivers and soils, or in forms available to plants by chemical and biological processes. Although Si sources are varied, most global silicon mass balance calculations found in the literature assume that all inputs of silicon into the oceans come from mineral weathering reactions. The role of biogenic silica stored in soils and plants has been disregarded. A growing body of evidence suggests that plants transform silicon into labile forms acting as potential sources or sinks of Si that control delivery to terrestrial aquatic and marine systems. Plants absorb silicon in the form of silicic acid (which forms primarily from the weathering of alumino-silicate minerals like feldspar) and precipitate it in cellular plant tissues in or between epidermal cells. Higher plants in terrestrial systems, specifically, have developed behaviors to where they passively and actively take up silicic acid and store (as precipitate) large reservoirs of biogenic silica. The precipitation of silica during evapotranspiration occurs as micron-sized phytoliths, amorphous hydrogenated forms of silica, which accumulate in the soil or are recycled as plants die. In essence, collecting the necessary data to evaluate the influence of terrestrial biogenic silica on weathering rates and the global silicon cycle is the focus of this study.

The most significant questions heading off this research are: *What are the quantities of biogenic silica mobilized and stored in grassland and forest systems that span climatic and geologic gradients? What are the effects of vegetation type and varying bioclimatic and geologic setting (parent material and tectonic setting) on weathering rates and the geochemical behavior of biogenic silicon? Are there different forms of biogenic silica that are more labile than others and is this a function of plant species? Does the biogenic Si among systems carry a unique Si isotopic fingerprint?* This study will not only characterize the geochemical behavior of biogenic silica and define reservoirs in end-member systems, but it will serve as a modern analog aimed to enhance our understanding concerning climate change and weathering rates in a variety of ecosystems.

Long-term response of shortgrass steppe vegetation to removal of *Bouteloua gracilis*

Munson, S.M., and W.K. Lauenroth

Department of Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO 80523-1472

The aim of this project is to assess the long-term response of shortgrass steppe vegetation to the removal of the dominant perennial grass species, *Bouteloua gracilis*. Since complete aboveground removal of *B. gracilis* from 1 m^2 plots in 1997, plant density and cover by species have been monitored annually. Treatment and control plots are located inside and outside grazing exclosure sites to address grazing impact. Removal of *B. gracilis* affected vegetation dynamics. Perennial forb and subshrub density peaked 2-4 years after removal and then declined. Density of annuals was initially higher in treatment plots, but over time showed no difference from control plots. Certain subdominant grass and sedge species initially increased in relative abundance in treatment plots, while cacti density was higher in treatment plots seven years after *B. gracilis* removal. Dominant shortgrass removal did not change species density or diversity and there were no significant grazing interactions.

Prospectus for elementary educational book: <u>My Home, Your Home: The Shortgrass Steppe</u>

Meghan H. Quirk[1,2], Lynne Fox-Parrish[1,2], Rebecca Ramirez[2], Marilyn Hilller[2], and John C. Moore[1]

[1]Department of Biological Sciences, and Mathematics and Science Institute (MAST) University of Northern Colorado, Greeley 80639; [2]S. Christa McAuliffe Elementary School, Greeley, CO 80634

The National Science Foundation (NSF) has provided the opportunity to incorporate science content into elementary curriculum through the grant program Graduate Teaching Fellows in K-12 Education (GK-12). The Colorado Front Range GK-12 grant brings graduate fellows into the classroom and K-12 teachers into the field. The GK-12 research of human impacts on ecosystems provides students with hands-on science learning. Science literacy can be used as a vehicle to teach reading, writing and mathematics. The partnership with University of Northern Colorado fellows and S. Christa McAuliffe Elementary teachers has provided an opportunity to create a book about the prairie ecosystem over the next year (2005-2006). The goal of this book, <u>My Home, Your Home: The Shortgrass Steppe</u> (working title), is to help students understand their surroundings from a scientific standpoint. The book is being written for Weld County District Six in connection with the Colorado Model Content Standards, in particular Standard 5, where students are expected to *know and understand interrelationships among science, technology, and human activity and how they can affect the world.* The book will present a story about the shortgrass steppe and the roles of various keystone species of the prairie, and contain science and math components (teaching units) that second-fourth grade teachers will be able to use in their classrooms. Students from two fourth grade classes at S. Christa McAuliffe will participate with the development of the story, science activities, and illustrations. The students will visit the SGS-LTER site in Nunn, Colorado, during fall 2005 to explore various prairie dog towns, participate in on-site science activities, and become familiar with the prairie ecosystem. The purpose of this book is to educate elementary students about the prairie ecosystem and provide teachers with an educational tool to engage students in science literacy where reading, writing and mathematics are integrated into a single unit.

Impacts of altered UV radiation on below ground food web communities in the shortgrass steppe

Quirk, Meghan H.[1], Jennifer King[2], Daniel Milchunas[3,4], Arvin Mosier[5,4], Jack Morgan[6], and John C. Moore[1]

[1]Department of Biological Sciences, University of Northern Colorado, Greeley, CO 80639; [2]Department of Ecology, Evolution and Behavior, and Department of Soil, Water and Climate, University of Minnesota, St Paul, MN 55108; [3]Forest, Range, and Watershed Stewardship Department, Colorado State University, Fort Collins, CO [4]Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523; [5]USDA-Agricultural Research Service, Soil-Plant-Nutrient Research Unit, Fort Collins, CO 80522; USDA-Agricultural Research Station, Rangeland Resources Research Unit, Fort Collins, CO 80526

A three-year study was initiated in spring of 2001 in the Colorado shortgrass steppe to identify the effects of two different components of climate change; UV radiation and CO2 on below ground and litter food webs. Interactions between UV radiation and elevated CO2 have very seldom been studied. In the field, open-air structures were constructed of solid plastic sheet material that either passed all wavelengths of solar radiation or passed all wavelengths except for UV (280-315 nm). Litterbags containing plant tissue grown under different CO2 conditions were placed under some of the structures to monitor decomposition and soil fauna. Precipitation under all structures was applied by manual watering, and two levels were maintained to simulate high precipitation or drought conditions. Litter grown under elevated CO2 yielded more recalcitrant vegetative material. UV radiation had a significant effect on overall densities of arthropods. The exclusion of UV significantly favored higher numbers of arthropods over all three years. In dry conditions, densities of bacteria cells were significantly effected by the interaction between litter grown under ambient CO2 and exposed to ambient UV radiation and litter grown under elevated CO2 and exposed to excluded UV radiation. Litter grown under ambient CO2 conditions and exposed to ambient UV radiation in wet conditions, however, favored higher densities of fungal hyphae. These data suggest that UV-B radiation alters belowground and litter food web structure.

Arthropod diversity and abundance on a suburban remnant of the shortgrass steppe

Rocky Mountain High School Biology Students (classes 2002-2005)
Tom Creegan, Tamara Driskill, Carol Seemueller
Rocky Mountain High School, Fort Collins, Colorado 80525

Arthropod censuses are conducted on the SGS-LTER site as a part of long-term ecological monitoring. As the Colorado Front Range becomes more developed, remnants of the shortgrass steppe become surrounded by human habitation. Arthropods are affected by the subsequent increase in pesticide use, change in water availability, and change in food sources. Long-term monitoring of arthropod communities on a remnant shortgrass steppe enclosed by development may provide baseline data useful for local agencies creating management plans for natural areas along the Front Range. Each spring and fall since 2002, Biology students from Rocky Mountain High School have monitored arthropods at the Cathy Fromme Prairie in Fort Collins. Students install pitfall traps in a riparian area, on a prairie dog colony, near the road, and on a rocky ridge top. Arthropods caught are identified to order, genus, or species.

Plant community changes associated with prairie dog grazing on a suburban remnant of the shortgrass steppe

Rocky Mountain High School Biology Students (classes 2002-2005)
Tom Creegan, Tamara Driskill, Carol Seemueller
Rocky Mountain High School, Fort Collins, Colorado 80525

Dr. Detling and others have documented changes in plant communities in the mixed grass prairie caused by the herbivory of the Black-tailed prairie dog, *Cynomys ludovicianus*. Canopy height, litter cover, and graminoid cover relative to forbs decrease, while species diversity, nitrogen mineralization, and crude protein increase. The shortgrass steppe is significantly different from the mixed grass prairie: precipitation is lower, the grasses are dominated by the drought resistant (hence grazing resistant) grass Blue Grama, and prairie dog colonies are killed off periodically by plague. Additionally, in the suburban setting, large herbivores are excluded, habitat is fragmented, human interaction increases, and there is an increased presence of non-native species. Currently, researchers are studying changes in plant communities in response to prairie dog herbivory on the short grass steppe at the SGS-LTER site and Pawnee National Grasslands in order to compare to the results from the mixed grass prairie. Students from Rocky Mountain High School are tracking changes in the plant community in response to prairie dog herbivory on a suburban short grass steppe remnant which we hope to compare to the results from the SGS-LTER/PNG and the mixed grass prairie. We hope to provide useful data for local agencies creating management plans for natural areas along the Colorado Front Range.

Gene flow in metapopulations of black-tailed prairie dogs

Lisa Savage and Mike Antolin

Department of Biology, Colorado State University, Fort Collins, CO 80523-1878

Black-tailed prairie dog populations have declined dramatically over the past century not only from habitat destruction and eradication efforts but also from the introduction of the sylvatic plague, *Yersinia pestis*, which causes almost 100% mortality in black-tailed prairie dog colonies. Because of these factors, populations have become fragmented, involving both a decrease in population size and an increase in population isolation. In areas with plague, populations also experience metapopulation dynamics by undergoing regular local extinction and recolonization The objective of this study is to delineate the relationship between genetic variability and both fragmentation and metapopulation dynamics in black-tailed prairie dogs. Black-tailed prairie dogs were sampled in fragmented areas with the plague (Fort Collins, CO and Pawnee National Grassland, CO), in a naturally fragmented area without the plague (Wind Cave national Park, SD), and in a well-connected, unfragmented area without the plague (Buffalo Gap national Grassland, SD).

Analysis showed that there is a significant level of dispersal between colonies of black-tailed prairie dogs at all study sites which helps to moderate, although not completely, the effects of fragmentation and plague on genetic structure.

Prairie dog populations in Colorado (PNG and FC) are functioning as metapopulations, with gene flow between colonies high enough to decrease genetic differentiation between plague epizootics to levels similar to that of a fragmented population not subject to epizootics from plague.

Colorado GK12 human impacts along the Front Range: Integrating the Poudre Learning Center with local school district curricula

Rodney T. Simpson[1], William Hoyt[2], Catherine Hoyt[4], Raymond Tschillard[4], David Swift[5], and John C. Moore[1,3]

[1]Dept. of Biological Sciences, [2]Dept. of Earth Sciences, [3]Math and Science Teaching Institute (MAST), University of Northern Colorado, Greeley, CO 80639; [4]Greeley-Evans School District 6, Greeley, CO 80631; [5]Natural Resource Ecology Laboratory, Colorado State University, Ft. Collins, CO 80523

The mission of the Colorado GK-12 grant project is to bring university-based research into the classroom. Within this mission fellows and teachers work closely together to introduce students to scientific concepts that would not typically be introduced into K-12 classrooms. The next phase of this project will be to integrate a newly developed natural systems learning center into local school district curricula. Education programs offered at the Poudre Learning Center will reinforce concepts presented in the classroom. The Center will be a focal point for sustainable study of the Poudre River through use of laboratory and field activities, as well as field trips. Field research activities carried out at the Poudre Learning Center will serve as a model for research projects that can be carried out in Schoolyard Ecology plots. An interdisciplinary M.A. of Natural Sciences degree for practicing teachers is being offered at UNC and is being developed at CSU. Persons pursuing this degree will have the opportunity to carry out projects at the Center in order to gain research experience.

Effects of plague on small mammal communities in prairie dog colonies in shortgrass steppe

P. Stapp

Department of Biological Science, California State University, Fullerton, CA 92834

Prairie dogs (*Cynomys ludovicianus*) are extremely vulnerable to plague, a bacterial disease that infects other rodents, including other ground squirrels (*Spermophilus tridecemlineatus*). Species such as grasshopper mice (*Onychomys leucogaster*) may be resistant to plague, and act as key reservoirs and dispersal agents for the disease or infected fleas. In 2004, small mammals were sampled at 35 sites on the Pawnee National Grasslands, Colorado, including 18 active colonies, four colonies that experienced plague in 2004, six colonies had been unoccupied for >6 years (inactive), and seven grassland sites without prairie dogs (controls). Rodents were live-trapped on 1.35 or 2.25-ha plots for four consecutive nights and mornings to estimate abundance and to collect blood and fleas for plague surveys. Each site was trapped at least once from May to September. Vegetation characteristics and burrow densities were measured to determine if grazing and burrowing by prairie dogs affects small mammal communities. Grasshopper mice and ground squirrels were captured on 91% of the sites and comprised 39% and 31% of individuals captured, respectively. Species richness ranged from 1-6 species, but most sites only had these two species. Ground squirrels were least abundant on active and plague colonies, and most abundant on inactive colonies and controls. However, there were no significant site-related differences in abundance of any other species, including grasshopper mice. Rodent species richness was highest on control sites, where taller vegetation provided habitat for rarer species. Multivariate analyses, however, revealed no significant differences among sites in either their rodent or plant communities, underscoring the relatively small differences in the effects of prairie dogs in shortgrass steppe compared to other grasslands. There were no significant changes in abundance of any rodents during and after the 2004 epizootic. Grasshopper mice were consistently common, and ground squirrels remained abundant on plague sites, despite their reported susceptibility to the disease.

Effect of grazing on soil temperature and moisture and subsequent implications

Jen Wolchansky[1], Peter Blanken[1], Jack Morgan[2], David Smith[2], Joseph Alfieri[1], Robert Grossman[1]

[1]Department of Geography, University of Colorado, Boulder, CO 803009-0260, [2]USDA-ARS Rangeland Resources Research Unit, Fort Collins, CO 80526

Cattle grazing, a common form of land use on grasslands, may affect transpiration and evaporation from soil by defoliation and, in turn, could alter the climate at the surface. This study focused on whether physical landscape changes associated with grazing could have a significant impact on soil temperature and moisture, and thereby affect the microclimate. Objectives were to analyze how soil temperature and moisture vary with simulated grazing treatments. Climatological data were collected at a USDA shortgrass steppe in northeastern Colorado. Eight (1 x 1 meter) plots were selected to represent variations in the fraction of bare ground, while two (1 x 1 meter) plots were used to measure the impact of the arrangement of bare ground. Soil temperature and soil moisture measurements were recorded under a vegetated and bare area in each plot. Additionally, the eddy covariance method was used in the recommended practice of moderate grazing (40% reduction in above-ground biomass). Results from the plots were used to discuss implications for the effect of different grazing densities on the microclimate and water budgets of moderate grazing management and the accuracy of remote sensing images (using large pixels).

Effects of black-tailed pairie dog activity on fungal-arthropod densities and interactions

K. A. Wyant[1], J. M. Camenisch[1], M. H. Quirk[1], and J. C. Moore[1,2]

[1]Department of Biological Sciences, University of Northern Colorado and [2]Math and Science Teaching Institute (MAST), University of Northern Colorado; Greeley, CO 80639

This study examines the effects of burrowing activity of the black-tailed prairie dog (*Cynomys ludovicianus*) and resulting fungal-arthropod densities as part of a larger effort studying relationships between soil food web structure and nutrient flow with respect to prairie dog activity. In 2003, we studied how populated and repopulated colonies affected belowground biotic systems. We found significant differences in fungal densities among sites in the spring and fall suggesting a possible landscape effect ($p<0.1$). Differences were observed for arthropod densities among the sites, which were attributed to a landscape effect. In 2004, a more localized study was initiated in order to examine belowground community structure on a finer scale. Analyses of on and off mounds (crater and dome) within active and extant prairie dog colonies were sampled in spring and fall. Counts of total arthropods densities and in particular, densities of Cryptostigmata and Astigmata mites were higher in active colonies versus extant colonies. These results indicate a relationship between the structure of the soil food web system and disturbance from prairie dog colonization.

Section 5:

Information Management: Nicole Kaplan and Bob Flynn

Information Management System of the Shortgrass Steppe Long Term Ecological Research Project

Nicole Kaplan, IM Team Leader and Bob Flynn, IT/GIS Manager

Goals

The goals of the information management system (IMS) of the Shortgrass Steppe (SGS) Long Term Ecological Research Project (LTER) are to support site, network, and community science. A functional information management system must be well organized, yet nimble enough to support ecological research efforts that change with advances in technology (Stafford et al. 1986a, b).

The IM team reaches these goals by designing and managing a system to:

- Facilitate access to data and metadata by LTER scientists, the scientific and educational communities, and the public
- Create a robust Information Technology (IT) infrastructure that supports computing needs
- Manage and disseminate data with standardized metadata to support local, network, and community research efforts
- Ensure usability of data in the future
- Employ tools that facilitate management, discovery, and integration of information to support collaboration, outreach and synthesis
- Contribute to Network initiatives, such as Ecological Metadata Language (EML) implementation, and the LTER Network Databases

Design and Implementation of the SGS Information Management System

Scope

The scope of the data and metadata in the SGS IMS encompasses 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. Legacy data sets were produced by the 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. Most of these data and metadata have been migrated to our database from hard-copies of field data forms, Fortran card decks, an extensive series of technical reports, and over two dozen 7-track tapes (Stafford et al. 2002).

The SGS database is extensive, with over two-hundred data tables and dozens of GIS layers. A data dictionary contains important fields, such as unique data table identifiers, to locate data and metadata tables. GIS data are categorized first by geographic location, and second as static land feature data or research study data. Data tables for ongoing long term datasets are updated annually. All metadata and most data are accessible on-line in accordance with the SGS Data Acquisition Policy (http://sgs.cnr.colostate.edu/Data/AcquisitionPlcy.htm).

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://sgs.cnr.colostate.edu/Publications/searchpblctns.htm). GIS data are accessible on-line through a download page or through a map viewing tool (ArcIMS) on the SGS website. The basic version of the map viewing tool requires an internet browser, while the advanced version offers a freely downloadable java tool for customized maps (http://sgs.cnr.colostate.edu/website/). Larger GIS data files and a few of our on-going, current datasets, which 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). The large amount of storage necessary for SGS data increases dramatically each year and presents a challenge to the IM team and the existing IT infrastructure.

Design

For the past decade, SGS researchers and students worked on a network of over 20 separate Unix servers, attached to many different physical computers and networked into a coherent yet cumbersome Network File System model. In addition, there was no consistent rule for creating project directories with adequate metadata. This situation, although workable, begged for a more streamlined and efficient design. The new IMS includes a windows-based server (Ascalon) with RAID technology (Redundant Array of Inexpensive Disks) that centralizes the management of data, metadata and other information, while public accessible information is available off a web server (Limberpine) (Figure 1). This set-up allows the IM team the flexibility to migrate the system to other locations within the University 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. Everyone associated with the project is instructed to store their LTER data and other files on the centralized server so as to take advantage of the backup system and facilitate real-time capture of their LTER products. 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.

Web Page

The website currently serves metadata, data, and citations for publications dynamically from a Relational Database Management System (RDBMS) in Microsoft Access using Active Server Page technology. Project level metadata is organized by category of research, which provides an access point to downloadable metadata and data in ASCII format (http://sgs.cnr.colostate.edu/Data/DataLibrary.htm).

The IM team has plans to improve on-line searching capabilities for data and metadata by developing new website tools. We have recognized the need for better integration of related data sets, spatial and non-spatial data, publications and other research information. Recommendations from the LTER Network Website Design Working Group will be considered when implementating the second generation SGS web site (Kaplan 2005).

Documentation

The architecture, procedures, and protocols for usage and back-up of the IMS has been clearly documented in a series of guidelines that are distributed to our users. IM team roles and responsibilities are updated regularly to plan and delegate how our system is maintained and projects are completed (Table 1). Methodologies for research projects are available on-line and documented in the annual Field Crew Manual (http://sgs.cnr.colostate.edu/Research/ResearchTopics.htm).

Review of IM Team Roles

SGS formed an IM team and Nicole Kaplan moved into a full time leadership position in response to reviews of the 2002 renewal proposal. Nicole has an advanced degree in Rangeland Ecosystem Science from CSU and has conducted and supervised field sampling in the shortgrass steppe since 1996. Nicole works closely with Bob Flynn, GIS and IT manager. She consults with lead PIs to establish IM priorities and strategies annually. We are making progress toward integrating our non-spatial and spatial data sets, as recommended by past reviewers. It is important to balance our commitment to site support, Network initiatives and outside ecoinformatics projects. Nicole is also involved with the Network IM and broader ecoinformatics community as a member of LTER IMexec and Leader of the Website Design Working Group.

SGS Information Management System Supports Site, Network, and Community Science

Site Science

The IM team's support of SGS science begins with project initiation. The IM team stays involved during data collection, verification, entry, QA/QC, archiving, and publication (Brunt 2000) (Figure 2). The IM team meets with researchers annually to discuss and update metadata and data. Graduate students are instructed by their advisors to submit research metadata and data to the IM team before publication of their theses or dissertations. The guidelines for use of the SGS server facilitate the organization of raw and revised data files that are easily retrieved for migration to the web server.

Policies

SGS IMS users have access to most data and metadata as they are collected and entered following each field season. Researchers and students are made aware of policies that address public access to and use of SGS data and metadata. The few data and metadata that have restricted access contain information regarding the location of species of concern or infectious diseases. The newly adopted LTER Network data access and use policies are being interpreted and applied by the SGS IM team and PIs.

Metadata

Metadata in the SGS IMS vary in richness, since fifteen percent of our data sets are legacy data sets from the USFS and IBP. Because of this, information required to meet the new LTER standard metadata content of EML may not be available. Metadata for more recent and current SGS data sets can be submitted directly to the RDBMS by students and PIs via web-based forms. We recognize the importance of maintaining robust metadata to ensure the usability of data in the future and are making efforts to conform our metadata tables in the RDBMS to EML according to the EML Best Practices document. We have a strategy to bring metadata in the RDBMS to Level 2 EML by exporting metadata content in XML (Extensible Mark-up Language) and converting the XML to EML with XSLT (Extensible Stylesheet Language Transformation) conversion scripts. Experts at the LTER Network Office have contributed to our efforts by providing licenses for software tools, example code, and tools for harvesting SGS metadata to a Metacat, a remote ecological metadata catalog. The SGS has also contributed to a community model metadata management system in RDBMS that is being developed and implemented at various LTER sites. Lastly, a GIS EML tool developed at the CAP (Central Arizona Phoenix) LTER site was tested on SGS GIS metadata to generate EML.

Data

We are developing a suite of programs, called the Matrix, whose code originates from older Fortran QAQC programs. The Matrix currently checks and formats meteorological data for submission to CLIMdb (http://www.fsl.orst.edu/climdb/) and is being expanded to support data tables produced by floral dynamics research, which includes over sixty percent of our studies. The IM team will continue to work with researchers to develop tools to more efficiently process, quality check and publish their data with high integrity. Since February 2002, data usage has been tracked in the database with required fields on a web-based form (Figures 3, 4, and 5).

Contributions to LTER Network and community activities

Nicole and/or Bob have attended and contributed to the annual IM meetings, since 2001. Current SGS data have been uploaded to LTER Network databases including: Data Table of Contents, SiteDB, ClimDB, All Site Bibliography, and Personnel (Table 2). SGS participates in cross site and other community driven IM activities. Such activities include contributing to the development of templates for data entry, integration, analysis, and visualization of aboveground net primary production data collected at distinct grassland sites for the Canopy Databank Project (http://canopy.evergreen.edu/bcd/home.asp) at The Evergreen State College. In addition, SGS has contributed to a US Geological Survey, National Biological Information Infrastructure "data cooperative" to accelerate the sharing, standardization, completeness, and accessibility of data on the distribution and abundance of non-native plants, animals, and diseases across the United States (Kaplan 2003). Synthesis of nutrient enrichment data is being demonstrated by the Science Environment for Ecological Knowledge (http://seek.ecoinformatics.org/) project and includes SGS data and input for constructing ontologies of aboveground grassland vegetation measurements. SGS remains closely connected to the LTER IM community as Nicole Kaplan is a member of the IM Executive Committee. She presented a talk at the 6th World Conference on Systemics, Cybernetics, and Informatics. She also participated in a Web Services workshop, at the San Diego Super Computer Center (http://www.sdsc.edu/), where IMs created prototypes to synthesize distributed datasets using web-based tools. She also co-authored six articles in the LTER Network Newsletter, the LTER IM Newsletter Data Bits, and Digital Government.

Summary

SGS has a rich legacy of data sets that serve as a resource for future generations. There is a strong flow of data and metadata from the field to the IMS and communication with PIs and students along the way. The IM team and PIs need to work together to supplement the quality of metadata for legacy data sets and continue to record robust metadata for new studies to participate in synthesis research, and address broader scale ecological questions in the future. The SGS 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 IM team has developed a prototype based on the existing RDBMS to harvest EML to a metacat, design more efficient web tools, and better integrate project and data table level information. The IM team and IT infrastructure are challenged by increasing quantities of data, samples, and specimens. Software and hardware upgrades are necessary to maintain a strong IT infrastructure that supports SGS computing needs.

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List of Information Management Acronyms for SGS-LTER

ArcIMS – Internet Mapping Service product by ESRI

ARS, USDA – Agricultural Research Service, United States Department of Agriculture

CPER – Central Plains Experimental Range

EML – Ecological Metadata Language

GIS – Geographic Information System

GPS – Global Positioning System

IM – Information Management

IMS – Information Management System

IT – Information Technology

LTER – Long Term Ecological Research

PNG – Pawnee National Grassland

RDBMS – Relational Database Management System

SEEK – Science Environment for Ecological Knowledge

SGS – Shortgrass Steppe

USFS – United States Forest Service

XML – Extensible Markup Language

XSLT - Extensible Stylesheet Language Transformations

More Information About SGS-LTER Information Management Projects

Ecoinformatics.org - Ecoinformatics.org is an open, voluntary collaboration of developers and researchers that aims to produce software, systems, publications, and services that are beneficial to the ecological and environmental sciences. Source: http://www.ecoinformatics.org/

EML - Ecological Metadata Language (EML) is a metadata specification developed by the ecology discipline and for the ecology discipline. It is based on prior work done by the Ecological Society of America and associated efforts (Michener et al., 1997, Ecological Applications). EML is implemented as a series of XML document types that can by used in a modular and extensible manner to document ecological data. Each EML module is designed to describe one logical part of the total metadata that should be included with any ecological dataset.

LTER has generated a vast number of data sets, which have the potential to greatly enhance understanding of the complexity of the biosphere. However, broad-scale or synthetic research is stymied because data are largely unorganized and inaccessible as a consequence of their tremendous heterogeneity, complexity, and spatial dispersion in many separate repositories. EML has been adopted as the first metadata content standard for the LTER Network and was designed specifically to facilitate integration of ecological data. Wide adoption and use of EML will create exciting new opportunities for data discovery, access, integration and synthesis. New IM Review Criteria state that metadata *shall* be EML-compliant at level 2 (discovery). Source: http://knb.ecoinformatics.org/software/eml/

JAVA - A high-level programming language developed by Sun Microsystems, which is well suited for developing applications for the world wide web. Source: http://www.webopedia.com/TERM/J/Java.html

RDBMS – A type of data management system that stores data in the form of related tables. Information including data, metadata, personnel, and citations for different publications are spread across different tables, and as a result, the information can be joined together to be viewed in many different ways. Source: http://www.webopedia.com/TERM/R/RDBMS.html

XML - Extensible Markup Language is a text format that is simple and flexible enough to allow designers to create their own tags, which enable the definition, transmission, validation and intepretation of data between applications and organizations. Sources: http://www.webopedia.com/TERM/X/XML.html, http://www.w3.org/XML/

XSLT – Extensible Stylesheet Language Transformations allow us to transform our structured information into an order that meets a purpose other then how it is created and stored. The transformation is expressed in an XML model of elements and attributes, in our case, from the SGS-LTER RDBMS. The transformation occurs by creating "an example" of how data from the SGS-LTER XML model maps to the EML model. Source: http://www.xml.com/pub/a/2000/08/holman/index.html?page=3#xsltdesc

Information about Ecoinformatics Projects at SGS-LTER

Canopy Databank – DataBank is a resource for presenting, sharing, archiving, and searching for ecological studies. The project has focused on forestry and canopy studies. Currently, Reseachers at three LTER grassland sites (JRN, SEV, and SGS) independently collect similar, but not directly comparable NPP data. These data were chosen for an integration experiment. We devised generalized conceptual models for NPP field data and site-plot representations and implemented corresponding database components. We generated and later populated MS Access databases, and automatically created metadata specific to the three grassland sites, in the newly developed Ecological Metadata Language (EML).
Source: http://scidb.evergreen.edu/databank

SEEK – The goals of the Science Environment for Ecological Knowledge (SEEK) are to make fundamental improvements in how researchers can 1) gain global access to ecological data and information, 2) rapidly locate and utilize distributed computational services, and 3) exercise powerful new methods for capturing, reproducing, and extending the analysis process itself. Sources: http://www.ecoinformatics.org/projects.html, http://seek.ecoinformatics.org/

Web Design Working Group – Since our first generation LTER web sites were launched, our users' expectations, information technologies, and design techniques have evolved. Our challenges today are serving gigabytes of metadata and data for hundreds of data sets from a federated system of LTER web servers, updating backend databases with dynamic content, and keeping up with drifting standards and media in which to publish data in various formats. A working group was formed within the LTER IM community to address these challenges. The group plans to create recommendations for developing new or second generation web sites that will allow sites to maintain their own web tools that fit in with their local organizational structure and meet the needs of their local site users.
Source: http://intranet.lternet.edu/archives/documents/Newsletters/DataBits/05spring/#2fa

Table 1. Roles and delegation of critical tasks for SGS IM team personnel.

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

* Planned to begin 2005 Fall Semester

Table 2. SGS data are updated on the Network Information System databases quarterly.

Database	Last Updated
DTOC	Spring 2005
SiteDB	Spring 2005
ClimDB	Spring 2005
Allsite Bibliography	Spring 2005
Personnel	Spring 2005

Figure 1. SGS-LTER Information Technology Infrastructure

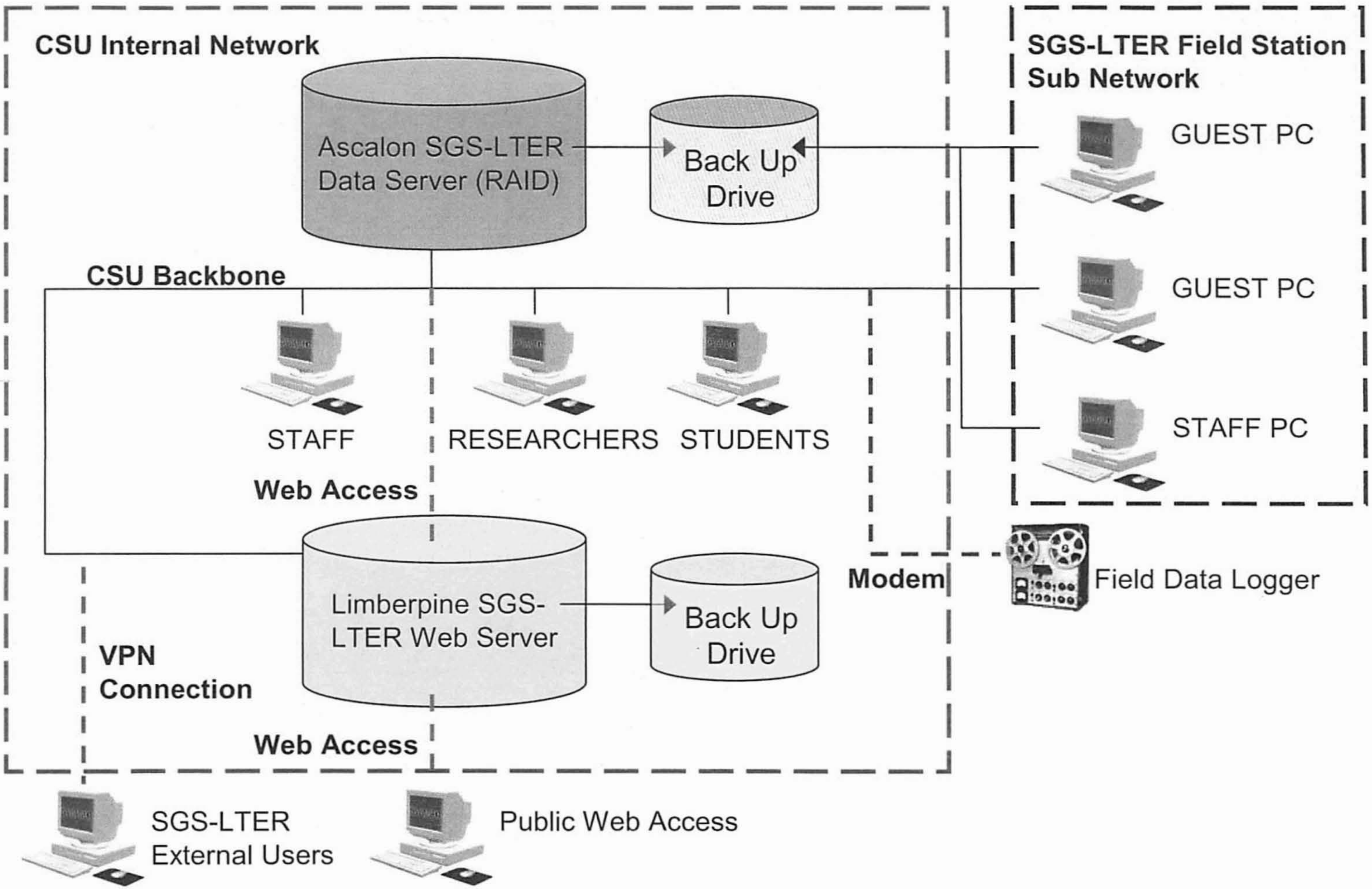


Figure 2. Time line of collecting, verifying, archiving, and publishing data

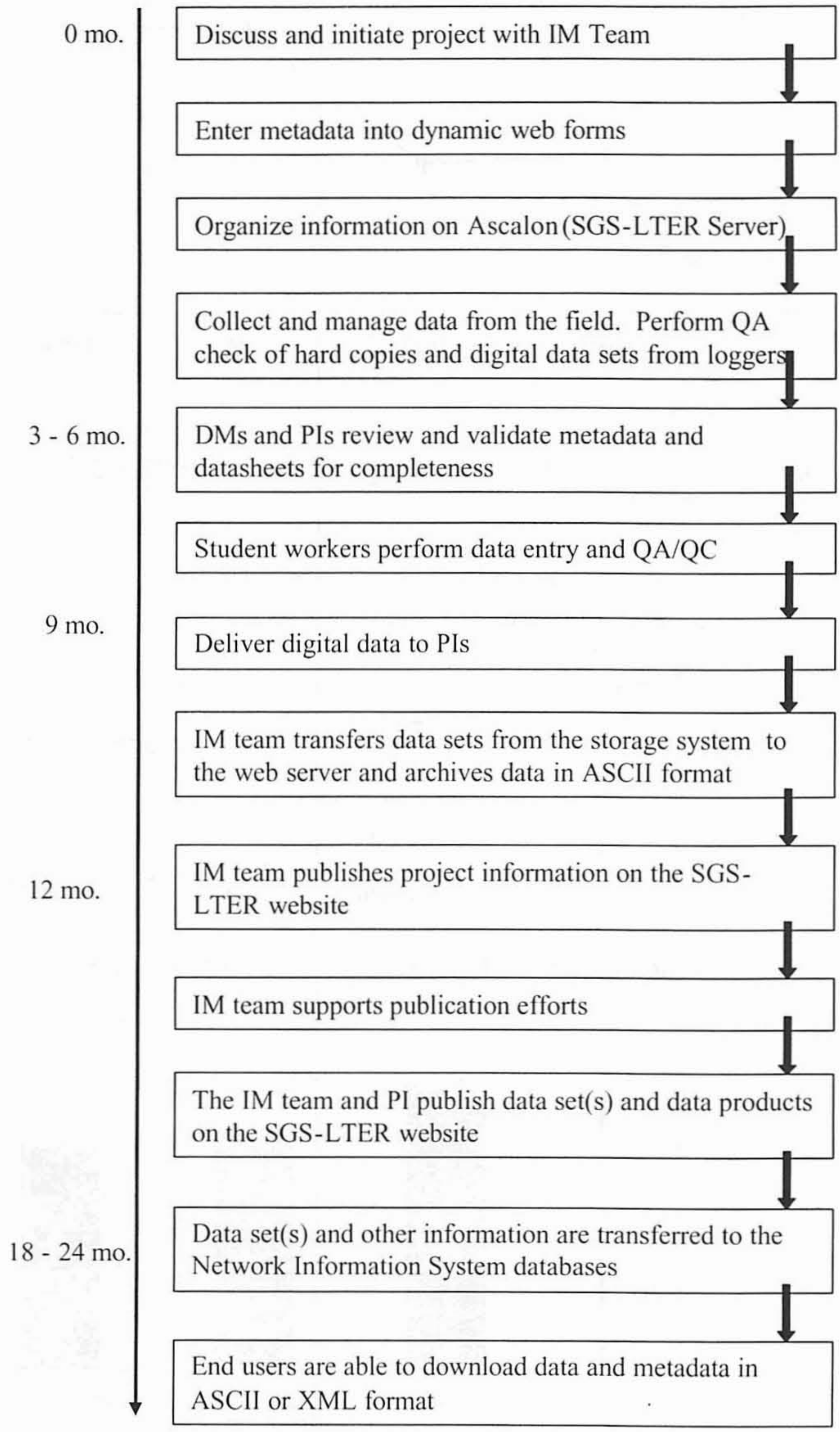


Figure 3. Number of Data Requests per Year (February 2002 - July 2005)

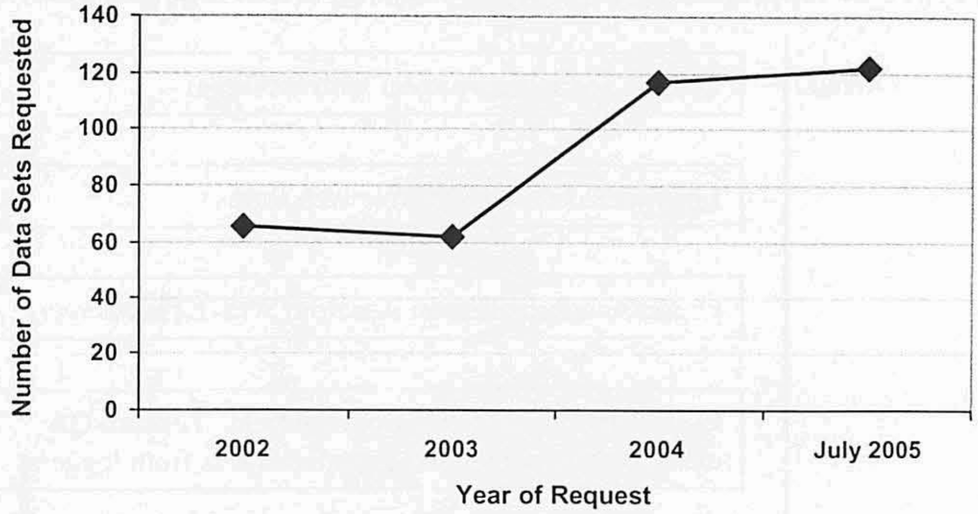


Figure 4. Mean Monthly Data Usage (February 2002 – July 2005)

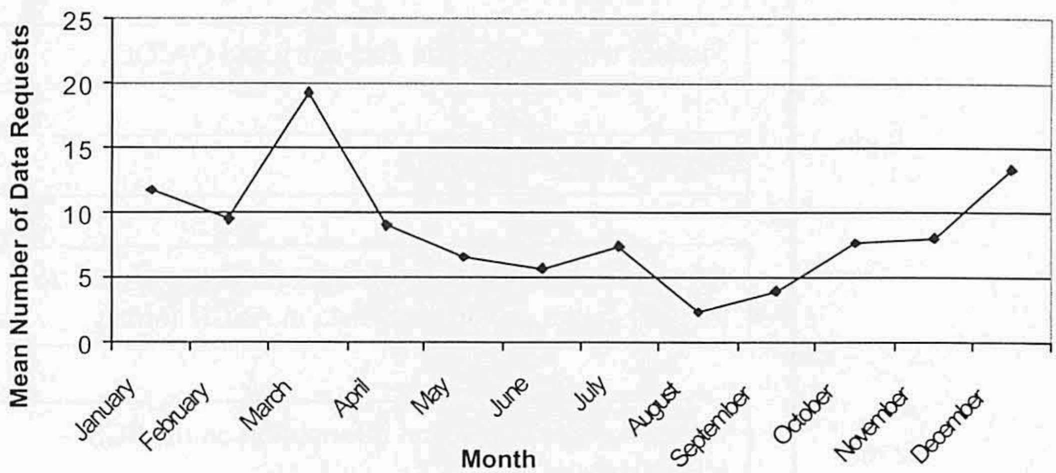
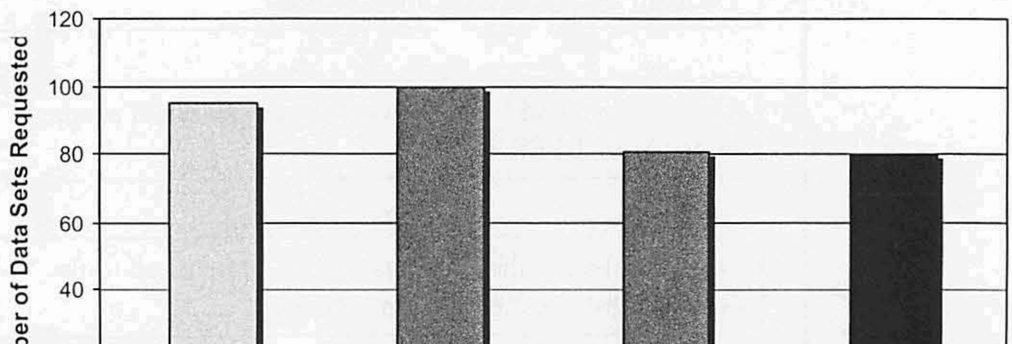


Figure 5. Data usage summary by user type (February 2002 – July 2005)



Section 6:

Education and Outreach Activities: John Moore and Laurel Hartley

Educational, Outreach, and Training Activities

John C. Moore and Laurel Hartley

1. Research Experience for Undergraduates

We have sponsored five REU students in LTER V.

Year	Student	Institution	Advisor
2003	Karl Wyant	University of Northern Colorado	John Moore
2004	Julia West	Middlebury College	Indy Burke
2004	Chris Warren	Earlham College	Bill Lauenroth
2004	Josh Metten	Colorado State University	Bill Lauenroth
2004	Martin Dangelmayr	Colorado State University	Indy Burke

2. Schoolyard Ecology

Participants represent a wide range of schools (one K-6, one 6-12, one middle school and 5 High Schools) from districts in the northern Front Range, eastern plains of Colorado and the Navajo Reservation in Arizona.

School	Science Teacher
Akron High School, Akron, CO	Ms. Deanna Schrock
Frontier Academy, Greeley, CO	Dr. Sean Madden
Greeley West High School, Greeley, CO	Mr. Gary Prewitt
John Evans Middle School, Greeley, CO	Mr. Jason Mclaughlin
Rocky Mountain High School, Ft. Collins, CO	Mr. Dave Swartz
Rough Rock High School, Navajo Nation, AZ	Mr. William Rosenberg
S. Christa McAuliffe Elementary School, Greeley, CO	Ms. Rebecca Ramirez
Union Colony Prep School, Greeley CO	Ms. Cathy Hoyt

3. Research Assistance for Minority High School Students (RAMHSS)

The following students were supported with LTER RAMHSS funds in 2003. The students were participants in the UNC Upward Bound Math and Science program known as COSMOS. The students were supported with room and board, tuition and stipends for the six-week summer program, and provided stipends during the academic year.

Student	Gender	Ethnicity	High School
SaDune Quarles	M	African-American	Greeley West
Jaime Salazar	M	Hispanic	Greeley West
Lucio Smith	M	African-American	Greeley Central

4. *GK-12: Human Impact along the Front Range of Colorado*

The project is an NSF-funded collaborative between the University of Northern Colorado and Colorado State University. Graduate students in STEM disciplines are placed in K-12 classrooms during the academic year to assist K-12 teachers with the transference of research. K-12 teachers work with the graduate students during the summer on research. The project promoted the schoolyard ecology program, and provided teachers with graduate credit hours, travel to National Meetings (e.g., the ESA in Savanna, GA in 2003). The following Graduate students have been supported:

Students	Institution
Ms. Laurel Hartley	Department of Biology, Colorado State University
Mrs. Meghan H. Quirk	Department of Biological Sciences, Univ. of Northern Colorado
Mr. Rodney Simpson	Department of Biological Sciences, Univ. of Northern Colorado

5. *CLT-W: Center for Teaching and Learning in the West*

The CLT-W is an NSF-funded collaborative between Montana State University, the University of Montana, Colorado State University, Portland State University, and the University of Northern Colorado with the objective of researching the achievement gap between students of color and whites, providing K-12 professional development for teachers in STEM, and providing graduate programs in science education. The project supported research in the nature of the student-mentor relationship, and initiated an outreach program with Native American Tribes in Arizona, Montana and South Dakota (2004 Environmental Education supplement).

6. *Teachers on the Prairie*

The project is an NSF-funded collaborative between Portland State University, Oregon State University and the University of Northern Colorado, designed to provide K-12 teachers with focused professional development in prairie ecology. The following workshops were offered during June – August 2003:

Topic	Instructor(s)
Bagging Big Bugs	Dr. Boris Kondratief
GIS Workshop	Dr. Melinda Laituri
Invasive Species	Mr. Greg Newman
Peaks to Prairie	Ms. Laurel Hartley and Ms. Angie Moline
Soil Ecology	Dr. John Moore
Soil Formation	Dr. Gene Kelley

7. *Native American Outreach*

The project is an NSF-funded program through the Education and the Environment venture fund. Piloted in the summer of 2004 with funds from the UNC MAST Institute, the Native American Outreach program brought K-12 students, teachers, and elders from the Rough Rock High School in Arizona to the SGS-LTER site for intensive on site training in ecological principles and methodology. The team returned to Rough Rock and established a long term research monitoring program on the effects of grazing on soil erosion. The summer of 2005 will expand the program to include the Crow Reservation in Montana, and the Lakota Reservation from North Dakota.

Section 7:

Publications 2002 – 2005

- **Journal Articles**
- **Books and Book Chapters**
- **Abstracts**
- **Dissertations and Theses**

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Aber, J.D., E.S. Bernhardt, F.A. Dijkstra, R.H.Gardner, K.H. Macneale, W.J. Parton, S.T.A. Pickett, D.L Urban, and K.C. Weathers. 2003. Standards of practice for review and publication of models: Summary of discussion. Models in Ecosystem Science, No. 11.

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Antolin, M.F., P. Gober, B. Luce, D.E. Biggins, W.E. Van Pelt, D.B. Seery, M. Lockhart, and M. Ball. 2002. The influence of sylvatic plague on North American wildlife at the landscape level, with special emphasis on black-footed ferret and prairie dog conservation. Transactions of the North American Wildlife and Natural Resources Conference. 67: 104-127.

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Avashia, S.B., J.M. Petersen, C. Lindley, M.E. Schriefer, K.L. Gage, M. Cetron, T.A. Demarcus, D.K. Kim, J. Buck, J.A. Monteneiri, J.L. Lowell, M.F. Antolin, M.Y. Kosoy, L.G. Carter, M.C. Chu, K. Hendricks, D.T. Dennis, and J.L. Kool. 2004. First reported prairie dog-to-human tularemia transmission, Texas, 2002. Emerging Infectious Diseases 10: 483-486.

Bakker, E.S., J.M.H. Knops, D.G. Milchunas, H. Hillhouse, M.E. Ritchie and H. Olff. 2005. Effects of different sized grazers on nitrogen cycling across a grassland productivity gradient. *(in prep)*

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